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Durability of resin bonding to translucent zirconia materials: A review

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Abstract
Translucent zirconia ceramics have gained prominence in restorative dentistry due to their aesthetics and strength. However, resin bonding remains a challenge due to zirconia's polycrystalline structure and lack of silica, limiting chemical adhesion. This review summarizes current *in vitro* data on bonding durability to translucent zirconia, analyzing surface treatments such as airborne particle abrasion, tribochemical silica coating, and laser techniques. It also evaluates functional monomers, particularly 10-MDP, and resin cements under artificial aging. Studies suggest that combining mechanical and chemical treatments with appropriate resin cements improves bond durability. Standardized protocols and clinical trials are needed to optimize outcomes.

Keywords: translucent zirconia, resin bonding, surface treatment, 10-MDP, *in vitro*, bond strength, durability

Introduction
Over the past few decades, the rising demand for aesthetics in dentistry has gradually replaced metal-ceramic prostheses with a growing preference for indirect metal-free restorations [1]. Metal-ceramic fixed partial dentures (FPDs) have long been considered the gold standard for posterior restorations due to their excellent mechanical strength. However, their dark substructure often compromises aesthetics, particularly in areas with limited space for veneering. Increasing aesthetic demands have driven a shift toward metal-free restorations, with zirconia emerging as a leading material due to its strength, biocompatibility, and improved aesthetics [2]. Zirconia with newer high-translucent variants offering improved optical properties. These materials are well-suited for monolithic full-contour restorations across a range of posterior and anterior clinical applications [3].
Translucent zirconia has transformed restorative dentistry by enabling strong, chip-resistant monolithic restorations. Compatible with CAD-CAM, it allows standardized, cost-effective fabrication with minimal thickness and conservative tooth preparation [1].
Zirconia is a polymorphic material that exists in monoclinic, tetragonal, and cubic phases depending on temperature. Its properties are largely determined by yttria content. Resin bonding protocols effective for conventional zirconia are also successful with high-translucent zirconia. Airborne particle abrasion combined with phosphate monomer primers or resin cements ensures durable long-term bonds [3]. Zirconia restorations can be cemented with conventional cements; however, resin cements form more durable long-term bonds following airborne particle abrasion [4].

Overview of zr materials
Zirconia, a crystalline oxide of zirconium, holds good mechanical, optical, and biological properties [5]. During the second half of the 20th century, dentistry faced the challenge of meeting increasing patient demands for esthetic yet mechanically reliable restorations. Since aluminous porcelain's introduction in the 1960s, improvements in strength, esthetics, and fabrication have expanded clinical options. By the late 1990s, CAD/CAM advances led to the first zirconia coping, veneered with porcelain due to its gray, opaque appearance [6].

Classification of zirconia [6]

Zirconia is classified into five generations based on its chemical composition [6]:

- **1st Gen:** 3Y-TZP-A (opaque, >1000 MPa)
- **2nd Gen:** 3Y-TZP-A (900 MPa, +5% translucency)
- **3rd Gen:** 5Y-TZP (600 MPa, +15% translucency)
- **4th Gen:** 4Y-TZP (750 MPa, +10% translucency)
- **5th Gen:** Multilayered 3Y/4Y/5Y-TZP (550-1200 MPa)

Translucency is essential for achieving natural-looking restorations and depends on how the material interacts with light. Yttria-stabilized zirconia offers various translucency levels. Enhancing translucency involves adding 0.1% aluminum oxide to limit grain growth and improve low-temperature degradation resistance. Increasing lanthanum oxide to 0.2% and adjusting grain size and sintering conditions also contribute. Optimal translucency is achieved with grain sizes under 100 nm, although excessively small grains (~200 nm) may compromise strength and fracture toughness [7]

Indications of Translucent Zirconia

- **High Translucency:** Ideal for thin restorations like veneers
- **Medium Translucency:** Dentin replacement with veneering
- **Low Translucency:** Core build-ups and masking discolored structures [7]

