Ceramics in Dentistry—Part I: Classes of Materials

Many different types of ceramic systems have been introduced in recent years for all types of indirect restorations, from very conservative no-preparation veneers, to multi-unit posterior fixed partial dentures (FPDs) and everything in between.

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It is overwhelming and can be confusing knowing all the different nuances of materials and material processing systems. This article will cover what types of ceramics are available based on a classification of the micro-structural components of the ceramic. A second, simpler classification system based on how the ceramics are processed will give the main guidelines for their use. Part 2 of this article will cover in great detail the clinical decision-making process for using the various materials available and give very specific guidelines for the appropriate clinical conditions for the various ceramic systems.

What Makes a Ceramic a Ceramic?

The word "ceramic" is derived from the Greek word "keramos" that translates to mean, "burnt earth." It came from the ancient art of fabricating pottery where mostly clay was fired to form a hard, brittle object. A more modern definition is a material that contains metallic and non-metallic elements (usually oxygen). These materials can be defined by their inherent properties; they form hard, stiff, and brittle materials due to the nature of their inter-atomic bonding, which is ionic and covalent. Contrast that to a metal; metals are non-brittle (display elastic behavior), and ductile (display plastic behavior). This is because of the nature of the inter-atomic bonding, which is called a metallic bond. These bonds are defined by a cloud of shared electrons that can easily move when energy is applied. This is what makes most metals great conductors. Ceramics can be very translucent to very opaque. In general, the more glassy the microstructure (ie, noncrystalline) the more translucent it will appear, and the more crystalline, the more opaque. Many other factors contribute to translucency, eg, particle size, particle density, refractive index, and porosity, to name a few. The nature of this article does not allow a discussion of these various issues.

Dental ceramic materials can exist in a glass form (an amorphous solid), which has no crystalline phase; a glass with varying amounts and types of crystalline phase; a mostly crystalline material with small amounts of glass; all the way to a polycrystalline solid (a glass-free material). How ceramics are classified can be very confusing. Ceramics can be classified by their microstructure, (ie, amount and type of crystalline phase and glass composition). They can also be classified by processing technique (power-liquid, pressed, or machined). They can also be classified by their clinical application. We will give a classification based on the microstructure of ceramics, with the inclusion of how the ceramics are processed and that processing's effect on durability, so the reader will better understand the ceramics available in dentistry. More importantly, we will give a classification based on clinical indications for the various materials.

Microstructural Classification

At a microstructural level, we can define ceramics by the nature of their composition of glass-to-crystalline ratio. There can be infinite variability of the microstructures of materials, but they can be broken down into four basic compositional categories, with a few subgroups:

- **Composition Category 1**—Glass-based systems (mainly silica)
- **Composition Category 2**—Glass-based systems (mainly silica) with fillers, usually crystalline (typically leucite or, more recently, lithium disilicate)
- **Composition Category 3**—Crystalline-based systems with glass fillers (mainly alumina)
- **Composition Category 4**—Polycrystalline solids (alumina and zirconia)

Composition Category 1—Glass-Based Systems

Glass-based systems are made from materials that contain mainly silicon dioxide (also known as silica or quartz), which contains various amounts of alumina Alumino-silicates found in nature, which contain various amounts of potassium and sodium, are known as feldspars. Feldspars are modified in various ways to create the glass used in

FIG. 1

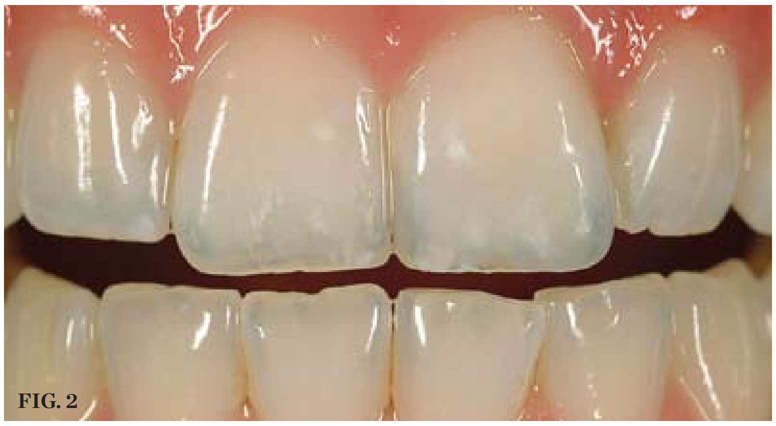

FIG. 2

BEFORE AND AFTER (1.) Preoperative view of a case requiring restoration. **(2.)**Postoperative view of the same case restored with a bonded veneer fabricated from a powder/liquid veneer made from a two-phase glass VM7 (Vita/Vident).

