

A New Classification System for All-Ceramic and Ceramic-like Restorative Materials

Stefano Gracis, DMD, MSD^a/Van P. Thompson, DDS, PhD^b/Jonathan L. Ferencz, DDS^c/
Nelson R.F.A. Silva, DDS, MSc, PhD^d/Estevam A. Bonfante, DDS, MSc, PhD^e

Classification systems for all-ceramic materials are useful for communication and educational purposes and warrant continuous revisions and updates to incorporate new materials. This article proposes a classification system for ceramic and ceramic-like restorative materials in an attempt to systematize and include a new class of materials. This new classification system categorizes ceramic restorative materials into three families: (1) glass-matrix ceramics, (2) polycrystalline ceramics, and (3) resin-matrix ceramics. Subfamilies are described in each group along with their composition, allowing for newly developed materials to be placed into the already existing main families. The criteria used to differentiate ceramic materials are based on the phase or phases present in their chemical composition. Thus, an all-ceramic material is classified according to whether a glass-matrix phase is present (glass-matrix ceramics) or absent (polycrystalline ceramics) or whether the material contains an organic matrix highly filled with ceramic particles (resin-matrix ceramics). Also presented are the manufacturers' clinical indications for the different materials and an overview of the different fabrication methods and whether they are used as framework materials or monolithic solutions. Current developments in ceramic materials not yet available to the dental market are discussed. *Int J Prosthodont* 2015;28:227–235. doi: 10.11607/ijp.4244

Ceramics have been the mainstay of esthetic dentistry for more than 100 years. Originally in the naturally occurring feldspathic form, ceramics were used primarily for anterior teeth as high fusing porcelain jacket crowns, denture teeth, and partial coverage. Beginning with John McLean's introduction of aluminous porcelain in the mid-1960s,¹ there have been continuous improvements in strength, esthetics, and methods of fabrication, resulting in dozens of products for clinicians to choose from.

Due to the high number of products available and the speed at which new products are being introduced, today's clinician faces a complex decision process when choosing a ceramic restorative material for a particular indication. The selection is seldom made on the basis of a thorough understanding of the materials' characteristics. More often, it is based on criteria such as strength measured in vitro, degree of translucency, manufacturing techniques, the preference of the dental laboratory technician, and even advertising claims.

A classification system of the ceramic materials used in dentistry is useful for a variety of purposes, including communication and education. Ideally, a classification system should be helpful in providing clinically relevant information about where to use the material (anterior versus posterior), for what type of restoration (partial versus full, short versus long-span), and how to lute it (adhesively versus traditionally). Different classification systems have been proposed that focus on clinical indications, composition, ability to be etched, processing methods, firing temperatures, microstructure, translucency, fracture resistance, and antagonist wear.^{2–6} These classifications, however, tend to be either vague or imprecise, and they do not easily allow for the inclusion of new restorative materials.

^aPrivate Practice, Milan, Italy.

^bProfessor, Department of Biomaterials, Biomimetics and Biophotonics, King's College London, Guys Hospital, London, United Kingdom.

^cClinical Professor, Department of Prosthodontics, New York University College of Dentistry; Private Practice, New York, New York, USA.

^dAssociate Professor, Department of Restorative Dentistry, Federal University of Minas Gerais, Belo Horizonte, Minas Gerais, Brazil.

^eAssistant Professor, Department of Prosthodontics, University of São Paulo—Bauru College of Dentistry, Bauru, São Paulo, Brazil.

Correspondence to: Dr Stefano Gracis, Via Brera, 28/a, 20121 Milan, Italy. Email: sgracis@dentalbrera.com

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Classifying ceramics according to their composition is a logical step in the right direction, because an understanding of ceramic composition by both technician and clinician is essential for optimal results. So far, attempts have been shown to be too general and impractical, unfortunately.⁷⁻¹⁰

An often-used classification system by Kelly and Benetti,¹¹ for example, describes ceramic materials according to glass content and can be described as follows: (1) predominantly glassy materials, (2) particle-filled glasses, and (3) polycrystalline ceramics in which no glass is present. In this glass content classification system, the clinician might be confused by the lack of clarity in attempting to quantify the amount of glass phase required for the ceramic to be included in either the predominantly glassy or the particle-filled glasses category. Also, a direct correlation has been proposed in this classification system between the amount of glass and the resultant esthetics and strength characteristics of the completed ceramic restoration. This correlation states that predominantly glassy ceramics are highly esthetic, whereas polycrystalline ceramics are much less esthetic and are meant to be used solely as framework material. In a way, it suggests a relationship between ceramic composition and indications. However, current development in polycrystalline ceramic microstructure has challenged this concept. Esthetics is becoming less of a problem as more translucent zirconia and stronger but more opaque glass-ceramics have become available. This has allowed for the use of translucent and esthetic zirconia not only as a substructure for veneered reconstructions, as formerly recommended,^{12,13} but also as full-contour reconstructions.^{13,14}