Properties of zirconia

- **Physical Properties:** Zirconia is a stable and durable restorative material. It resists acid erosion, though some agents may increase surface roughness (Tanweer *et al*., 2022). It has very low thermal conductivity and a thermal expansion coefficient of 10×10^{-6}/°C, unaffected by yttria content (Ban, 2021) [5].
- **Mechanical Properties:** Zirconia exhibits the highest hardness among dental materials (Ban, 2021), with excellent flexural strength. Conventional zirconia has greater bi-axial strength than high-translucent types (Kontonasaki *et al*., 2020). Due to higher yttria, 5Y-TZP shows ~50% lower fracture toughness than 3Y-TZP (Belli *et al*., 2021). Flexural strength is 584 MPa for 3Y-TZP and 373 MPa for 5Y-TZP (Liao *et al*., 2023). Fracture strength depends on implant design and abutment type (Bethke *et al*., 2020), with 1-piece zirconia implants having twice the strength of 2-piece designs (Kohal *et al*., 2009) [5].
- **Optical Properties:** Zirconia is esthetic but less translucent than glass-ceramics. Proper luting cement helps maintain translucency (Heboyan *et al*., 2023; Bilgrami *et al*., 2022). Increasing yttria content raises the cubic phase, enhancing translucency but lowering strength due to fewer tetragonal phases. Zirconia also offers greater radiopacity than aluminum or titanium, aiding diagnosis due to its high density (Ban, 2021). However, speed sintering reduces translucency, as regular sintering yields larger grain sizes and better translucency (Kongkiatkamon & Peampring, 2022) [5].
- **Biological Properties:** Zirconia is highly biocompatible, as confirmed by multiple animal and human studies (Bapat *et al*., 2022; Christel *et al*., 1989; Josset *et al*., 1999). Christel *et al*. found no cytotoxicity in rat muscle implants, and Josset *et al*. observed good adhesion, proliferation, and osteogenic differentiation of human osteoblasts. Its hydrophilic surface promotes protein absorption and fibroblast attachment, with lower contact angles enhancing cell adhesion (Kim *et al*., 2015). Zirconia causes less tissue reaction than titanium (Degidi *et al*., 2006) and exhibits reduced bacterial adhesion and biofilm formation—12.1% on zirconia vs. 19.3% on titanium (Scarano *et al*., 2004) [5].
- **Transformation Toughening:** Transformation toughening in zirconia involves stress-induced conversion from the tetragonal to monoclinic phase, causing volume expansion and compressive stress at crack tips, which helps prevent crack growth. To enable this at room temperature, stabilizing oxides like yttrium, magnesium, calcium, or cerium are added. Based on stabilizer content, zirconia is classified as fully stabilized (FSZ, >8 mol% Y_2O_3, cubic phase), partially stabilized (PSZ, 3-8 mol% Y_2O_3, mixed phases), or tetragonal zirconia polycrystals (TZP, ~3 mol% Y_2O_3, mostly tetragonal), each offering varying degrees of toughness and strength [8].
- **Coloring Effect:** Monolithic zirconia can be colored using pre-shaded blocks or metal oxide solutions. While pre-colored zirconia may experience altered mechanical properties due to lattice changes, immersion or brushing methods can reduce strength and hardness. Infiltration coloring yields better esthetics. Finishing and polishing are preferred over glazing, as glaze layers tend to wear off within six months [8].
- **Wear Properties of Zir:** Wear of zirconia and opposing enamel depends on surface roughness and microstructure. Polished monolithic translucent zirconia with uniform crystals shows minimal abrasiveness. Glazed zirconia may roughen with aging, increasing enamel wear. Studies show polished zirconia causes less antagonist wear than other ceramics, though slightly more than natural enamel [8].

Adhesion to Zirconia

Zirconia lacks silica, making it more challenging to bond than glass ceramics, which can be easily etched and silanized. Despite being "cementable," zirconia restorations—especially thin or low-retention types—benefit from resin luting agents. Proper surface treatment and carboxyl-based monomers improve adhesion and durability in translucent zirconia ceramics [6].