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dentistry. Synthetic forms of alumino-silicate glasses are also manufactured for dental ceramics. The authors could not find any documented references which showed that naturally occurring alumino-silicate glasses performed better or worse than synthetic glasses, even though there have been claims to the contrary. These materials were first used in dentistry to make porcelain denture teeth. More recently, powder-liquid versions were made for the specific veneering of alumina-based core systems, eg, In-Ceram® (Vita Zahnfabrik, distributed by Vident, Brea, CA) and NobelProcera™ (Nobel Biocare, Yorba Linda, CA). These materials have a low coefficient of thermal expansion (CTE) around 8×10^{-6}/K. These materials can also be used for porcelain veneers using either a refractory die technique or platinum foil (Figure 1 and Figure 2). These materials have also been developed into very fine-grain machinable blocks, such as Vitablocs Mark II (Vident) for use with the CEREC® CAD/CAM system (Sirona Dental Systems, Charlotte, NC) (Figure 3 and Figure 4). This material is the most clinically successfully documented machinable glass for the fabrication of inlays and onlays, with all studies showing a < 1% per year failure rate, which compares favorably with metal-ceramic survival data, CEREC, and metal-ceramic references.[1-6] The benefit of a pre-manufactured block is that there is no residual porosity in the finished core that could act as a weak point, which could lead to catastrophic failure.

Composition Category 2—Glass-Based Systems with Fillers

This category of materials has a very large range of glass-crystalline ratios and crystal types, so much so, that this category can be subdivided into three groups. The glass composition is basically the same as the pure glass Category 1. The difference is that varying amounts of different types of crystals have either been added or grown in the glassy matrix. The primary crystal types today are leucite, lithium disilicate, or fluoroapatite. Leucite is created in dental porcelain by increasing the K_2O (potassium oxide) content of the alumino-silicate glass. Lithium-disilicate crystals are created by adding Li_2O (lithium oxide) to the alumino-silicate glass. It also acts as a flux, lowering the melting temperature of the material.

Subcategory 2.1: Low-to-moderate leucite-containing feldspathic glass—these materials have become called "feldspathic porcelains" by default. Even though other categories have a feldspathic-like glass, this category is what most people mean when they say "feldspathic porcelain." Leucite is added to these materials to raise the coefficient of thermal expansion (CTE) of the material so that they can be applied to metals and zirconia. The amount of leucite is adjusted in the glass based on what type core it has and its CTE. These materials are typical powder-liquid materials that are used to veneer core systems and are also the ideal materials for porcelain veneers (Figure 5 and Figure 6). The original materials had a fairly random size and distribution of leucite crystals, with the average particle size being around 20 µm. This random distribution and large particle size contribute to the material's low fracture resistance and abrasive properties relative to enamel.[7] Newer generations of materials (eg, VM 13, Vita) have been developed with much finer leucite crystals and very even particle distribution throughout the glass. These materials are less abrasive and have much higher flexural strengths.[8]

Subcategory 2.2: High-leucite-containing (approximately 50%) glass. Again, the glassy phase is based on an alumino-silicate glass. These materials have been developed in both powder/liquid, machinable, and pressable forms. The most widely used version is the original IPS Empress® (Ivoclar Vivadent, Amherst, NY) but there are several other products in this category. This material is called a glass ceramic, which has had the crystalline phase grown within the glass matrix by a process called "controlled crystallization of glass." Conventional (or what has become called feldspathic) porcelain has the crystalline leucite added to the glass matrix. Pressable and machinable versions designed for both the CEREC and E4D (D4D Technologies, LLC, Richardson, TX) of high-leucite ceramics have performed excellently clinically when used for posterior inlays and onlays, and anterior veneer and crown restorations.[8-13]

