REVIEW ARTICLE

CONTEMPORARY ALL-CERAMIC MATERIALS, PART- 1

Shriharsha Pilathadka, Dagmar Vahalová

Charles University in Prague, Faculty of Medicine and University Hospital in Hradec Králové, Czech Republic: Department of Prosthodontics

Summary: Over the past 35 years, multiple types of all-ceramic materials have been introduced as an ideal alternative for metal-fused to ceramic. This review covers state-of-the-art development of all-ceramic systems in terms of history, material composition, fabrication technologies, and structural and strength properties. These materials are proved to be ideal in terms of mechanical properties and biocompatibility, making metal-free ceramic restorations a realistic clinical alternative for conventional metal-fused-to ceramic.

Key words: *All-ceramic; Glass-ceramic; Particle-filled ceramics; Polycrystalline ceramic; Substructure ceramic; Strength; Fracture toughness*

Introduction

Dental ceramics are the most natural appearing replacement material for missing tooth substance available in a range of shades and translucencies to achieve life like results. Ceramics were the last to move into the high-technology phase of development. During the past decade, the demand for non-metallic highly biocompatible dental restorative material has, however, markedly increased. The esthetic demands made on dental restorations have resulted in an increased use of dental ceramics. Esthetically, these materials are a preferred alternative to traditional materials and ceramics are also regarded as bio-compatible and inert materials. Furthermore, the introduction of bonding procedures and new luting techniques has increased the general acceptance of these all- ceramic systems. In an attempt to meet the requirements of dental materials and to improve their strength and toughness, several new all-ceramic materials and techniques have been developed during the past decade. These recent developments have attempted to overcome the principal disadvantages of inherent brittleness and strength by either the use of increasingly complex technology or by simplification of existing techniques and/or materials.

Recent material, technical and clinical innovations in restorative dentistry have increased the complexity of treatment planning and decision-making. Many of these advances have not replaced, but have rather augmented a wide variety of already existing materials or treatment protocols, as well as clinical technique and skills. Dentists today can choose from a variety of all-ceramic material systems and hence should be familiar with the range of all-ceramic material available for fabrication of ceramic restorations. This review outlines the developments in evolution of all ceramic systems over the last decade and considers the state-of-the-art in several extended materials and material properties.

Historical background

Dental ceramics are composite materials (2, 7). Conventional metal-fused ceramic material composition contains 75 to 85 % (by volume) vitreous phase (matrix) contains and is reinforced by crystalline phase (fillers). Most of the ceramics used for metal-fused ceramic contain 15 to 25 % Lucite as crystalline phase. Leucite is a potassium-alumino-silicate with a large coefficient of thermal expansion ($20x10^{-6}/°C$). All-ceramic systems use different types of crystalline phases. The nature, amount, particle size and coefficient of thermal expansion of crystalline phases influence the mechanical and optical properties of the materials (2). In 1965 Mclean and Hughes (13) reported on strengthening feldspathic glass by adding of aluminium oxide particles (70 % vol), Thereby increasing the strength and fracture toughness. The introduction of "shrink free" (16) (Cerastore, coores Biomedical, Lake wood, Colo) and castable glass-ceramic crown system (12) in the 1980s provided additional flexibility for achieving esthetics with new innovative processing methods. The application of computers to ceramic processing started during the late 1980s and through the 1990s led to introduction of high strength, 100 % polycrystalline "**substructure**" ceramics. This type of ceramic doesn't have glassy components. This allows us to understand that higher strength substructure ceramics are **generally crystalline,** and highly aesthetic dental ceramics are predominantly **glassy** (9).

Classification

The term 'all-ceramic' refers to any restorative material composed exclusively of ceramics, such as feldspathic porcelain, glass ceramic, and alumina core systems and with any combination of these materials (4). In 2004 Kelly (9) also clarified that ceramics as "composite" means a composition of two or more distinct entities. He proposed the most simplified way of organizing the panorama of all ceramic systems as,
a. Predominantly glassy materials,
b. Particle filled glasses,
c. Polycrystalline ceramics.