Factors Affecting Zirconia-Resin Bond Strength

Bond strength between zirconia and resin cement is influenced by multiple factors, including the type of cement, use of MDP-containing primers (separately or within the cement), surface treatment methods, timing of treatment (pre- or post-sintering), and bond aging[6]. With emerging long-term studies, evidence now suggests that airborneparticle abrasion with 10-methacryloyloxydecyl dihydrogen phosphate and certain design features can help achieve a robust bond between zirconia and tooth structure [9].

Resin cement

Resin cements are methacrylate-based, low-viscosity composites formulated to provide appropriate film thickness, working time, and setting characteristics. Their mechanical and clinical performance depends on variations in filler content and photo-initiators. Due to the wide range of chemical constituents—such as phosphoric acid esters, 10-

MDP, HEMA, GPDM, 4-META, bis-GMA, and TEGDMA are classified based solely on composition [6].

Bonding mechanisms for adhesive resin cements

To facilitate bonding to dental tissues, many resin cements require the dental substrate to be pre-treated. resin cements can be categorised into three groups based on their bonding properties: etch-and-rinse, self-etch and self-adhesive resin cements.

Etch-and-Rinse

Etch-and-rinse adhesives require careful technique. Phosphoric acid etches dentin, allowing resin infiltration. However, excess moisture can hinder bonding and polymerisation. Techniques like multiple coatings, solvent evaporation, and hydrophobic resin overlay improve bond strength. Light polymerisation is preferred over self-curing to ensure proper adhesive performance, especially under indirect restorations [10].

Self-etch

Self-etch adhesives etch and prime without rinsing, retaining hydroxyapatite for micromechanical and chemical bonding, especially via 10-MDP. Their effectiveness depends on pH. One-step systems show reduced bond strength and higher failure. Dual- or self-cured cements with multi-step systems are preferred; phosphoric acid remains ideal for strong enamel bonding [10].

Self-adhesive resin cements

Self-adhesive resin cements allow one-step application by chemically bonding to dental tissues through phosphate group interaction with hydroxyapatite. While they reduce postoperative sensitivity and simplify procedures, their bond strength to enamel and dentin is lower than that of conventional multi-step systems. They are unsuitable for veneers or low-retention restorations; enamel pretreatment is advised [10]

Chemically activated resins

Chemically activated resin cements use a dual-paste system of benzoyl peroxide and tertiary amine to initiate polymerisation without light. Ideal for opaque restorations, they ensure deep curing but have limited working time, yellowing tendency, and shorter shelf life. Proper mixing is crucial for uniform setting and optimal performance [10].

Light-activated resin

Light-activated resin cements are ideal for translucent restorations like veneers. They come in a single tube, reducing mixing errors and air entrapment. Camphorquinone (CQ) is the common photo-initiator but may yellow over time; alternatives like PPD and TPO are used. Polymerisation requires close light proximity and a 90° curing angle to ensure effective depth cure. Proper technique ensures optimal mechanical properties and complete resin conversion [10].

Dual-cured activated resins

Dual-cured resin cements combine photo- and chemical curing for optimal polymerisation, even in areas with limited light. They contain two pastes: one with benzoyl peroxide (initiator) and another with photo-activated resin and tertiary amine. While they offer flexibility and depth curing, inadequate light activation can reduce conversion, compromising hardness, strength, solubility, and dentin bond quality compared to fully light-cured systems [10].

Clinical Recommendations

To enhance the longevity of bonded restorations, apply a dentin adhesive immediately after preparation (Immediate Dentin Sealing) and optionally add a hydrophobic resin coat to increase bond strength and resist water degradation. Avoid eugenol-based temporary cements and thoroughly clean preparations using air abrasion and water spray. When using etch-and-rinse systems, chlorhexidine can preserve hybrid layer collagen but should be avoided with self-etch or self-adhesive cements. Applying greater seating pressure during bonding reduces water infiltration and improves adhesive interface quality. Proper technique and material selection are crucial for achieving optimal bond strength and clinical success [10].