The same observation is applicable to some particle-filled glass-ceramics. Formerly indicated for use only as substructure materials, their use as monolithic materials that achieve high levels of esthetics is gaining in popularity (eg, lithium disilicate). Therefore, classification of materials involving attempts to differentiate them on the basis of their use and indication appears confusing. Furthermore, the Kelly and Benetti classification does not recognize a fundamental development in ceramic technology that has occurred in the industry: The manufacturing process of these materials has moved away from naturally occurring components (ie, feldspar) to synthetically derived ceramics. This has resulted in an improvement in the standardization and quality control of these materials. It is important for the dentist and the dental technician to understand this difference because these synthetic materials will provide unmatched consistency.

Last but not least, the existing classifications of ceramic materials do not include resin-matrix materials that are highly filled with ceramics. These are

now available from various manufacturers and are recommended as esthetic alternatives for a variety of clinical indications, as described in this article. These materials recently have been coded as “ceramics” by the American Dental Association (ADA) because they have ceramic-like properties and should not be ignored in any classification system.^{15,16}

In light of this and other considerations, the authors proposed a new approach to classifying ceramic restorative materials into three families (Fig 1), based on the presence of specific attributes in their formulation, as follows:

- 1. Glass-matrix ceramics:** nonmetallic inorganic ceramic materials that contain a glass phase
- 2. Polycrystalline ceramics:** nonmetallic inorganic ceramic materials that do not contain any glass phase
- 3. Resin-matrix ceramics:** polymer-matrices containing predominantly inorganic refractory compounds that may include porcelains, glasses, ceramics, and glass-ceramics.

The glass-matrix ceramics family is further subdivided into three subgroups: naturally occurring feldspathic ceramics, synthetic ceramics, and glass-infiltrated ceramics. Polycrystalline ceramics are subdivided into four subgroups: alumina, stabilized zirconia, zirconia-toughened alumina, and alumina-toughened zirconia (currently in development). The third group, resin-matrix ceramics, is divided into several subgroups according to their composition.

Based on the above groupings, the following is a detailed description of the proposed classification.

Ceramic Restorative Materials Classification

1. Glass-Matrix Ceramics

1.1 Feldspathic (eg, IPS Empress Esthetic, IPS Empress CAD, IPS Classic, Ivoclar Vivadent; Vitadur, Vita VMK 68, Vitablocs, Vident)

This traditional group of ceramics is based on a ternary material system composed of clay/kaolin (hydrated aluminosilicate), quartz (silica), and naturally occurring feldspar (a mixture of potassium and sodium aluminosilicates). Potassium feldspar ($K_2Al_2Si_6O_{16}$) forms leucite crystals (crystalline phase), which, depending on the amount, not only increase the intrinsic strength of the restoration, but also make this porcelain suitable for veneering metal substructures (coefficient of thermal expansion approximately 10% or less below that of the