The fracture resistance or strength of categories 1, 2.1, and 2.2 is based more on the processing technique to fabricate the material than on the crystal type, amount, and distribution of the crystal within the glass matrix. Machinable and


FIG. 3


FIG. 6


FIG. 4

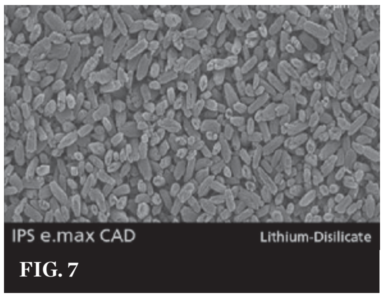


FIG. 7


FIG. 5


FIG. 8


FIG. 9

GLASS-BASED SYSTEMS (3.) Preoperative image of posterior teeth requiring restoration. **(4.)** Image of bonded CEREC Vitabloc Mark II restorations. **(5.)**Preoperative view of a case with a leaking and discolored veneer on tooth No. 8. **(6.)** Postoperative view of a conventional veneer tooth on tooth No. 8 and a minimal preparation veneer on tooth No. 9 made with VM13 (Vita/Vident). **(7.)** SEM of lithium disilicate (e.max CAD). **(8.)** Preoperative view of teeth requiring restorations. **(9.)** Postoperative view of a full onlay on tooth No. 30 and an inlay on tooth No. 31 made from a full-contour machining of e.max CAD.

pressable systems have much higher fracture resistance than powder/liquid systems and have shown excellent clinical results for posterior inlay and onlay applications and anterior veneer and crown restorations.[1-6,9-13]

Subcategory 2.3: Lithium-disilicate glass ceramic is a new type of glass ceramic introduced by Ivoclar as IPS Empress® II (now called IPS e.max®), where the alumino-silicate glass has lithium oxide added as stated above. The crystals that form within this material are needle-like in shape (Figure 7) and comprise about two thirds of the volume of the glass ceramic. The shape and volume of the crystals contribute to roughly double the flexural strength and fracture toughness of this material.[14-18] The material comes in a pressable and machinable form (e.max). This material can be very translucent even with the high crystalline content; this is due to the relatively low refractive index of the lithium-disilicate crystals. This material is translucent enough that it can be used for full-contour restorations (Figure 8 and Figure 9) or, for the highest esthetics, can be veneered with a special porcelain. Porcelain veneering materials for lithium-disilicate glass ceramics are also alumino-silicate glasses that contain fluoroapatite crystals rather than leucite. Fluoroapatite is a fluoride-containing calcium phosphate with the chemical formula $Ca^5(PO_4)^3F$. The fluoroapatite crystals contribute to the veneering porcelain's optical properties and CTE, so that it matches the lithium-disilicate pressable or machinable material. Both the veneering material and the lithium-disilicate material are etchable due to the glassy phase. Initial clinical data for single restorations are excellent with this material, especially if it is bonded.[19]

Composition Category 3—Crystalline-based Systems with Glass Fillers

Glass-infiltrated, partially sintered alumina was introduced in 1988, and marketed under the name In-Ceram. The system was developed as an alterative to conventional metal-ceramics, and has met with great clinical success.[20,21] The system uses a sintered crystalline matrix of a high modulus material (85% of the volume), in which there is a junction of the particles in the crystalline phase (Figure 10). This is very different than glass or glass-ceramic materials in that these ceramics consist of a glass matrix with or without a crystalline filler in which there is no junction of particles (crystals). The crystalline phase consists of alumina, alumina/zirconia, or an alumina/magnesia mixture appropriately named "spinell," that is fabricated by a process called slip casting,[22] or it can be milled from a pre-sintered block of either material (Figure 11).[23] The alumina or spinell framework is then infiltrated with a low-viscosity lanthanum glass at high temperature (Figure 12 and Figure 13). Extremely high flexural strengths have been reported for this new class of dental ceramic, three to four times greater than any other class of dental ceramic.[24-26] It is theorized that this high strength is due to the primarily crystalline nature of this material and minimal glassy phase, in which a flaw would have to propagate through either the high modulus alumina or spinell to cause ultimate failure. Several clinical studies support the use of glass-infiltrated alumina (In-Ceram) for single units anywhere in the mouth: in one study by the main author, In-Ceram alumina had the same survival as that of PFMs up to the first molar, with a slightly higher failure rate on the second molar.[27] In unpublished data from the author's samples, the alumina/zirconia version of In-Ceram had a < 1% per year failure rate on second molars, which is consistent with metal-ceramic failure data. The alumina/zirconia material should only be used on molars because of its very high opacity, which is not ideal for anterior esthetics. For anterior teeth, the alumina/magnesia version of In-Ceram (called spinell) is ideal because of its higher translucency. The strength is about half of the alumina/zirconia version, so it should not be used for posterior teeth.