Tab. 1 and 2 give some commercial examples and composition of different ceramic systems,

Predominantly glassy ceramics

Ceramics can best reproduce the natural optical properties of natural teeth. They contain an amorphous (non-crystalline) matrix of glass (vitreous phase). The glass-forming matrix uses the basic silicon-oxygen (Si-O) network. The silicon atom combines with 4 oxygen atoms, forming a tetrahedral configuration. The larger oxygen atoms serve as a matrix, with the smaller metal atoms tucked into spaces between the oxygen atoms. Thus each silicon atom (Si) is

Tab. 1: Esthetic ceramics: composition, usage, and commercial examples.

Base	Fillers	Usage	Commercial examples
Predominantly glassy ceramics			
Feldspathic glass	Colorants Pacifiers High-melting glass particles	Veneer for ceramic substructures, inlays, inlays, veneers	Alpha, VM7 (Vita) Mark I I (Vita) Allceram (Degudent)
Moderately filled glass ceramics			
Feldspathic glass	Leucite (17–25 mass %) Colorants Opaciffers High-melting glass particles	Veneer for metal substructures, inlays, veneers	VMK-95 (Vita) Omega 900 (Vita) Vita Response (Vita) Ceramco11 (Dentsply) Ceramco 3 (Dentsply) IPS d.SIGN (Ivoclar-Vivadent) Avante (Pentron) Reflex (Wieland dental)
Highly filled ceramics			
Feldspathic glass	Leucite (40–55 mass %) Colorants Pacifiers	Single-unit crowns, inlays, inlays, veneers	Empress (Ivoclar) OPC (Pentron) Finesse All-Ceramic (Dentsply)

Tab. 2: Substructure ceramics: basic composition, usage, and commercial examples.

Glass	Fillers	Usage	Commercial examples
Highly filled glassy ceramics			
Feldspathic glass	Leucite (40–55 mass %)	Inlays, Onlays, Veneers, Single-unit crowns	Empress (Ivoclar) OPC (Pentron) Finesse All-ceramic (Dentsply)
Feldspathic glass	Aluminum oxide (55 mass %)	Single-unit crowns	Vitadur-N (Vita)
Lanthanum	Aluminum oxide (70 % vol %) Zirconium oxide (20 vol %)	Single-unit crowns, Anterior three-unit bridges	In-ceram Zirconia (Vita)
Modified feldspathic glass	Lithium disilicate (70 vol %)	Single-unit crowns, anterior three-unit bridges	Empress2 (Ivoclar) 3G (Pentron)
Polycrystalline ceramics			
Aluminium oxide	More than 0.5 mass %	Single-unit crowns	Procera (Noble Biocare)
Zirconium oxide	Yittrium oxide (3–5 mass %)	Single-unit crowns	Procera (Noble Biocare)
Zirconium oxide	Yttrium oxide (3–5 mass %)	Single-unit crowns, Three-unit bridges, Four-unit bridges	Cercon (Dentsply) Lava (3M-ESPE) Y- (Vita)

surrounded by four oxygen atoms (O). The atomic bonds in this glass structure have both covalent and ionic characteristics which make them stable. Several such linked silicate unit chains form the continuous SiO_4 (tetrahedral) network in glass. A stable structure, with strong atomic bonds and no-free electrons, not only makes glass an excellent insulator for thermal and electrical conduction, but also chemically inactive. The strong covalent and ionic bonds make this ceramic biocompatible, resistance to chemical and heat attack (2).

Particle-filled glasses

Fillers are used in this glass matrix to improve mechanical properties and to control optical effects such as opalescence, colored, and opacity. These fillers are basically crystalline but can be also particles of a higher melting glass. One of the first fillers used in ceramic (for conventional metal fused ceramic) is leucite. It is a potassium aluminum silicate mineral with a large coefficient of thermal expansion ($20 \times 10^{-6}/^{o}C$) when compared to feldspathic glasses ($8 \times 10^{-6}/^{o}C$). Adding the leucite 17 to 25 mass % to feldspathic glass to match thermal expansion of the alloys used in metal ceramic prevents thermal mismatch. Along with this, leucite has the same refractive index as that of feldsapthic glass.

The strength of ceramics was increased considerably by dispersing the suitable fillers through out glass, called "**dispersion strengthening**". The first filler used for this was aluminum chloride 50 mass %. In 1965 MacLean developed aluminum porcelain, using this to improve the strength of ceramic without sacrificing the esthetics. This alumina reinforced core material was used to fabricate the all-ceramic restoration (4). Leucite is also used for dispersion strengthening. The all-ceramics having leucite as fillers are hot pressed into mold to attain the substructure for crowns: example Empress, Empress 2 Ivoclar-Vivadent [Schaan Liechtenstein]; and Finess All-ceramic, Dentsply [York, Pennsylvania].