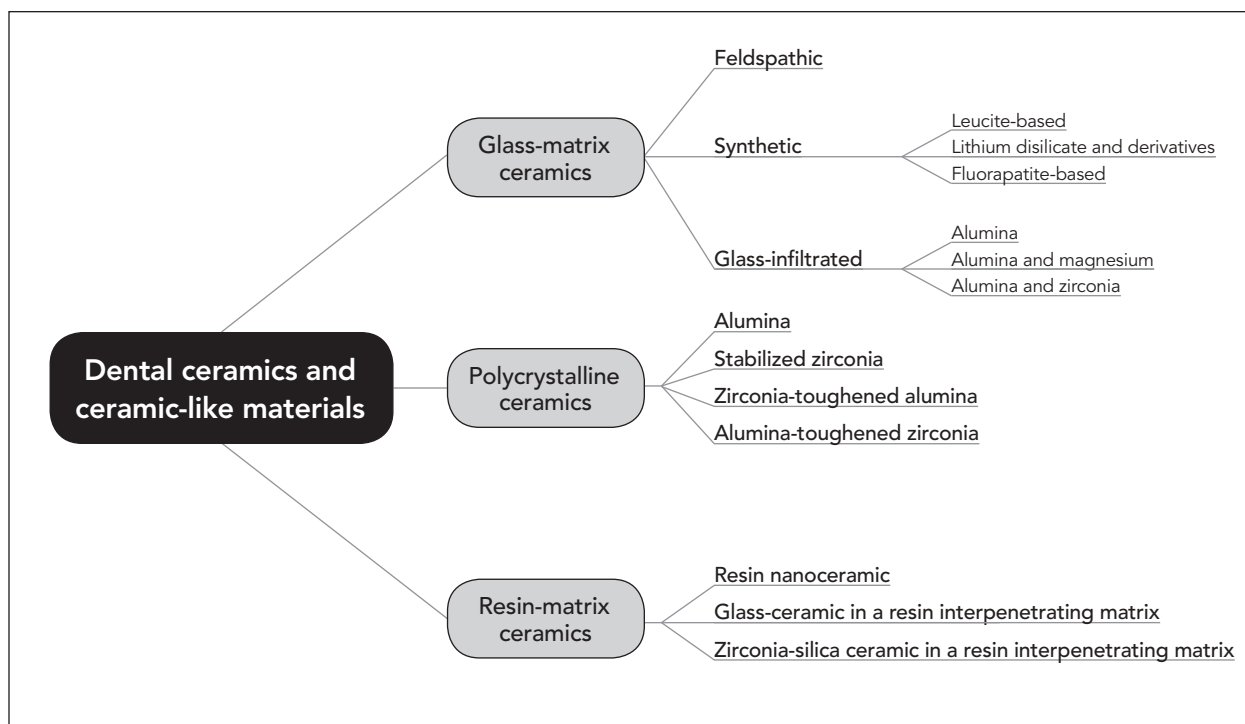


Fig 1 Overview of the proposed classification system of all-ceramic and ceramic-like materials.

substructure).^{3,5,6} These materials are still used as a veneering material on metal alloy and ceramic substrates and as an esthetic material bonded onto tooth structure.

1.2 Synthetic: leucite-based (eg, IPS d.Sign, Ivoclar Vivadent; Vita VM7, VM9, VM13, Vident; Noritake EX-3, Cerabien, Cerabien ZR, Noritake); **lithium disilicate and derivatives** (eg, 3G HS, Pentron Ceramics; IPS e.max CAD, IPS e.max Press, Ivoclar Vivadent; Obsidian, Glidewell Laboratories; Suprinity, Vita; Celtra Duo, Dentsply); **fluorapatite-based** (eg, IPS e.max Ceram, ZirPress, Ivoclar Vivadent)

To remain less dependent on natural resources of raw materials and their inherent variations, the ceramic industry has begun to use synthetic materials. The composition varies among manufacturers, but commonly includes silicon dioxide (SiO_2), potassium oxide (K_2O), sodium oxide (Na_2O), and aluminum oxide (Al_2O_3). Their glass phases may be combined with apatite crystals, in addition to leucite, for thermal expansion compatibility with metals and for improved strength. When used as a veneer material on all-ceramic frameworks, these materials are modified to match the coefficient of thermal expansion of their respective frameworks (eg, Vita VM7 and Cerabien for polycrystalline

alumina and glass-infiltrated ceramics, and VM9, Cerabien ZR, IPS e.max Ceram for polycrystalline zirconia).

For enhanced mechanical properties and use as a substructure material, crystalline phase reinforced feldspathic porcelains are available. These are composed of SiO_2 (63%), Al_2O_3 (17%), K_2O (11.2%), Na_2O (4.6%), ceric oxide (CeO_2 ; 1.6%), boron trioxide (B_2O_3), calcium oxide (CaO), barium oxide (BaO), titanium dioxide (TiO_2) (< 1%) (eg, IPS Empress), or of approximately 70% lithium disilicate (IPS Empress 2) (SiO_2 (57% to 80%), Al_2O_3 (0% to 5%), lanthanum oxide (La_2O_3 ; 0.1% to 6%), magnesium oxide (MgO ; 0% to 5%), zinc oxide (ZnO ; 0% to 8%), K_2O (0% to 13%), lithium oxide (Li_2O ; 11% to 19%), phosphorous pentoxide (P_2O_5 ; 0% to 11%). A further development within the lithium disilicate system (SiO_2 - Li_2O - K_2O - ZnO - P_2O_5 - Al_2O_3 -[zirconium dioxide] ZrO_2) (IPS e.max for either press or computer-aided design/computer-assisted manufacture [CAD/CAM] manufacturing) demonstrates improved mechanical properties for use as inlays, onlays, crowns, and three-unit fixed dental prostheses in the anterior region. With recent patent expiration, the variations on this latter material have become available from other manufacturers (eg, 3G HS from Pentron Ceramics). In addition, lithium silicate ($\text{Li}_2\text{O}_3\text{Si}$)-reinforced ceramics enriched with zirconia have been introduced (eg, Suprinity; Celtra