Composition Category 4—Polycrystalline Solids

Solid-sintered, monophase ceramics are materials that are formed by directly sintering crystals together without any intervening matrix to from a dense, air-free, glass-free, polycrystalline structure (Figure 14). There are several different processing techniques that allow the fabrication of either solid-sintered aluminous-oxide or zirconia-oxide frameworks. Solid-sintered ceramics (polycrystalline glass-free) have the highest potential for strength and toughness, but because of high firing temperatures and sintering, shrinkage techniques were not available until only recently to use as high-strength frameworks for crowns and FPDs. There are three basic techniques for fabricating solid-sintered, monophase, ceramic frameworks for porcelain application. One system, DCS Precident, (DENTSPLY Austenal, York, PA) machines the final desired framework shape from a solid sintered block of material. This system is expensive and has not proven cost effective because of the excessive machining time and manual labor necessary to adjust and fit the coping. The Procera system uses an oversized die where a slurry of either aluminous oxide or zirconia oxide is applied and subsequently fired; it fully sinters and shrinks to fit the scanned die. The third method that has been recently developed machines an oversized coping from a partially sintered block of zirconia-oxide material (alumina is not used in dentistry for this process), which is then fired to full sintering temperature. This then shrinks to fit the die.

Zirconia has unique physical characteristics that make it twice as strong and twice as tough as alumina-based ceramics. Reported values for flexural strength for this new material range from over 900 MPa to 1,100 MPa.[10,16] It is important to note there is no direct correlation between flexural strength (modulus of rupture) and clinical performance. With all things being equal, it is better to have an inherently stronger material than a weaker one. A more important physical property is fracture toughness, which has been reported to lie between 8 MPa and 10 MPa for zirconia.[10] This is significantly higher than any previously reported ceramic, and roughly twice the amount reported for the alumina materials. Fracture toughness is a measure of a material's ability to resist crack growth. Zirconia has the apparent physical properties to be used for posterior three-unit FPDs. Initial reports on zirconia have not demonstrated a problem with the zirconia framework.[28-30] There have been some problems associated with chipping and cracking of porcelain. At UCLA, the author and his team has done some pilot testing of cracking resistance of porcelain fired to zirconia. Using a slow-cooling protocol at the glaze bake to equalize the heat dissipation from the zirconia and porcelain increased the fracture resistance of the

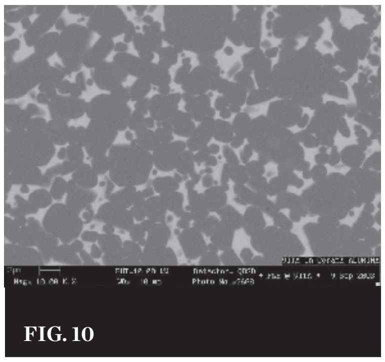
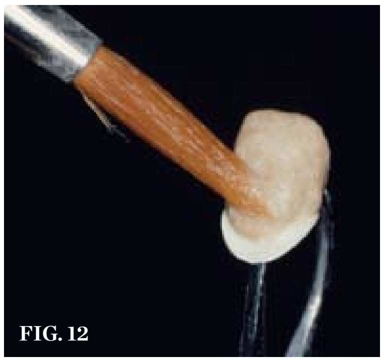