Polycrystalline ceramics

This type of ceramic has no glassy components. All the atoms are packed into a regular pattern making it dense and stronger. They are difficult to fabricate into different shapes. The availability of the computer made fabrication possible. In 1993 Anderson M. and Oden A (1), with the cooperation of Noble Biocare AB (Sweden), introduced the Procera system. This is a computer-aided designing and computer-aided manufacturing system (**CAD-CAM**). At the design station, a computer-controlled optical scanning device maps the surface of the master die and sends it via modem to the production facility (3). This **3-D** data set is used to create an enlarged die upon which ceramic powder is packed (Procera; Noble Biocare, Goteborg, Sweden) or to manufacture an oversized part for firing by machining blocks of partially fired ceramic powder (Cercone, Dentsply Prostetics; Lava, 3M-ESPE [Seefeld, Germany]; Y-Z, Vita Zahnfabrik [BadSackingen, Germany]). These approaches rely upon well-characterized ceramic powders for which firing shrinkage can be exactly predicted. These new high strength materials are used as substructure materials upon which glass ceramics are veneered, to attain the highest esthetics. Due to its more opaque color, to attain better esthetics it can also be stained (13). The esthetic effect of different all-ceramic veneer and core material has been well documented (14). Polycrystalline ceramics are formed from powders that can be packed only to 70 % of its density. Hence, polycrystalline ceramics shrink about 30 % by volume when it is fired to attain density. To manufacture well-fitting restoration, the amount of shrikage is predicted and compensated by enlarging the die (1).

Transformation-toughened ceramic

This technique relies on a crystal structure change under stress to absorb energy from cracks. It involves the incorporation of a crystalline material that is capable of undergoing a change in crystal structure when placed under stress. The crystalline material usually used was zirconium oxide. At sintering temperature zirkonia is a tetragonal form, and at room temperature it will be in monoclinic form. The monoclinic form occupies about 4.4 vol % more than the tetragonal form. This monoclinic phase is unstable at room temperature. Stabilization can be achieved by adding a small amount of (3–8mass %) of calcium and yttrium. When the stress is localized, any areas on this material is sufficient to transform the grains in the vicinity to a monoclinic stage. The volume increase of 4.4 % squeezes the crack closed. These are the potential substructure material for posterior crowns and FPDs (9).

Strength and Fracture Toughness

Strength and fracture toughness consideraion is important for the assessment of structural value. In 1999 Kelly, suggested the ideal methods to test the failure testing so as to mimic clinical failure (8). New all-ceramic systems have improved flexural strength and fracture toughness. The most documented failure mode of all-ceramic is by cone cracks, radial cracks and quasiplastic damage (11). But radial cracks, which originate from the cemented surface, are the dominant failure mechanism. It was also suggested that strength and selection of core material is important than the veneer porcelain because core material supports more of the flexural load during function.

Strength

It is the more frequently encountered physical property of all-ceramic systems in professional literature. But it is the universal measure of the type and nature of cracks (resistance to crack initiation), fracture toughness (resistance to crack propagation) and influence of water. Strength is not a measure of inherent material property in judging the material. Fracture toughness is better to compare the structural performance of different systems (9, 5).

Tab. 3: Comparison of Flexural strength and Fracture toughness values.

System manufacturer	Core material	Flexural-strength (Mpa)	Fracture toughness (Mpa/m$^{1/2}$)
Empress II (Ivoclar North America, Amherst, NY)	Lithium Disilicate	300–400	2.8–3.5
InCeram Alumina (Vita Zahnfabrick, Bad Sackingen, Germany)	Glass-infiltrated alumina	236–600	3.1–4.61
In-Ceram Zirconia (Vita Zahnfabrik, Bad sackingen, Germany)	Glass-infiltrated alumina with 35 % partialy stabilized zirkonia	421–800	6–8
ProceraAllCeram Bridges (Noble Biocare, Goteborg, Sweden)	Densely sintered high-purity alumina	487–699	4.48–6
Cercon (DENTSPLY Ceramco, Burlington, NJ)	Y-TZP	900–1200	9–10
DCS-Precident DC-Zircon (Dentsply Austenal, York, Pa)	Y-TZP	900–1200	9–10
Lava (3M ESPE, St. Paul, Minn)	Y-TZP	900–1200	9–10