Duo; composition [% by weight]: SiO_2 [56% to 64%], Li_2O [15% to 21%], K_2O [1% to 4%], P_2O_5 [3% to 8%], Al_2O_3 [1% to 4%], ZrO_2 [8% to 12%], and CeO_2 [0% to 4%]).

1.3 Glass-Infiltrated: alumina (eg, In-Ceram Alumina, Vita); **alumina and magnesium** (eg, In-Ceram Spinell, Vita); **alumina and zirconia** (eg, In-Ceram Zirconia, Vita)

The first glass-infiltrated material, In-Ceram Alumina, introduced in 1989, is fabricated utilizing the slip-casting technique. A slurry of densely packed Al_2O_3 is sintered to a refractory die, and after a porous skeleton of alumina particles is formed, infiltration with lanthanum glass is performed in a second firing to infiltrate the porosity and increase strength. Three different particle sizes of alumina are observed, including large elongated grains (10 to 12 μm long and 2.5 to 4 μm wide), faceted particles (1 to 4 μm diameter), and spherical grains of less than 1 μm diameter. Due to its opacity, porcelain veneer layering is required. The composition, according to the manufacturer, is Al_2O_3 (82%), La_2O_3 (12%), SiO_2 (4.5%), CaO (0.8%), and other oxides (0.7%).

In-Ceram Spinell, introduced in 1994, is processed in a similar manner, but the glass is infiltrated into a synthetically produced porous magnesium aluminate (MgAl_2O_4) core. In-Ceram Zirconia is a modification of In-Ceram Alumina where partially stabilized zirconia oxide is added to the slip composition of the Al_2O_3 to strengthen the ceramic. According to the manufacturer, the composition is Al_2O_3 (62%), ZnO (20%), La_2O_3 (12%), SiO_2 (4.5%), CaO (0.8%), and other oxides (0.7%).

The use of this class of materials is diminished due to the increased popularity of lithium disilicate and zirconia, particularly for CAD/CAM fabrication.

2. Polycrystalline Ceramics

The main feature of the ceramics classified in the polycrystalline group is a fine-grain crystalline structure providing strength and fracture toughness, but tending to have limited translucency. In addition, the absence of a glass phase makes the polycrystalline ceramics difficult to etch with hydrofluoric acid, requiring long etching times or higher temperature.¹⁷

2.1 Alumina (eg, Procera AllCeram, Nobel Biocare; In-Ceram AL)

This material consists of high-purity Al_2O_3 (to 99.5%). It was first introduced by Nobel Biocare in the mid-1990s as a core material for fabrication with CAD/CAM. It has very high hardness (17 to 20 GPa) and relatively high strength. The elastic modulus

($E = 300 \text{ GPa}$),⁴ highest of all dental ceramics, has led to vulnerability to bulk fractures.^{18,19} This tendency to core fracture and the introduction of materials with improved mechanical properties, such as the transformation toughening capabilities found in stabilized zirconia, has led to a decreased use of alumina.

2.2 Stabilized zirconia (eg, NobelProcera Zirconia, Nobel Biocare; Lava/Lava Plus, 3M ESPE; In-Ceram YZ, Vita; Zirkon, DCS; Katana Zirconia ML, Noritake; Cercon ht, Dentsply; Prettau Zirconia, Zirkonzahn; IPS e.max ZirCAD, Ivoclar Vivadent; Zenostar, Wieland)