FIG. 10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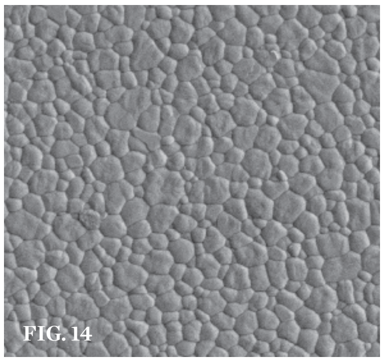
FIG. 14

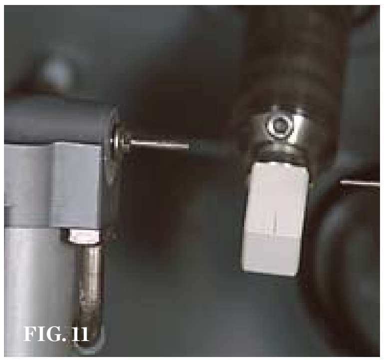
FIG. 11


FIG. 13

IN-CERAM (10.) SEM of In-Ceram, which demonstrates a high level of crystalline structure with glass filler. **(11.)** Milling from a pre-formed monoblock of In-Ceram alumina.

INFILTRATION GLASS SINTERING (12.) Applying the infiltration glass to the In-Ceram coping. **(13.)** After firing of the infiltration glass. **(14.)** SEM of solid sintered zirconia (Lava).

porcelain by 20%. Work is ongoing in this area and a full report will be coming later this year.

Within Composition Categories 2 and 3 there can be great variation of composition and there are several commercial materials in these groups. Glass-based systems (Categories 1 and 2) are etchable and thus easily bondable. Crystalline-based systems (Categories 3 and 4) are not etchable and thus much more difficult to bond. Categories 1 through 3 can exist in a powdered form that is then fabricated using a wet-brush technique, or they can also be pre-processed into a block form that can be pressed or machined. As a general rule, powder/liquid systems have much lower strength than pre-manufactured blocks because of a much larger amount of bubbles and flaws in the finished restoration.

Classification Based on Processing Technique

A more user-friendly and simplistic way to classify the ceramics used in dentistry is by how they are processed. It is important to note that all materials can be processed by varied techniques but, in general, for dentistry they can be classified as: (1) powder/liquid, glass-based systems; (2) machinable or pressable blocks of glass-based systems; and (3) CAD/CAM or slurry, die-processed, mostly crystalline (alumina or zirconia) systems. The authors believe it is important to classify glass-based systems this way because they have seen a greater correlation to clinical success (and thus failure) based on the processing techniques of these materials than based on their chemical or micro-structural nature within classes of materials. Specifically, machined blocks of materials have performed better than powder/liquid versions of the same material.

Powder/Liquid, With or Without Crystalline Fillers

These are the porcelains that are made for veneering cores made from either metal, alumina, or zirconia but can be used for porcelain veneers on either a refractory die or platinum foil technique. For veneers, they are ideally suited for anterior teeth, especially when bonding to enamel. They are not the ideal material for inlays and onlays because they are much weaker than densely manufactured blocks of glass-based ceramics.

FIG. 15

FIG. 16

LAVA AND VM9 RESTORATION (15.) Preoperative situation of a patient requiring a implant-supported restoration and restoration of an old class 4 composite. **(16.)** Postoperative view of a Lava and VM9 crown on tooth No. 9 and a mini-veneer made of VM9 on tooth No. 8.

Machinable or Pressable Manufactured Blocks, With or Without Crystalline Fillers

Vitabloc Mark II for the CEREC and pressable and machinable versions of IPS Empress are the primary materials available in this classification. These materials are ideally suited for inlay and onlay restorations, anterior crowns and veneers, and possibly bicuspid crowns. They have to be bonded, they can be used full contour as there are polychromatic machinable versions of both, Forte Vitabloc, and Multi Empress. Both materials can be veneered with a powder/liquid porcelain that comes with the system to create maximum esthetics. E.max is a new lithium-disilicate glass ceramic described earlier. Because of its higher strength and fracture toughness (roughly double that of IPS Empress), it has the potential to be used for any type of single restoration anywhere in the mouth. According to the manufacturer, e.max can be conventionally cemented, but because of the glass matrix e.max can be etched and bonded, which is what the authors highly recommend.

