- Optimizing Shade Match Using All-Ceramic and Composite Materials
- Incorporating Flowable Composites into the Minimally Invasive Treatment Sequence
- Ten-Unit All-Ceramic Anterior Fixed Partial Denture Using Y-TZP Zirconia
- Atraumatic Ridge Expansion and Implant Site Preparation With Motorized Bone Expanders
A TEN-UNIT ALL-CERAMIC ANTERIOR FIXED PARTIAL DENTURE USING Y-TZP ZIRCONIA

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High-strength, all-ceramic systems are being recommended with increasing frequency for both anterior and posterior restorations. There are some significant differences in the physical and mechanical properties of these materials that ultimately affect their clinical performances. Consequently, these differences should be clearly understood before the restorative team selects the use of a particular system. This article reviews these differences and demonstrates the use of Y-TZP zirconia for the fabrication of a 10-unit anterior fixed partial denture.

Learning Objectives:
This article describes several of the significant physical properties of different high-strength, all-ceramic systems. Upon reading this article, the reader should:

- Understand the differences in the manufacturing and processing of high-strength, all-ceramic systems.
- Recognize the significant physical and mechanical properties to evaluate when comparing the different systems.

Key Words: high-strength ceramics, zirconia, fracture toughness, cyclic loading, transformational toughening

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For over three decades, the most common and accepted procedure for prosthetically replacing missing teeth has been the metal-ceramic fixed partial denture (FPD). In recent years, however, the demand for more aesthetic restorations has driven efforts to find all-ceramic materials that provide the durability of the metal frame in the conventional metal-ceramic FPD. In addition to enhancing translucency and light transmission, all-ceramic systems often negate the need for opacifying ceramics that result in the high values common in most metal-ceramic restorations. The all-ceramic restoration also eliminates the display of metal at the margin, which allows the finish line of the preparation to be placed at or slightly beneath the free gingival margin without compromising aesthetics. In those instances of high aesthetic concern, the use of porcelain color modifiers at or near the ceramic margin also negates the need for cutback of the frame and use of the porcelain butt margin, which is the technique-sensitive procedure required in metal-ceramic systems. Britteness, however, has limited the clinical range of all-ceramic materials. Historically, ceramics have been unable to withstand deformation of more than 0.1% to 0.3% without fracturing. To compensate for this characteristic of traditional glass matrix dental ceramics, newly developed materials are primarily crystalline in nature, enabling clinicians to fabricate FPD frameworks with flexural strengths and fracture toughness values that are much higher than those of previous ceramics.

Materials Review

There are three types of ceramics that are currently recommended for use in both anterior and posterior crowns and anterior FPDs. These are glass-ceramic materials, glass-infiltrated ceramics, and polycrystalline ceramics. Polycrystalline ceramics are the strongest of the three and are the only ones suitable for use in posterior FPDs as well. Yet even among polycrystalline ceramics, there are significant differences in composition and strength that must be considered when one is choosing a restorative material.

Glass-ceramic is a multiphase material that consists of an amorphous glassy phase and crystalline particles, included as reinforcing agents (i.e., IPS Empress 2, Ivoclar Vivadent, Amherst, NY). Glass-infiltrated ceramics consist of a product formed by infiltrating molten glass into a partially sintered oxide material (e.g., alumina oxide, alumina-zirconia oxide), such as In-Ceram Aluminum and In-Ceram Zirconia (Vident, Brea, CA). Polycrystalline ceramics are materials with densely packed particles containing no glassy components, such as the densely sintered, high-purity aluminum oxide system (i.e., Procera All-Ceram, Nobel Biocare, Yorba Linda, CA) and the yttria tetragonal zirconia polycrystal (Y-TZP) systems (e.g., Lava, 3M Espe, St. Paul, MN; Cercon, Dentsply Ceramco, York, PA; Procera All-Zirconu, Yorba Linda, CA). All of these zirconia-containing systems use computer-assisted machining (CAM) of manufactured and partially sintered Y-TZP blocks, followed by the complete sintering of the shaped product at 1350°C to 1500°C. The partially sintered or soft “green state” material is milled from a pressed block to a size that is 20% to 25% larger than the final sintered core or frame to compensate for the shrinkage that occurs during final sintering in the dental laboratory.