MDP-Containing Self-Adhesive Resin Cements (SARCs)

Introduced in 2002, MDP-containing SARCs offer simplified application and strong chemical bonding to zirconia via phosphate ester groups. Air abrasion followed by MDP primer enhances bonding. Incorporating 10-MDP into cements or primers improves bond strength and hydrolytic stability. Products like Clearfil and Monobond Plus retain adhesion even after thermocycling and water aging, ensuring long-term durability [6].

Zirconia Surface Treatment Unlike silica-based ceramics, zirconia lacks a glass phase and silica content, making hydrofluoric acid and silane treatments ineffective for durable bonding. To enhance zirconia-resin adhesion, various surface treatments have been proposed, generally classified into three main categories: mechanical (e.g., air abrasion), chemical (e.g., MDP primers), and mechanico-chemical techniques that combine both methods [6].

Mechanical Bonding technique

Airborne Particle Abrasion

Air abrasion is a widely used method for zirconia surface treatment, enhancing roughness, energy, and wettability for better bonding. Using 30-110 µm particles at 0.5-4 bar is effective. Despite microcrack risk, it doesn't affect 3Y-TZP stability and ranks just below tribochemical silica coating in effectiveness [6].

Diamond and Disc Grinding

Diamond grinding increases zirconia surface roughness but can cause microcracks due to its aggressive nature. Though stone abrasion yields higher roughness (Ra 0.14 µm) than air abrasion (0.9 µm), studies show air abrasion achieves significantly better shear bond strength with resin cement [6].

Electrical Discharge Machine (EDM)

EDM uses electrical sparks in a dielectric medium to shape conductive materials, but zirconia's high resistivity limits its use. In 2010, a modified EDM device enabled treatment of non-conductive zirconia. Studies show EDM yields the highest shear bond strength (17.05 MPa) and surface roughness, creating deep valleys and peaks, outperforming tribochemical coating, lasers, and air abrasion [6].

TiO_2 nanotubes

TiO_2 nanotubes, due to their nanoscale dimensions and high surface area, exhibit unique physical and chemical properties. Their incorporation increases surface energy by enhancing the number of surface atoms and interfaces. While nano-TiO_2 particles are valued for their large surface area, a previous study reported no significant improvement in shear bond strength between zirconia and resin cement following their integration into the zirconia surface [6].

Nanostructured Alumina Coating (NAC)

Nanostructured Alumina Coating (NAC) is a non-invasive surface treatment that applies a thin, lamellar-like alumina layer to zirconia, creating nano-roughness without damaging the surface. Studies show that NAC significantly improves shear bond strength with self-adhesive resin cement compared to 50 µm air abrasion and does not adversely affect the mechanical or optical properties of translucent zirconia [6].

Non-thermal Atmospheric Pressure Plasma (NTP)

Non-thermal Atmospheric Pressure Plasma (NTP) enhances zirconia surface wettability by reducing carbon and introducing polar groups, using gases like argon or oxygen. Unlike air abrasion, NTP increases bond strength with minimal roughness and no damage. Its effectiveness is due to increased surface polarity and superhydrophilicity, improving resin adhesion [6].

Laser

Laser treatment of zirconia aims to create surface roughness and enhance wettability, similar to sandblasting, to promote micromechanical retention. Various lasers (Er:YAG, Nd:YAG, Yb:YAG, CO_2) have been studied using different settings. However, most studies report no significant improvement in bond strength compared to sandblasting, often due to microcracks and phase transformation that compromise zirconia's mechanical integrity. Thus, lasers are generally not considered reliable for surface pretreatment. Nonetheless, some evidence suggests that Er, Cr: YSGG laser, when properly adjusted, may offer a non-destructive alternative [11].

Fusion Sputtering

Fusion sputtering, introduced by Aboushelib in 2012, is a zirconia surface treatment performed before sintering. It involves spraying a 50% ethyl alcohol solution containing 7-12 µm un-sintered zirconia particles onto the surface using an airbrush. This technique significantly improved the microshear bond strength (µSBS) between zirconia and MDP-containing self-adhesive resin cement compared to 50 µm Al_2O_3 air abrasion. SEM analysis showed a higher surface roughness with fusion sputtering (Ra = 4.14 µm) versus air abrasion (Ra = 0.68 µm), attributed to embedded zirconia beads on the surface enhancing mechanical retention [6].