CAD/CAM or Slurry/ Die-Generated, Mostly or All-Crystalline Alumina- or Zirconia-Based Systems

Alumina materials in this classification are Procera, which is solid sintered alumina, and In-Ceram, which is glass infiltrated. These materials work well for cores for single crowns that are veneered with a powder/liquid glass-based material (porcelain). As already stated, they have demonstrated clinical success similar to that of PFMs up to the first molar. As a general recommendation, if single-crown all-ceramics is all the reader intends on using in clinical practice, alumina-based ceramics should be highly considered because of their excellent track record and the fact that they cost less than zirconia-based systems. Zirconia materials in this classification are supplied by virtually all dental ceramic manufacturers; the most recognizable names are Lava™ (3M ESPE, St. Paul, MN), Vita YZ (Vident/Vita), and Cercon® (DENTSPLY, York, PA). These materials were designed as a PFM alternative for single crowns and three-unit bridges anywhere in the mouth. Larger bridges have been discussed but no large sample clinical documentation exists for this application. In the authors' experience of more than 1,200 either Lava or Vita YZ restorations (Figure 15 and Figure 16) placed either personally or in the UCLA Center for Esthetic Dentistry over the last 5 years, they have seen a < 1% per year failure rate for core fracture. Chipping of the porcelain was noted in > 6% of the restorations that could be recalled that required replacement, with many more showing chipping not requiring replacement. The slow-cooling firing treatment on the glaze bake has minimized or almost eliminated this problem. To summarize, the authors' clinical data shows that if the **proper porcelain firing protocol is used**, single restorations anywhere in the mouth and three-unit bridges (specifically Lava and Vita YZ) have performed well as a PFM substitute.

Conclusion

Ceramics can be classified in many ways. Two classification systems were given here to aid the reader in understanding the types of ceramics available for dental use. Processing technique has a very large impact on strength and, thus, clinical performance and should be one of the primary considerations in choosing a material.

There are so many clinical aspects that are important for success with all-ceramic materials that are not as critical with metal-based restorations, they are not possible to cover here (eg, preparation design, management of stresses, cementation techniques, and others). The reader is advised that significant knowledge and training in these areas are a prerequisite for success with all-ceramic materials.

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Ceramics

A sampling of ceramic materials available to enhance esthetics and provide durable, biomimetic restorations.

Ceramics. Derived from the Greek word for "burnt earth," these materials have eclipsed their origins in pottery and decorative tilework and established a secure place in the world of esthetic dental restorative materials. Here *Inside Dentistry* presents a sampling of products that are on the market for ceramic restorations. For more detailed information on these products, visit www.insidedentistry.net or any of the manufacturer Web sites listed on this page.

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VITA VM (veneering material) porcelains combine true enamel wear characteristics and incredibly lifelike esthetics. An effective and greatly simplified technique and an impressive array of modifiers and powders in VITA Classical and VITA 3D-Master-shades help provide an esthetically superior, long-lasting product. Prescribe VM7 with alumina substructures, VM9 with YZ substructures, and VM13 with metal substructures

For more information, call 800-828-3839 or visit www.prescribevita.com.

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Shofu Ceramage

Now offering new gum colors and bleach shades, expanding the extensive shade selection, Shofu's Ceramage®, a zirconium silicate micro-ceramic, creates indirect restorations that exhibit virtually the same light transmission as natural teeth and have remarkable translucency.

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Introducing IPS e.max® HT

Ivoclar Vivadent is proud to announce the launch of IPS e.max HT (high translucency) lithium disilicate material. HT rounds out the IPS e.max line and gives dental professionals full flexibility to provide patients with the best possiblerestorations. Available for both pressing and CAD/CAM fabrication, IPS e.max lithium disilicate exhibits superior strength (360-400 MPa) and esthetics for monolithic, full-contour restorations.

For more information, contact john.isherwood@ivoclarvivadent.us.

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