Some other systems (e.g., DC-Zircon, Popo DCS, Greendale, WI; Zircore, Outsource International, Manhattan, KS) use fully sintered, hard Y-TZP blocks to mill fully sintered infrastructures. No shrinkage is involved in the processing of the fully sintered material, and cores fabricated from such materials have been shown to be structurally more reliable than the postsintered green state material. Since the blocks of this material are industrially prepared ZrO, and have been fully sintered under high heat and isostatic pressure (HIP’d), they have less than 1% porosity and their physical properties do not vary from one block to the next. The milled frameworks are certifiable up to the point of application of the veneering porcelain, regardless of which laboratory performs the milling process.

Clinical Considerations

The lack of sufficient clinical studies on high-strength ceramics has led researchers and clinicians to emphasize their mechanical properties as a predictor of clinical success. The most commonly cited property is the flexural or fracture strength of the material, though it is
generally accepted that the potential for clinical success of dental ceramics should not be characterized solely by mean fracture strength. Under cyclic loading, micro-cracks propagate and weaken the restoration, a phenomenon described as slow crack growth, which stress corrosion caused by the infiltration of oral fluids further enhances crack propagation. The lifespan of the restoration is decreased by the accumulation of this damage from repeated occlusal contacts, even at loads considerably lower than those needed to produce single-cycle degradation, which is typically measured when determining the fracture strength of a material.

The survival of a material is actually determined by its density, or lack of porosity, and by the severity and location of critical flaws, inclusions, and large-grained zones. These, in turn, are the direct result of the process used to manufacture the material and variability of the fabrication process used by a laboratory in preparing the final prosthesis. Consequently, some ceramic restorations will fail at load levels far below the expected strength level of that particular material.

There are several means by which ceramic materials may be strengthened, and a general rule is that the higher the glass content, the weaker its mechanical properties. The glassy phase of a material offers little resistance to crack propagation, hence its failure at lower stress loads. In glass-infiltrated ceramics, partially sintered oxides of alumina or alumina-zirconia are added to the glass to increase its fracture toughness. Fracture toughness, which is independent of flaw distribution, is thought to be a better indication of a material's reliability than its fracture strength. Fracture toughness is a measure of the resistance offered by a material to the rapid propagation of an internal crack. Improving the fracture toughness of a material can improve its in-service reliability.

Several toughening mechanisms have been used to improve the properties of these dental ceramics. These have been described by Swain and predominantly involve the interaction of a propagating crack with a crystalline reinforcing material. The higher the fracture resistance of a material, the more clinically acceptable it is thought to be.

With polycrystalline ceramics, the nature of the material itself and its overall porosity become the important factors. Zirconia-based materials are stronger and tougher than densely sintered, high-purity alumina-zirconia materials, which are recommended for single-crown use only. The mechanical properties of zirconia are primarily attributed to its multiphase structure and its tetragonal-to-monoclinic phase transformation. This transformation, which can be induced by external stresses, grinding, and cooling, results in a 4% increase in volume that causes compressive forces. These forces can develop on a ground surface or at a crack tip. This clamping effect must then be overcome by a crack in order to propagate, which explains the significant increase in fracture toughness of zirconia over other dental ceramics. This property is known as transformational toughening. All zirconia materials are not the same, however, and the metastability of the transformation has been shown to be dependent on the composition, size, and shape of the zirconia particles, the type and amount of the stabilizing oxides, the interaction of zirconia with other phases, and the processing of the material itself.