Etching Using Acidic Solutions

Hydrofluoric acid (4%-10%) is commonly used to etch glass ceramics, enhancing resin cement bonding by exposing silica particles for silane coupling. However, this method is ineffective for Y-TZP at room temperature due to its high crystallinity and lack of silica. Studies have shown that strong acids applied for extended periods at elevated temperatures can modify zirconia's surface morphology, increasing surface energy and improving resin bond strength. Etching with 40% HF for 10 minutes yielded the best wettability, highest shear bond strength (SBS), and minimal phase transformation compared to hot sulfuric acid and 50 µm Al_2O_3 sandblasting. Longer etching times increased surface roughness and reduced contact angles [6].

Chemical Bonding Technique

Selective Infiltration Etching (SIE): SIE uses heat-induced grain boundary diffusion to convert Y-TZP's smooth surface into a retentive, 3D structure for resin infiltration. It involves ceramic infiltration with molten silica and oxides, followed by HF acid etching to create micromechanical roughness, improving resin bond strength. Though effective, SIE demands precise handling and is technique-sensitive. Alternatives like ceramic coating, fusion sputtering, nanostructured alumina, and TiO_2 nanotubes show potential, but require further research for clinical applicability [11].

10-MDP Primer: 10-MDP (methacryloyloxydecyl dihydrogen phosphate) is a unique molecule that forms a chemical bond with zirconia through its phosphate group, hydrophobic spacer chain, and polymerizable end. It bonds via hydrogen bonding (P=O with Zr-OH), ionic bonding (Zr-O-P), and intermolecular hydrogen bonds between MDP molecules, enhancing bond strength and concentration. MDP primers significantly improve surface energy and shear bond strength compared to airborne abrasion, even after aging. However, their main drawback is hydrolytic degradation, which weakens adhesion over time across all application forms [6].

Silane

Silane is widely used with silica-based ceramics due to its bifunctional structure: methoxy-silyl groups form siloxane bonds with silica, while methacryloyl groups bond with resin via free radical polymerization. However, its effectiveness on zirconia is limited due to zirconia's polycrystalline, silica-free nature. Silane primarily enhances surface hydroxylation, energy, and wettability when used with silica-coated zirconia. Studies show that combining silane with MDP-based primers may reduce bond strength, as interactions between MDP and zirconia can be compromised in multi-primer systems. Thus, silane's role in zirconia bonding remains supportive rather than primary. A 1% silane solution improved bonding between zirconia and composite resin. Additionally, heat treatment of silane-treated zirconia further increased bond strength [12].

Mechanico-Chemical Bonding Technique (Tribo-Chemical Silica Coating)

Tribo-chemical silica coating (TSC) enhances zirconia-resin bonding by combining mechanical and chemical processes. It involves blasting the zirconia surface with silica-coated alumina particles (30-110 µm, 0.8-4 bar, ~10 mm distance), embedding silica into the surface. This creates micromechanical retention and allows chemical bonding through silane application and siloxane chain formation.TSC methods like CoJet and Rocatec have shown improved bond strength, with Rocatec performing better due to larger particle size (110 µm) and an added air-abrasion step. TSC also induces tetragonal-to-monoclinic phase transformation more than laser treatments, without compromising flexural strength [6].

Timing of Surface Treatment: Most zirconia surface treatments, such as air abrasion, laser, and tribo-chemical silica coating, are applied after sintering. However, certain pre-sintering methods, like fusion sputtering, have shown positive effects on bond strength. Fusion sputtering significantly improved the microshear bond strength between zirconia and resin cement. Studies suggest that modifying zirconia before sintering can be effective, provided it does not cause phase transformation or deep subsurface damage [6].