Pure zirconia is found in three allotropic forms: monoclinic, which is stable up to 1,170°C, where it transforms to tetragonal, and then cubic when the temperature exceeds 2,370°C.^{20,21} The tetragonal to monoclinic transformation is accompanied by a shear strain and large (4%) volume increase. This volume increase can close cracks, leading to large increases in fracture toughness of the material. Using this transformation toughening in practice requires that the tetragonal or cubic phases must be stabilized at room temperature by alloying pure zirconia with oxides such as yttrium, magnesium, calcium, and cerium. These elements will fully or partially stabilize either of these phases.²² A classification of zirconia ceramics has been proposed according to their microstructure as fully stabilized zirconia (FSZ), partially stabilized zirconia (PSZ), and tetragonal zirconia polycrystals (TZP).²³ In FSZ, zirconia is in its cubic form and contains more than 8 mol% yttrium oxide (Y_2O_3). PSZ is formed by nano-sized tetragonal or monoclinic particles in a cubic matrix, and TZPs are monolithic materials mainly of tetragonal phase stabilized most commonly with yttria or ceria.²³ Dental zirconias are all of the TZP type, most commonly Y-TZP, as this form has the highest strength and fracture toughness after machining and sintering.

Zirconia ceramic was historically employed as a prosthetic framework material to be veneered with ceramics, but it can also be used to manufacture monolithic restorations. It is available as a monochromatic uniform material, which, if needed, can be stained by infiltration. There is an increasing trend to use polychromatic (or blended) CAD/CAM blocks and disks manufactured to imitate the variation in color from dentin to enamel (eg, Katana Zirconia ML, Kuraray). In addition, these materials are being manufactured with increasing translucency (eg, Lava Plus; Cercon ht; NexxZr T; Zenostar Full Contour Zirconia; and Zirlux FC2).

2.3 Zirconia-toughened alumina and alumina-toughened zirconia

Because zirconia generally remains partially stabilized in the tetragonal phase, and alumina presents a moderate toughness, there is a trend in the development of alumina-zirconia (zirconia-toughened alumina [ZTA]) and zirconia-alumina (alumina-toughened zirconia [ATZ]) composites with structure at either the micro or nano scale, as proposed for arthroplasty applications^{24,25} (composites described as a composition of two or more different phases, here alumina and zirconia).²⁶ In 1976, Claussen first described that the addition of unstabilized zirconia to alumina increased the fracture toughness of alumina due to interaction between the crack front and the second phase combined with interactions between the crack front and pre-existing microcracks formed during the tetragonal to monoclinic transformation of zirconia.^{26,27} The percentage of zirconia or alumina in the composite can be tailored and may be altered according to demand or manufacturers' manipulation. For classification purposes, the authors suggest that ZTA should have > 50% by weight of Al, whereas ATZ should present > 50% by weight of Zr. An example of ZTA is the combination of ZrO₂ 67.9 mass%; Al₂O₃ 21.5 mass%; CeO₂ 10.6 mass%; MgO 0.06 mass%; TiO₂ 0.03 mass% (NANOZR, Panasonic Electric Works). The latest technology is associated with methods to apply nanoparticles of zirconia to alumina microparticles before sintering.^{28,29} Advantages of these composite materials when compared to Y-TZP are resistance to low-temperature degradation, higher strength, and fracture toughness,^{30,31} and more than twice Y-TZP's cyclic fatigue strength.³²

A recent material development that, so far, has not been made available to the profession is that of graded alumina and graded zirconia. They are a variation of the polycrystalline restorative materials in which glass is infiltrated into the surface of either alumina or zirconia substrates. This infiltration creates a more damage-tolerant and esthetic system for improved clinical performance.³³ A graded structure consists of a material composition (low stiffness glass to high stiffness core) that gradually changes across an interface (eg, between core and veneer and/or the core intaglio surface). In one set of studies,^{34–36} zirconia was infiltrated with a silicate glass with a matched coefficient of thermal expansion. The percentage of glass changes from 100% to 0% across a 120- μ m interphase. The resulting elastic modulus varied from 125 GPa at the infiltrate surface to 250 GPa at depth.^{34–37} While there was little change in toughness between infiltrated and noninfiltrated specimens, contact loads required to break

bars infiltrated on both the top and bottom surfaces were nearly twice that of noninfiltrated bars of the same dimensions. It is noteworthy that the relative impact of the graded structures was greater for the thin specimens.^{35,37} By reducing the modulus in the near-surface regions, much of the stress in the specimen is transferred into the stiffer material beneath the surface. On the intaglio surface this transfer of stress limits crack initiation and greatly improves the fatigue life of both alumina and zirconia.³⁷

The graded structure eliminates the sharp interface now resulting from traditional core-veneer fabrication, reducing the potential for delamination between the layers.^{35,38} Furthermore, the residual glass at the surfaces encapsulates the zirconia, impeding water absorption and thereby limiting the hydrothermal degradation.³⁵ This approach opens promising new possibilities for creating thinner dental restorations with robust biomechanical properties and esthetics.