Fracture toughness

Because ceramics fail via crack growth from existing flaws, it is better to measure how it happens. Cemented all-ceramic restorations comprise three material structures, in which ceramic is fully supported by dentin. During occlusal loading, high tensile stress develops below the loaded area in ceramic at its junction with cement. There is interfacial stress due to differences in the modulus of elasticity of dentin, cement and ceramic. Ceramic, being stiffer, yields and fractures. This is designated as $K_{IC\ VALUE}$, where K – Stress intensity, I – Mode opening and C – Critical- value. They are used to compare the material systems.

Conclusion

All ceramic systems are being used as one of the most successful artificial replacement in the oral cavity due to their high esthetic property, biocompatibility, and chemical inertness. There are many fillers used to enhance the strength and toughness of ceramic. After the introduction of high strength, fully polycrystalline ceramic as substructure, it is being used in premolar and as fixed partial dentures. However, the strength and fracture toughness values are promising. This clearly aids us in selecting the right material for a wide range of clinical situations. These systems are simple and less technique-sensitive to handle from a clinical standpoint. Proper utilization of manufacturer guideline is and good knowledge of the material can prove to be a clinical success. The second part of this article will cover the success rate, selection criteria, and clinical aspects of all-ceramic systems.

References

1. Andersone M, Oden A. A new all-ceramic crown: a dense-sintered, high purity alumina coping with porcelain. Acta Odont Scand 1993;51:59–64.
2. Denry IL. Recent advances in ceramic for dentistry. Crit Rev Oral boil Med 1996;7:134–43.
3. Dostálová T, Šimůnek P. Charvát J. Celokeramická rekonstrukce chrupu. Quintessenz – Laboratoř 2005;9:22–26.
4. Frazier K B, Mjor I A. The teaching of all- ceramic restorations in North American dental schools: materials and techniques employed. J Esthet Dent. 1997;9(2):86–93.
5. Guazzato M, Albakry M, Ringer, Swain MV. Strength, fracture toughness and microstructure of a selection of all-ceramic materials. Part 2. Zirconia-based dental ceramics. Dental materials (2004) 20, 449–456.schools: materials and techniques employed. J Esthet Dent 1997;9(2):86–93.
6. Heffernan MJ, Aquilino SA, Diaz-Arnold AM, Haselton DR, Stanford CM, Vargas MA. Relative translucency of six all-ceramic systems. Part 2: Core and veneer materials. J Prosthet Dent 2002;88:10–5.
7. Houndrum SO. A review of the strength properties of dental ceramics. J Prosthet Dent 1992;67:859–65.
8. Kelly JR. Clinically relevant approach to failure testing of all-ceramic restorations. J Prosthet Dent 1999;81:652–61.
9. Kelly JR. Dental Ceramics: current thinking and trends. Dent clin N Am (2004) 513–530.
10. Kelly JR, Nishimura I, Campbell SD. Ceramics in dentistry: Historical roots and current perspectives. J Prosthet Dent 1996;75:18–32.
11. Lawn BR, Pajares A, Yuzang et al. Materials design in the performance of all-ceramic crowns. Biomaterials 25(2004);2885–92.
12. Malament KA. The cast-glass ceramic restoration. J Prosthet Dent 1987;57:674–83.
13. Mclean JW, Hughes TH. The reinforcement of dental porcelain with ceramic oxides. BR Dent J 1965;119;251–67.
14. Raigrodski AJ Contemporary all-ceramic fixed partial dentures: a review Dent Clin N Am 48 (2004) 531–44.
15. Rosenstiel SF, Land MF, Fujimoto J. Contemporary Fixed Prosthodontics 2nded, Mosby: 1995.
16. Sozio RB, Riley EJ. The shrink-free ceramic crown. J Prosthet Dent 1983;49:182–9.

Submitted December 2006.
Accepted April 2007.

Corresponding author:

Shriharsha Pilathadka, M.D., University Hospital Hradec Králové, Department of Prosthodontics,
Sokolská 581, 500 05 Hradec Králové, Czech Republic, e-mail: shreeharsha_70@yahoo.co.in