Artificial Aging

Artificial aging methods like liquid storage and thermocycling simulate oral conditions to assess zirconia-resin bond durability. Water, acids, and esterase cause hydrolytic degradation, while 5000 thermocycles represent six months of aging[6]. Autoclave aging for 20 hours doesn't affect 3Y-TZP bond strength[13]. Though not fully replicating oral conditions, these methods show reduced adhesion. Tribo-chemical silica coating demonstrates the highest resistance to aging effects [6].

Applications in Dentistry

Zirconia-Based Dental Posts

Zirconia posts, introduced to address the esthetic and biocompatibility issues of metal posts, offer translucency, radiopacity, and light transmission. Available in various shapes, they reduce stress via rounded apices. Though clinically successful, they face challenges like high rigidity, poor bonding post-thermocycling, and limited retreatment. Custom posts can now be fabricated via CAD/CAM from direct or indirect impressions [8].

Zirconia-Based Crowns and Bridges

Zirconia (Zir) frameworks are widely used in crowns and bridges, offering a metal-free solution for single-tooth prostheses and fixed partial dentures. They have demonstrated favorable early clinical results. In one study, 65 Zir bridges were fabricated using DCS President® technology and monitored over three years. Minor chipping of veneering material occurred in 6% of cases, resulting in a cumulative survival rate of 86% [8].

Zirconia-Based Implant Abutments

Zirconia (Zir) shows superior biocompatibility compared to titanium oxide and matches alumina, with no reported cytotoxic, mutagenic, or carcinogenic effects. Its high strength and lower modulus of elasticity make it suitable for implant-supported restorations. Stabilized and transformation-toughened Zir overcomes alumina's brittleness, reducing implant failure risk.

Zir abutments offer excellent tissue compatibility, reduced plaque accumulation, and natural tooth color. *In vivo* studies report high success rates (98-100%), including a four-year trial showing 100% survival of 53 Zir abutments. Despite successful osseointegration, issues like veneering porcelain fractures and aging sensitivity limit long-term success.

Zir implants, particularly 3Y-TZP, are proposed as alternatives to titanium due to better aesthetics, wear and corrosion resistance, and less plaque affinity. However, clinical data reveals a higher risk of early fractures, highlighting mechanical integrity as a key concern [8].

Zirconia Bar-Retained Implant Overdenture: Bar attachments for overdentures are typically made from base metal or titanium alloys. However, zirconia (Zir) is gaining popularity due to its excellent biocompatibility, strength, and tooth-like color. Zir bars can be precisely fabricated using CAD/CAM technology, reducing technical steps and minimizing errors linked to conventional casting methods [8].

Single-Retainer Zirconia Resin-Bonded Bridge (RBB): When key clinical criteria are fulfilled, single-retainer ceramic RBBs have shown to be one of the most reliable options. Previously, materials like InCeram (alumina) and e. max (lithium disilicate) were commonly used. However, zirconia is now preferred for its superior connector strength [8].

Zirconia Esthetic Orthodontic Brackets: Zirconia (Zir) is used in the fabrication of esthetic orthodontic brackets, offering improved toughness over traditional alumina ceramic brackets. Polycrystalline Zir brackets have largely replaced monocrystalline Al_2O_3 due to their strength and lower cost, though they are more opaque and slightly less esthetic. These brackets also demonstrate good sliding behavior with stainless steel and nickel-titanium archwires, along with reduced plaque accumulation [8].

Zirconia Veneers

Zirconia (Zir) veneers have evolved with improved microstructure and composition to enhance translucency without compromising strength. Translucent Zir is now used for crowns, monolithic anterior and posterior FDPs, conventional, and ultra-thin veneers. Ultra-translucent Zir veneers, with a minimal thickness of 0.1-0.3 mm, offer a more conservative alternative to glass ceramics.

Though Zir is chemically inert and difficult to etch with hydrofluoric acid, leading to lower adhesion in limited-retention preparations, *in vitro* studies show higher fracture resistance than feldspathic and lithium disilicate veneers. However, debonding remains a concern due to weak resin cement adhesion. While esthetically promising, more clinical research is needed to validate their long-term performance [8].