Regardless of the different formulations for composites alloying polycrystalline ceramics, future materials to be included in this category will likely follow the premise of the absence of a glass phase.

3. Resin-Matrix Ceramics

This category comprises materials with an organic matrix highly filled with ceramic particles. The presence of an organic matrix would theoretically exclude resin-matrix ceramic materials from the authors' classification proposal if the traditional definition of ceramics were considered: "nonmetallic inorganic materials usually processed by firing at a high temperature to achieve desirable properties."^{38,39} However, resin-matrix ceramics are being included because the 2013 version of the ADA Code on Dental Procedures and Nomenclature¹⁵ defines the term porcelain/ceramic as "pressed, fired, polished, or milled materials containing predominantly inorganic refractory compounds—including porcelains, glasses, ceramics, and glass-ceramics." Therefore, the materials presented in this section do fit into this category because they are composed predominantly (> 50% by weight) of refractory inorganic compounds, irrespective of the presence of a less predominant organic phase (polymer). Manufacturers suggest a wide range of indications for these ceramic-like materials in restorative dentistry. This is quite a change with respect to the former version of the referred code (2012), which defined porcelain/ceramic as "non-metal, non-resin inorganic refractory compounds processed at high temperatures (600°C/1,112°F and above) and pressed, polished, or milled, including porcelains, glasses, and glass-ceramics."

However, despite the controversies associated with the definition, the manufacturers' rationale to develop resin-matrix ceramic materials was to (1) obtain a material that more closely simulates the modulus of elasticity of dentin when compared to traditional ceramics, (2) develop a material easier to mill and adjust than glass-matrix ceramics (eg, synthetic ceramics of the lithium disilicate family) or polycrystalline ceramics, and (3) facilitate repair or modification with composite resin.

Resin-matrix ceramic composition varies substantially, but they are specifically formulated for CAD/CAM. Currently, the resin-matrix ceramic materials can be divided into several subfamilies, according to their inorganic composition, as follows:

3.1 Resin nanoceramic

(eg, Lava Ultimate, 3M ESPE)

It consists of a highly cured resin matrix reinforced with approximately 80% by weight nanoceramic particles. The combination of discrete silica nanoparticles (20 nm diameter), zirconia nanoparticles (4 to 11 nm diameter), and zirconia-silica nanoclusters (bound aggregates of nanoparticles) reduces the interstitial spacing of the filler particles, enabling this high nanoceramic content (information from 3M ESPE).

3.2 Glass ceramic in a resin interpenetrating matrix

(eg, Enamic, Vita)

This is typically composed of a dual network: a feldspathic ceramic network (86% by weight / 75% by volume) and a polymer network (14% by weight / 25% by volume). The specific composition of the ceramic part is 58% to 63% SiO_2 , 20% to 23% Al_2O_3 , 9% to 11% Na_2O , 4% to 6% K_2O , 0.5% to 2% B_2O_3 , less than 1% of Zr_2O and CaO . The polymer network is composed of urethane dimethacrylate (UDMA) and triethylene glycol dimethacrylate (TEGDMA). The manufacturer refers to this as a hybrid ceramic.

3.3 Zirconia-silica ceramic in a resin interpenetrating matrix

Tailored with different organic matrices as well as variation in ceramic weight percentage, eg, silica powder, zirconium silicate, UDMA, TEGDMA, micro-fumed silica, pigments (eg, Shofu Block HC, Shofu), its inorganic content comprises more than 60% by weight. Another example is the composite composed of 85% ultrafine zirconia-silica ceramic particles (spherical 0.6 μm) embedded in a polymer matrix of bisphenol A glycidyl methacrylate (bisGMA), TEGDMA, and a patented ternary initiator system (MZ100 Block, Paradigm MZ-100 Blocks, 3M ESPE).

It is likely that a number of new materials to be introduced for dental esthetic restorations will fit into the resin-matrix ceramics category.

Discussion

In the last decades, the types of all-ceramic and ceramic-like materials available to the dental profession have increased significantly, branching out in a complex array of commercial products whose names provide little clue to their true nature and, thus, to their proper use. Classifications should assist dental technicians and clinicians in understanding the main differences that are important for a rational selection of a product. Classification systems based on material properties⁴ such as intrinsic strength, fracture toughness, and hardness may indicate how and where the different materials should be used (eg, substructure or veneer, crown or fixed dental prostheses replacing missing teeth, anterior or posterior), but, usually, it is the manufacturer that will define the indications of its material(s). On the other hand, classifications according to degree of translucency can be confusing for the clinician. Polycrystalline ceramics, for example, can be used as substructures but also as full-contour restorations because they can now be fabricated with an acceptable esthetic appearance. Finally, it is not possible to organize materials by clinical performance because well-designed, long-term clinical trials addressing this parameter are not available.

