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Is Zirconia the Holy Grail of All-Ceramic Restorations?

A NEW ERA IN ALL-CERAMIC RESTORATIONS

Ceramics have been increasingly promoted as high-strength restorative dental materials, particularly zirconia and lithium-based glass-ceramics. The evidence for zirconia as a well-performing dental ceramic dates back to the late '90s. The very first dental zirconia was stabilized with 3 mol% (or 5.8 wt%) yttria and doped with 0.25 wt% alumina as a sintering aid. This material, also known as tetragonal zirconia polycrystal (3Y-TZP), exhibits an exceptionally high flexural strength (often exceeding 1,200 MPa) and a relatively high fracture toughness (typically around 5 MPa•$m^{1/2}$), but is predominantly opaque and thus primarily used as a strong framework to support weak but esthetic porcelain veneers. Clinical studies have revealed that though zirconia frameworks are comparatively fracture resistant, chipping and fracturing of porcelain veneers is a frequent issue.[1] In addition, a veneer/core system inevitably increases the restoration thickness, meaning that more underlying tooth structure needs to be removed.

Over the past 10 years, a heavy focus has been placed on improving the translucency and esthetics of zirconia for monolithic indications to circumvent issues with veneer chipping and fracture while reducing restoration thickness. Five successive generations have since been developed: the original strong but opaque 3Y-TZP (first generation); a partially translucent but still moderately strong 3Y-TZP (second generation); the more translucent but weaker 4Y- and 5Y-PSZ (partially stabilized zirconia; third generation); polychromatic multilayered structures (fourth generation); and, finally, graded compositions and shades (fifth generation). The microstructures of these various zirconia types come in different forms depending on the cubic phase content (5% to 80%) and grain size (0.2 μm to 5 μm).[2] Measured strengths vary from 500 to 1,200 MPa, and toughness from 2.5 to 5 MPa•$m^{1/2}$. Appearance varies from predominantly opaque to substantially translucent, with the latter approaching that of glass-ceramics. In general, strength and toughness increase as translucency decreases with increasing yttria content.[3] Consequently, modern zirconias have a variety of restorative uses, including full coverage crowns, multi-unit fixed partial dentures, frameworks for porcelain-veneered restorations, and even veneers. However, a wide range of clinical applications does not necessarily mean that zirconia is the best choice for all indications.

With the advent of innovations and technologic advances, the efficiency and accuracy of dental workflows are ever improving. Traditionally, fabrication of zirconia restorations requires a prolonged post–CAD/CAM machining or post–3D printing sintering process that inevitably becomes a major bottleneck in the workflow. Over the past 5 years, significant progress has been made in reducing sintering time. Nowadays, 3Y-TZP restorations can be sintered within 17 minutes, and 4Y- and 5Y-PSZ under 60 minutes. While effectively cutting down the sintering time by an order of magnitude, the effects of speed sintering on the densification behavior of zirconia, as well as its translucency and shade, are still not fully understood.

In the high-strength dental ceramic market, zirconia has a competitor: lithium-based glass-ceramics. Compared to zirconia, lithium-based glass-ceramics often result in better esthetics because they are better able to match the adjacent teeth owing to their superior translucency and wide range of shade selections. The downside to those superior esthetics is a

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comparatively lower strength and toughness, at least relative to first and second generation zirconias. Efforts in developing lithium glass-ceramics have been devoted to increasing flexural strength. Several lithium glass-ceramic variants have entered the market, with compositions varying from predominantly lithium disilicate to lithium silicate, to biphasic lithium disilicate/lithium silicate, to lithium disilicate/aluminosilicate. Glass-ceramic microstructures contain various crystal contents (40% to 80%) and crystallite sizes (0.2 to 10 μm) and morphologies (equiaxed or elongated).[4] Flexural strengths vary between 200 and 800 MPa, and toughness from 1.3 to 2.5 $MPa \cdot m^{1/2}$, which is adequate to resist mastication for inlays, onlays, partial and full coverage crowns, and 3-unit FPDs (up to the second premolar). Although their clinical indications are similar to that of cubic phase-containing 5Y-PSZ, glass-ceramics have a lower elastic modulus that better matches the underlying tooth support. The load-bearing capacity of lithium glass-ceramics can exceed that of 5Y-PSZ and even match that of 4Y-PSZ.[5] Another important advantage of silicate ceramics is that they can be acid etched and silanized, which promotes adhesive resin bonding and thereby increases fracture resistance.[6] Finally, the crystallization firing cycle is much shorter than zirconia sintering, with the conventional firing cycle around 20 minutes and speed firing under 7 minutes.

A LOOK TO THE FUTURE

High-performance ceramic materials suitable for digital fabrication will continue to dominate restorative dentistry. New materials with superior mechanical and esthetic properties will be developed by refining material composition and microstructure. With advances in functionally graded materials and surface science, new ceramics will likely have enhanced esthetic, mechanical, and adhesive bonding properties.[7] Novel ultrafast and high-temperature sintering technology capable of sintering high-strength ceramics as fast as 10 seconds will further improve the efficiency of digital workflows.[8] Innovative shaping and finishing protocols and 3D printing methods for fabricating better-performing ceramic restorations are a technologic imperative.

Despite advancements in digital technology, current CAD/CAM technologies for manufacturing ceramic restorations do not yield a finished product. Postmachining adjustment and surface polishing of the restoration are necessary. In addition, current carbide tool cutting of green zirconia and diamond bur milling of both partially crystallized glass-ceramic blocks and fully crystallized/sintered ceramics compromise their strength.[9] Thus, new "ductile" machining technology, which avoids the introduction of subsurface microcracks and other strength-limiting defects while improving the restoration's contour accuracy and surface finish, is called for. A side benefit of ductile grinding is the preservation of diamond burs. Interestingly, whereas strong progress has been made in ductile machining of brittle engineering materials—such as single-crystal semiconductors and amorphous glasses—in the manufacturing industry,[10] there has been virtually no movement toward this technology in the finishing of dental and biomedical prostheses.

Additive manufacturing (AM), or 3D printing, has now been fully integrated into CAD/CAM hardware as an alternative to subtractive machining and milling.[11] The most attractive aspect of AM is flexibility of design, as meshes of geometric parameters, material compositions, and even colors and shades can be readily controlled for optimal properties. Today, a number of 3D printing techniques have shown great potential in manufacturing ceramic dental prostheses, including direct inkjet printing (DIP), selective laser melting (SLM), and stereolithography (SLA). But all have major limitations. Most notably, porosity and flaws in final products are high, thus diminishing translucency, and, to a lesser degree, strength.[12] In addition, DIP and SLM have poor shape accuracy, whereas DIP and SLA involve prolonged drying, debinding, and sintering/crystallization processes. AM of ceramic dental prostheses remains a technology in progress.

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