Inlay-Retained Zirconia Fixed Dental Prosthesis (FDP)

In cases where implants are not an option, inlay-retained zirconia FDPs offer a minimally invasive alternative to full-coverage prostheses, requiring less tooth preparation. This approach is especially suitable when abutment teeth already have restorations, helping preserve more natural tooth structure and prolonging FDP retention. It also facilitates periodontal assessment.

Ideal candidates are patients with good oral hygiene and low caries risk. However, contraindications include severe parafunctional habits, absence of marginal enamel, major crown defects, and abutment tooth mobility [8].

Advancements, Applications, and Evaluations of Zirconia-Based Materials in Fixed Prosthodontics [14]

Guncu *et al*. conducted a six-year clinical study on monolithic zirconia FDPs fabricated via digital workflows in 58 patients. The results showed high reliability with no decementation or caries, though some gingivitis was noted. The study supports digital zirconia FDPs as a strong alternative to conventional restorations [14].

Ozden *et al*. examined the effect of sintering time on 4Y-TZP crowns. Short sintering durations impacted marginal fit, but remained within clinically acceptable limits, reinforcing the importance of following material-specific sintering protocols [14].

Ghodsi and Jafarian reviewed translucent zirconia's benefits, including minimal tooth preparation, biocompatibility, and superior esthetics. However, they highlighted a need for further research on how increased translucency affects material strength [14].

Arellano Moncayo *et al*. reviewed third- and fourth-generation zirconia, noting improvements in optical and mechanical properties, but emphasized a lack of comprehensive data on newer formulations [14].

Kongkiatkamon *et al*. provided a detailed classification of zirconia types, tracing the material's evolution and its growing range of restorative applications [14].

Schmidt *et al*. compared fracture resistance in cantilever

FDPs made from various zirconia types. They found performance differences related to yttria content and aging, particularly noting limited data on 5Y-TZP [14].

Schönberger *et al*. analyzed the fit of zirconia frameworks using two CAD/CAM systems. Though differences in internal fit were observed, all results remained clinically acceptable. High-translucent zirconia showed lower internal values in some cases [14].

Sachs *et al*. assessed fit accuracy of translucent zirconia in full-arch prostheses versus single crowns. Single crowns demonstrated better fit, but both showed acceptable marginal and internal accuracy, supporting their clinical viability [14].

Future and Challenges of Dental Zirconia

The future of zirconia and other ceramics relies on material science advances, industry innovation, and clinical expertise. A key challenge is improving esthetics without weakening fine-grained structures. Monolithic zirconia addresses chipping issues seen in veneered restorations and offers durability. Adding 0.2 mol% Al_2O_3 to 3Y-TZP improves translucency and aging resistance but reduces strength. 5Y-PSZ is more translucent but mechanically weaker [8]. Zirconia-toughened alumina enhances strength but is too opaque for anterior use. Research focuses on dopants, sintering, and nanopowders to optimize translucency, reduce porosity, and improve strength—positioning monolithic zirconia as a promising future material [8].

Conclusion

The success of zirconia restorations depends on a strong bond with resin cement through effective surface treatments. Studies over the past two decades highlight the need for standardized aging and thermocycling protocols. Bonding protocols effective for conventional zirconia also work best for high-translucent zirconia. Airborne particle abrasion and phosphate monomer-containing primers and/or composite resin cements ensure durable bonds[15]. Sandblasting followed by universal primer improves bonding more than primer alone on untreated milled surfaces [16]. Sandblasting with 50 µm aluminum oxide remains the most reliable for mechanical retention. Priming agents with hydrophobic phosphate monomer (MDP) provide durable bonds with translucent zirconia [17]. Using self-adhesive resin cements with 10-MDP enhances chemical bonding. Mechanochemical methods offer superior adhesion, while newer techniques like selective infiltration etching and low-fusing glass coatings show potential but need further development. Ongoing research is essential to improve and standardize zirconia bonding protocols [10].

Conflict of Interest

Not available

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