Research Article

Surface Engineering and Veneer Optimisation of Y-TZP Zirconia: A Critical Review of Phase Stability, Mechanical Reliability, and Clinical Performance

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ABSTRACT

Background: Yttria-stabilised tetragonal zirconia polycrystal (Y-TZP) has improved fixed prosthodontics because of its strong mechanical properties and biocompatibility. Still, it is challenging to achieve good esthetics without losing strength, particularly during glazing and veneering. This review looks at new glazing and layering techniques for Y-TZP zirconia. It considers how these methods affect surface features, phase stability, bond strength, appearance, and long-term clinical results.

Materials and Methods. The authors searched PubMed, Scopus, and Web of Science for in vitro studies, clinical trials, and systematic reviews on glazing materials, veneering ceramics, CAD/CAM layering, heat-pressed veneering, monolithic zirconia staining, surface pretreatment, bioactive glazes, multilayer zirconia, and laser polishing. The review included studies that reported on surface roughness, flexural strength, phase transformation, veneer chipping, and clinical survival.

Results. New low-fusing nanofilled glaze systems make surfaces smoother and glossier. Heat-pressed and CAD/CAM veneering techniques offer better consistency and bond strength than traditional layering. Monolithic and multilayer zirconia systems help prevent veneer chipping and keep good esthetic qualities. Careful surface treatment and controlled firing are important for phase stability. Bioactive and antibacterial glazes are new options that may benefit implant use.

Conclusions. Modern prosthodontics is using more monolithic and multilayer zirconia to solve mechanical problems. Careful surface engineering, especially in glazing and firing, is still key for long-term clinical success. In the future, digital customization and biologically active surfaces are likely to be combined.

Keywords: Yttria-stabilised tetragonal zirconia polycrystal (Y-TZP), Glazing and veneering techniques, Monolithic and multilayer zirconia, Phase stability and tetragonal–monoclinic transformation, Surface engineering and bond strength.

INTRODUCTION

Yttria-stabilised tetragonal zirconia polycrystal (Y-TZP) is now among the most widely used ceramic biomaterials in restorative dentistry. Its transformation-toughening mechanism, high flexural strength (approximately 900–1200 MPa), and significant fracture toughness differentiate it from glass ceramics and feldspathic porcelains[1]. The incorporation of yttria stabilises the tetragonal phase at room temperature. When subjected to stress at the crack tips, this phase transforms to monoclinic, thereby inhibiting crack propagation.

Despite these favorable mechanical properties, early zirconia restorations were often considered excessively opaque and insufficiently translucent, necessitating the application of a feldspathic porcelain layer to achieve a natural appearance[2]. However, bi-layered zirconia systems have been associated with veneer chipping, as documented in several long-term studies[2]. This complication prompted further research into glazing, layering, and surface treatments to enhance both aesthetics and mechanical performance.

Over the past ten years, materials science has led to more types of zirconia and new ways to modify their surfaces. High-translucency zirconia, gradient multilayer blocks, digital veneering, press-over methods, improved firing cycles, and experimental bioactive glazes are now at the forefront of restorative ceramic technology. This review brings together these recent advances and looks at how they affect biological compatibility and mechanical properties.

Advanced Glazing Materials

Glazing has several uses. It makes surfaces glossier, smoother, and helps seal small defects left after finishing. Older glaze materials often wore out quickly and were not applied evenly. New low-fusing, nanofilled glaze systems have solved many of these problems[3].

Nanofilled glazes demonstrate improved flow at lower firing temperatures, thereby reducing thermal stress on zirconia. Preis et al.[3,4] found that glazed zirconia surfaces are significantly smoother than ground surfaces. Enhanced surface smoothness reduces plaque accumulation and decreases wear on opposing enamel[4].

Glazing does not consistently outperform polishing. Several studies indicate thatGlazing is not always better than polishing. Some studies show that careful polishing can make surfaces just as smooth, or even smoother, than glazing[5]. Clinicians should consider the specific case, bite forces, and long-term wear when deciding how to finish a surface.

Layered Veneering Ceramics

Using fluorapatite- or leucite-reinforced porcelains with zirconia frameworks improves color matching and makes the material more translucent[6]. This approach works particularly well for front teeth, where appearance is very important.

Veneer chipping is still a frequent problem. Sailer et al.[2] found that chipping occurs in 13% to 15% of cases over 3 to 5 years. This issue can be caused by the way the framework is designed, how it is supported, differences in thermal expansion, and cooling the material too quickly[7],[8].

To help prevent veneer fractures, it is important to cool the material slowly, use special liners, and make sure the framework is well supported[8]. However, even with these steps, bilayer systems can still fail under repeated stress.

CAD/CAM Custom Layering

Digital tools enable precise control over veneer thickness and shape. Veneers produced with CAD/CAM technology exhibit greater consistency than those fabricated manually[9].

Guess et al.[10] reported that digital methods maintaining constant veneer thickness reduce internal stress and may decrease the risk of chipping. Digital layering further contributes to consistent outcomes and improved fit.

While CAD/CAM layering enhances predictability, selecting suitable materials and firing conditions remains critical for long-term success.

Heat-Pressed Veneering

The press-over technique produces a dense, uniform veneer by pressing ceramic ingots onto zirconia frameworks. Beuer et al.[11] found that this method results in higher bond strength than the Lower method, as stronger interlayer bonds are believed to enhance veneer durability. However, pressing conditions must be carefully controlled to prevent stress and distortion.