Rather, the criteria used to differentiate ceramic materials for this proposed classification system are based on the phase or phases present in their chemical composition. In this way, the entire array of all-ceramic and ceramic-like materials can be placed into one of three families. Traditional all-ceramic materials are categorized within only two groups, based on the presence (glass-matrix ceramics) or absence (polycrystalline ceramics) of a glass-matrix phase. Materials that contain an organic matrix belong to a totally new category: the resin-matrix ceramics. This simplification should be helpful for communication and educational purposes.

Table 1 provides an overview of all-ceramic and ceramic-like materials categorized according to the proposed classification and of their relative fabrication method, utilization (framework to be veneered or monolithic full-contour restoration), etching capability, and clinical indications according to manufacturer instructions.

These materials can be utilized to manufacture restorations by one or more of the following fabrication methods:

Table 1 Classification Summary of All-Ceramic and Ceramic-like Restorative Materials and Overview of Fabrication Methods, Type of Use, Possibility to Be Etched for Adhesive Cementation, and Clinical Indications According to Manufacturers

	Fabrication method	Framework (F) Monolithic (M) Veneer (V)	Etchable	Clinical indications				
				Veneer	Partial coverage restoration	Full-crown Anterior (A) Posterior (P)	FPD	Implant abutment
1. Glass-matrix ceramics								
1.1. Feldspathic ceramics	Refractory die, platinum foil, press	M/V	Yes	✓				
1.2. Synthetic ceramics								
a. Leucite-based	Press or CAD/CAM	F/M	Yes	✓	✓	✓(A)		
b. Lithium disilicate and derivatives	Press or CAD/CAM	F/M	Yes	✓	✓	✓ (A/P)	3-unit up to 2nd premolar	✓
c. Fluorapatite-based*	Press or layering	V	Yes	–	–	–	–	–
1.3. Glass-infiltrated								
a. Alumina	CAD/CAM or Slip-casting	F	Yes			✓ (A/P)	3-unit anterior	
b. Alumina and magnesium	CAD/CAM or Slip-casting	F	Yes			✓ (A)		
c. Alumina and zirconia	CAD/CAM or Slip-casting	F	Yes			✓ (A/P)	3-unit posterior	
2. Polycrystalline ceramics								
2.1. Alumina	CAD/CAM	F	No	✓		✓ (A/P)	✓	
2.2. Stabilized zirconia	CAD/CAM	F/M	No		✓	✓ (A/P)	✓	✓
2.3. Zirconia-toughened alumina and alumina-toughened zirconia	CAD/CAM	F/M	No		✓	✓ (A/P)	✓	✓
3. Resin-matrix ceramics								
3.1. Resin nanoceramics	CAD/CAM	M	No	✓	✓	✓ (A/P)		
3.2. Glass-ceramics in a resin interpenetrating polymer network	CAD/CAM	M	Yes	✓	✓	✓ (A/P)		
3.3. Zirconia-silica in a resin interpenetrating polymer network	CAD/CAM	M	No	✓	✓	✓ (A/P)		

CAD/CAM = computer-aided design/computer-assisted manufacture; FPD = fixed partial denture.

*Fluorapatite-based ceramics are used as veneering materials over metal alloy or zirconia substructures.

- Freehand layering on a refractory die, platinum foil (feldspathic ceramics), or zirconia substructure (fluorapatite-based ceramics)
- Hot pressing of an ingot into a mold (eg, lithium disilicate)
- Slip-casting technique (eg, glass-infiltrated alumina)
- CAD/CAM of a block or disk (eg, stabilized zirconia, lithium disilicate)

Different esthetically related variables influence the selection of the prosthetic material and the way to use it, but the color of the abutment and the degree of translucency of the natural teeth that need to be imitated and reproduced into the restoration are the

main ones. On this basis, the clinician and the technician make the decision of whether to use a particular material as a substructure to then be veneered with another ceramic or as a monolithic full-contour restoration that needs, at most, to be surface stained. In Table 1, the possible ways in which each material can be utilized are specified.