As noted, the processing of the soft green-state material requires that the core from each block of the partially sintered material be milled at a 20% to 25% enlarged state to compensate for shrinkage in the final sintering process. Because of the inherent inaccuracies in this approach, nonlinear and longer-span FPDs cannot be made to fit accurately. For this reason, green state materials are not recommended for FPDs beyond four units in length. Though the fit of each final core or FPD may be acceptable, there is no standardization in fit, strength, or fracture toughness of the finished frames from the different blocks of material. This is because of the different shrinkage factor of each block, inconsistencies in the handling of the material by the various laboratories once it has been milled, and the fact that the final sintering process does not take place under isostatic pressure. As with the glass-infiltrated ceramics, the greater the density of the polycrystalline material, the greater is its fracture toughness. Material sintered under pressure, with less than 1% porosity, will be more desirable than one with a porosity of 7% to 9%.

Due to the unpredictable strength of ceramics and the inherent nature of its flaws, a material may fail at lower than reported values. Another meaningful method
of characterizing the fracture potential of ceramic materials is through the Weibull analysis of strength data, or the m value. The Weibull modulus is a dimensionless number used to characterize the variability of measured strength of components made from brittle materials, which arises from the presence of flaws having a distribution in size and orientation. A large value of Weibull modulus ensures fewer fatal flaws, a smaller error in strength estimation, and greater clinical reliability. For example, concrete has an m value of about 5, implying that the measured strength of a nominally similar specimen can vary by as much as ±30%. Ceramics produced by sintering have flaw sizes that are smaller and much more uniform, such that m is approximately 10 to 15, and the variability in strength is only about ±10%. It is apparent, then, that in the fabrication process under dental laboratory conditions, it is critical that the preparation techniques be optimized to improve clinical performance. Alternatively, industrially produced and sintered ceramics have been shown to be more structurally sound and reliable, as illustrated by much higher m values.

Case Presentation
A 23-year-old female patient presented for an evaluation for the replacement of teeth #6(13) through #8(11), and #11(23) (Figures 1 through 3). The permanent canines were congenitally missing, and teeth #7(12) and #8 had a history of trauma and failed endodontic therapy. One of the mandibular incisors had been extracted, and the remaining three incisors were aligned into a stable, aesthetic, and functional relationship. Upon periodontal, occlusal, and aesthetic evaluation, the prognosis for the right lateral and central incisors was hopeless (Figure 4A), and there were several concerns regarding their replacement, as well as for the canines.
Figure 7. Facial view of matured gingival tissues and edentulous ridge area. A 1-mm sulcus was established on the facial aspect of the anterior teeth.

Figure 8. Occlusal view demonstrates rotation of tooth #5(14) and limited intra-arch space for replacement teeth #6(13) through #8 and #11(23).

Figure 9. View of 10-unit milled Y-TZP zirconia frame. This all-ceramic material had the highest tested fracture strength and fracture toughness of those currently in the market.

Figure 10. Gingival view of zirconia frame following application of veneering porcelain.

The treatment options consisted of dental implants and crowns, an FPD, or a combination of the two modalities. It was imperative that a healthy, normal-appearing and aesthetically shaped gingival architecture be established and maintained. In anticipation of establishing the contours of the definitive restoration, there was the realization that the position and spacing of the remaining teeth would hinder the placement of normalized and positioned maxillary canines. The existing physiologic occlusion precluded the use of further orthodontic therapy to open up space in the anterior segment for normal sized pontics or dental implants. Finally, because of the patient's aesthetic expectations, all-ceramic restorations would be selected.

During the initial phase, localized antibiotics were placed directly into the active lesions to bring the infection under control. Following occlusal equilibration, teeth #5(14) through #12(24) were prepared and provisioned using an acrylic provisional bridge. The left primary canine was extracted, and an ovate pontic form of the provisional, extending into the socket, was created. The lateral and central incisors were then surgically removed, revealing a complete loss of the facial plate of bone. Autogenous bone grafting was performed for the sockets (Figure 4B), and a subepithelial connective tissue graft was performed within each extraction socket orifice (Figure 5). The provisional bridge was modified to provide an ovate pontic form that extends 2 mm to 3 mm into the extraction sockets (Figure 6). At later visits, the provisional bridge pontics were again modified to support and shape the tissues as they matured.