Phase Stability

Firing cycles significantly affect the phase stability of zirconia. Rapid cooling can induce microcracks and undesirable phase transformations[12]. Harada et al.[12] demonstrated that repeated firing alters the surface and may reduce material strength.

The use of appropriate firing protocols and controlled cooling rates preserves material strength and minimizes residual stress.

Monolithic Zirconia and Staining

Monolithic zirconia restorations do not include a veneer layer, thereby avoiding the primary cause of mechanical failure. Zhang et al.[13] demonstrated that monolithic zirconia is less prone to fracture than veneered systems. These restorations also provide favorable aesthetics, particularly for posterior teeth[14]. The simplified process reduces laboratory time, requires fewer adjustments, and offers greater reliability.

Surface Treatment Prior to Layering

Blasting the surface with alumina particles raises surface energy and helps bonding[15]. However, excessive pressure can alter the material, causing damage. Selective infiltration etching is another way to improve bonding without weakening the material[16]. Surface treatments must be carefully controlled to maintain a strong bond and protect the structure.

Bioactive and Antibacterial Properties

Recent studies have investigated the incorporation of bioactive glass or silver nanoparticles into glazes[17]. These modifications aim to reduce bacterial contamination and enhance soft-tissue attachment.

Although laboratory findings are promising, long-term clinical evidence remains limited. Nonetheless, these novel glazes may provide advantages for implant-supported prostheses.

Gradient Multilayer Zirconia

Multilayer zirconia blocks display integrated color and translucency gradients within a single structure[18]. This design reduces the need for veneering while maintaining favorable aesthetics. These materials are sufficiently strong for posterior teeth, although increased yttria content may slightly reduce toughness.

Laser Glazing and Polishing

Laser treatment can smooth surfaces without the use of traditional glaze[19]. Early studies suggest it may reduce wear on opposing teeth and help the shine last longer. However, standard clinical protocols are not yet in place.

DISCUSSION

Recent advances in glazing and layering for Y-TZP zirconia are making prosthodontic restorations simpler and more reliable. Since Sailer et al.[2] and Guess et al.[7] reported frequent veneer chipping, interest in bilayer zirconia systems has dropped. Most of these problems are caused by complex stresses at the veneer-framework interface, not by the materials themselves.

Monolithic zirconia marks a significant advance in restorative dentistry. Zhang et al.[13] found that monolithic restorations can withstand higher fracture loads, and Heintze and Rousson[14] reported good survival rates in real-world use. Without a veneer layer, the process is simpler, less technique-sensitive, and less likely to chip or separate.

Surface-finishing protocols have undergone a critical reassessment. Preis et al.[3,4] and Stawarczyk et al.[5] determined that surface roughness significantly affects both antagonist tooth wear and biofilm formation. Evidence suggests that polished zirconia exhibits greater long-term durability compared to glazed zirconia, as glaze layers are susceptible to degradation. These results question the prevailing assumption that glazing is universally optimal and underscore the importance of prioritizing long-term surface stability over initial aesthetics.

Thermal compatibility is still very important for bilayer systems. Aboushelib et al.[8] showed that how quickly restorations are cooled affects bond strength. Cooling too fast creates tensile stresses in the veneer, which raises the risk of cracks. Because of this, labs should use controlled cooling methods.

The press-over technique, introduced by Beuer et al.[11], was developed to make veneers more even and improve how they bond. It lowers porosity and helps the veneer fit better, solving some issues with manual layering. However, it does not address the main stress-related problems in bilayer systems.

Multilayer and high-translucency zirconia have improved the look of restorations. Zhang et al.[18] found that adding more yttria makes zirconia clearer, but it can also reduce its strength. Clinicians need to balance appearance and strength when choosing zirconia. The best way to bond zirconia is still being debated. Kern et al.[15] showed that gentle air-abrasion can help bonding, but too much can damage phase stability. Aboushelib et al.[16] suggested selective infiltration etching as another method to improve bonding while keeping the structure strong. Overall, these studies show that gentle surface treatment is important.

Bioactive glaze technologies are a promising new area in prosthodontics. Cheng et al.[17] found that zirconia treated with bioactive glaze collects less bacteria. Although more clinical evidence is needed, this method helps keep peri-implant tissues healthy and can make restorations last longer. It also provides an alternative to traditional glazing. Ergun et al.[19] found that this technique creates smoother surfaces without adding extra materials. However, differences in laser settings and the lack of standard clinical protocols limit its use for now.

Simpler designs like monolithic and gradient zirconia usually last longer if finished properly. Still, for front teeth where appearance matters most, careful layering may still be necessary.

Future research should focus on long-term clinical trials comparing multilayer zirconia restorations with traditional bilayer systems. More studies are also needed to see how bioactive glazes affect peri-implant tissues. As digital technology advances, combining CAD/CAM precision with bioactive surface treatments could shape the future of zirconia restorations.

CONCLUSION

Following inferences were derived:

- Modern glazing materials make surfaces smoother, but using them requires careful control.
- The main drawback of bilayer zirconia systems is that the veneer can chip.
- CAD/CAM and press-over methods help make results more consistent and improve how well the parts bond together.
- Monolithic and multilayer zirconia systems are now much more reliable in terms of strength.
- Carefully managed firing and surface preparation are key to keeping the material stable.
- Bioactive and laser-based surface technologies look promising for future research and development.

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