Etchability of the ceramic or ceramic-like materials is also an important piece of information for the clinician because it will indicate, at least in part, the way the restoration can be luted: with a more traditional cement (glass ionomer, resin-modified glass ionomer, or even zinc phosphate cement) or a composite resin cement. Precise indications for adhesive cementation of all-ceramic crowns have been defined by Gehrt et

al⁴⁰ and include, among others, abutment height of less than 4 mm and angle of convergence between the abutment walls greater than 10 degrees. In other situations, the use of conventional glass-ionomer or resin-modified glass-ionomer cements as compared to adhesive bonding are suggested. In the prospective clinical study of up to 9 years by Gehrt et al,⁴⁰ the failure or complication rate of lithium disilicate crowns were not influenced by adhesive as compared to conventional cementation. However, the study was limited to fewer than 80 crowns per treatment. Additional comparative clinical studies on the outcomes of cementation procedures are warranted.

A long-lasting and stable composite resin adhesive bond relies on a properly etched prosthetic substrate on one side and tooth surface on the other. Hydrofluoric acid etching modifies the topography of the surface of glass-matrix ceramic restorations, creating very effective micro-retentions, which allow the restoration to be cemented reliably with composite resin luting materials. In addition, etching can remove surface damage in particle-filled glasses caused by adjustments or sandblasting and allows for the creation of a thin but likely significant graded layer on the intaglio surface. At specific concentrations, exposure times, and temperatures, hydrofluoric acid also etches and modifies the surface topography of dental zirconia (eg, 9.5% at 25°C for 1 hour), although it results in tetragonal to monoclinic phase transformation.¹⁷ The impact of such surface topography changes on bond strength and fracture toughness warrants further investigation. Nevertheless, this proposed ceramic classification provides information regarding materials' capabilities to be etched or not strictly according to manufacturers' current recommendations (see Table 1). Unfortunately, the resin-matrix ceramics group suffers from lack of information regarding the etching aspect because few manufacturers have clarified whether these materials should or should not be etched.

Lastly, it is interesting to know manufacturers' recommendations regarding the clinical indications of the material they produce, recognizing that, in general, they will be on the side of a cautionary and safe approach. This is why, for example, lithium disilicate is not recommended for the fabrication of resin-bonded prostheses at the moment, either with one or two wings, even though there are a number of publications^{41–44} documenting this application. Once again, Table 1 summarizes the clinical indications as stated by the manufacturers. Although the authors have included resin-matrix materials in the classification, they are reluctant to support its widespread use until long-term clinical studies looking at effectiveness have been reported.

Conclusions

The proposed classification system organizes all-ceramic and ceramic-like materials into three groups: (1) glass-matrix ceramics, (2) polycrystalline ceramics, and (3) resin-matrix ceramics. This system allows for recently introduced prosthetic materials to be accurately categorized.

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Literature Abstract

Tooth loss and atherosclerosis: The Nagahama study

Cardiovascular disease (CVD) has been associated with oral disease in several studies that have shown a link, although a significant relationship could not be elicited in several other studies. Inflammation is central to the pathogenesis of both CVD and oral disease, such as periodontal disease, which can cause tooth loss. Therefore, this study attempted to investigate the relationship between tooth loss and arterial stiffness, which is a measure of CVD, using baseline survey data from a Japanese cohort. Cross-sectional data were collated from 8,124 adult residents (30 to 74 years of age) of Nagahama City. The cardio-ankle vascular index (CAVI) was used to assess arterial stiffness, while tooth loss was assessed with examination of the oral cavity by one of two dentists. Congenitally missing, impacted, and third molar teeth were excluded from counts, and subjects who reported tooth loss due to orthodontic treatment, malpositioning, and trauma were excluded. The association between CAVI and tooth loss was assessed using general linear models adjusted for age, sex, body mass index, smoking, elevated glycated hemoglobin levels (HbA1c), and insulin or hypoglycemic use. Results of multiple regression analysis showed a significant correlation between CAVI and tooth loss only for males. This may be explained by estrogen and its beneficial effects on the cardiovascular system. Due to limitations of a cross-sectional study, such a correlation should not be taken to be a causal relationship.

Asai K, Yamori M, Yamazaki T, et al. *J Dent Res* 2015 Mar;94(suppl 3):52S–58S. **References:** 35. **Reprints:** K. Asai, Department of Oral and Maxillofacial Surgery, Graduate School of Medicine, Kyoto University, Kyoto, Japan. Email: yamori@kuph.kyoto-u.ac.jp—Debbie P.M. Hong, Singapore

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