After 4 months of healing, the surgical site was stable and a secondary periodontal procedure was performed to level out and create harmony for the gingival architecture between the right and left sides. Crown lengthening was performed on tooth #10(22), and the
pontic site for tooth #11 was enhanced and deepened, again via an ovate pontic form in the tissue. The pontics were again modified to facilitate soft tissue healing into the ovate pontic form.

Following 8 additional weeks of healing, maturation of gingival tissues was complete (Figure 7). The decision was made to complete the restoration as a 10-unit FPD using the industrially prepared Y-TZP zirconia material as the core (Figures 8 and 9), and the second premolars were included to help support the restoration. In fabricating the all-ceramic FPD (Figure 10), the aesthetic characteristics and occlusal scheme established in the provisional restoration were maintained (Figure 11). The prosthesis was inserted provisionally and maintained for 3 months prior to final cementation. During that time, there was no cement washout of any of the retainers, the tissue response was positive (Figures 12 and 13), and the patient was very comfortable. The bridge was subsequently cemented with resin-modified glass ionomer cement, and a maxillary occlusal guard was made for night use (Figure 14).

**Discussion**

At the time of tissue maturation, the decision to replace the missing teeth by means of dental implants or fixed prostheses was addressed. The use of implants raised several concerns. There was limited space in the position of tooth #11, and placing even a narrow implant would jeopardize the health and normal contour of the papillae between the implant-supported crown and the adjacent teeth. The ridge area between tooth #5 and #9(2)1 was not the span of a normal-sized canine, lateral, and central incisor. The rotated first premolar and the space left by the primary canine did not allow the placement of an implant in a normal canine position (Figure 8). The implant would have to be positioned in what would be the embrasures between the canine and lateral incisor. Another option was placing implants in the central and lateral incisor positions and cantilevering a canine pontic off the lateral fixture. However, the predictability of maintaining interimplant papillae over time was a significant concern.

In spite of the fact that the established gingival architecture could be more predictably maintained, the use of an FPD was not without its limitations. Although laboratory research has demonstrated that the zirconia-based materials may be strong enough to support all-ceramic prostheses, there are no long-term clinical data to verify this assumption. While short-term studies on shorter-unit bridgework appear promising, the use of these materials for long-span FPDs has not yet been demonstrated. Consequently, to assure that the best possible material was utilized in the construction of the restoration, a material that was fully certifiable with respect to its final physical properties was selected. This material was tested with the highest fracture strength value (ie, 1200 MPa) and the highest fracture toughness value (ie, $K_{IC} = 9.4$ MPa m$^2$) of all ceramic materials currently on the market. It also has both the lowest porosity percentage (ie, <1%) and the highest Weibull modulus value (ie, $m = 18.4$) of all other materials. Finally, studies have shown that under cyclic loading, it will bear loads considerably higher than 500 N, which is well above the clinically significant range for failure.

Prior to considering this type of restoration, several clinical factors also were evaluated. First, the patient had been wearing her provisional bridge for well over 6 months without experiencing cement washout of a retainer. Second, the patient did not show any signs of occlusal parafunction, and there was minimal wear on the provisional. Third, there was adequate space to
design a frame with the size of connector that is recommended for this material. Finally, addition of the second premolars to the splint would add greater support for the terminal abutments and allow for the optimization of the group function scheme of occlusion required for this prosthesis.

Conclusion
The success of this case is dependent upon many factors. Strict adherence to the prosthetic principles of case assessment and occlusal function was important in laying the groundwork for long-term successful function of the prosthesis. Skillful management of the periodontal tissues contributed to the aesthetic success of the case. Finally, the use of the best possible material (ie, DC-Zircon, DC Dental AG, Allschwil, Switzerland) in the construction of the restoration allowed the prosthesis as well as periodontal therapy to be optimized to their fullest.

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