All Ceramic Materials in Dentistry: Past, Present and Future: A Review

R Kumara Sundaram[1], Bensy Varghese[2]

ABSTRACT

Fixed partial dentures (FPDs) with high-strength all-ceramic systems are necessary for replacing missing teeth. Wide range of materials and methods are available to fabricate a restoration outside the mouth and subsequently integrate with a tooth. The traditional methods of ceramic fabrication have been described to be time-consuming, technique sensitive, and rather unpredictable due to the many variables present which affect the outcome. All-ceramic restorations, has become a segment of dentistry which has experienced tremendous improvements in the recent years. The increasing use of polycrystalline alumina and zirconia as framework materials and the increasing popularity and variety of computer-aided design and computer-aided manufacturing (CAD-CAM) systems seem to be mutually accelerating trends over the last three decades. This article presents a review of the development of all-ceramic restorations, including the evolution and development of materials, technologies and how to improve the strength of all-ceramic restorations, with respect to survival, applications, strength, color, and aesthetics. The literature demonstrates that multiple all-ceramic materials and systems that are currently available for clinical use and concludes there is not a single universal material or, system available to suit for all clinical situations.

Keywords: All Ceramics, CAD/CAM System Zirconia, Aluminum Oxide, Nano-composite

INTRODUCTION

The word Ceramic is derived from the Greek word "keramos" which literally means "burnt stuff" but which has come to mean more specifically as a material produced by burning or firing.[1] Dental ceramics are materials that are part of systems designed with the purpose of producing dental prostheses that in turn are used to replace missing or damaged dental structures. The literature on this topic defines ceramics as inorganic, non-metallic materials made by man by the heating of raw minerals at high temperatures.

EVOLUTION OF DENTAL CERAMICS

In dentistry, ceramic was first introduced as restorative materials in the late 1700s, taking advantage that they can replicate the shape and color of the natural dentition. Later around 1710, Böttger introduced feldspar as the flux in Chinese porcelains. Since the first use of porcelain to make a complete denture by Alexis Duchateau in 1774, numerous dental porcelain compositions have been developed. French Dentist De Chemant patented the first porcelain tooth material in 1789. Pfaff from Germany developed a technique that allowed the porcelain teeth to be used effectively in denture base construction in 1839. Dr. Charles Land patented the first Ceramic crowns in 1903.[2] Ceramic materials are rapidly progressed for a wide range of applications. These porcelain crowns showed good aesthetic properties, but low flexural strength resulting in a higher incidence of clinical failures compared to metal ceramic system which were the first system developed in 1962 that used approximately 17–25 wt% of leucite-containing feldspathic porcelain to avoid poor matches in the coefficient of thermal expansion between the metal framework and veneering ceramic.

In 1965, McLean and Hughes used a glass matrix core comprising of 40 to 50 wt% Al_2O_3 to fabricate the first all-ceramic porcelain jacket crown (alumina-reinforced core ceramic). Castable ceramics (Dicor) were later developed by Grossman in 1972 at corning glass works with low flexural strength (150 MPa), which thus limits its application for a single crown restoration.[3] The traditional methods of ceramic fabrication have been described to be time-consuming, technique sensitive, and rather unpredictable due to the many variables present which affect the outcome.

The introduction of computer-aided design and computer-aided manufacturing (CAD/CAM) technology to restorative dentistry was carried out in the Cerec system (Sirona, Bensheim,Germany) and developed in 1982. might be a good alternative in field research and development of dental ceramics.[4] The advances in CAD/CAM technology are instrumental in the research and for the development of high-strength polycrystalline ceramics such as stabilized zirconium dioxide which could not have been practically processed by traditional laboratory methods. CAD-CAM systems are initially used in the fabrication of ceramic onlays, inlays, veneers, and crowns.

In-Ceram system was introduced for the first all-ceramic core materials for crowns and three-unit anterior fixed

[1]Graded Specialist, Department of Prosthodontics, Military Dental Centre, Ahmednagar, Maharastra, [2]Commanding Officer & Classified Specialist, Department of Prosthodontics, Military Dental Centre, Ahmednagar, JK Road, Ahmednagar-414002 Maharastra, India

Corresponding author: Lt Col R Kumara Sundaram, Military Dental Centre, JK Road, ACC&S, Ahmednagar-414002 Maharastra, India.

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partial dentures (FPDs) in the Europe market in 1989. In 1993, Procera all-ceramic restorations was introduced(Nobel BiocareAB, Gothenburg, Sweden). These restorations were composed of a densely sintered, high purity aluminum oxide (Al2O3) using more than 99.9%, veneered with a compatible low-fusing dental porcelain.[5]

CLASSIFICATION OF ALL-CERAMIC SYSTEMS

In restorative dentistry, substituting metal-based restorations with all-ceramic ones has shown much growth.[6] This article further reviews a variety of all-ceramic systems with different methods of fabrication, strength and translucency that are currently available in the dentistry field.

CONVENTIONAL POWDER-SLURRY CERAMICS

Conventional feldspathic porcelain can be developed using a powder slurry technique. The slurry condensed in a layer on a platinum foil or refractory die and then sintered to produce the restoration. However, feldspathic porcelains are brittle and have low flexural strength approximately 60 to 70 MPa, hence, leucite-reinforced feldspar porcelains were developed using the same powder-slurry Technique. The presence of leucite in the glass matrix will slow down crack propagation and enhance the fracture toughness of the dental porcelain.[7]

CAST GLASS AND POLYCRYSTALLINE CERAMICS

Solid ceramic ingot products are used in the fabrication of cores or full contour restorations via lost wax and centrifugal casting technique.[8] Yttrium tetragonal zirconia polycrystal (Y-TZP) is a recently developed ceramic core in which yttrium oxide is mixed with pure zirconium oxide (ZrO2) at room temperature to produce a multiphase product known as partially stabilised zirconia. This material may be processed by casting technique or milling method. Y-TZP ceramics exhibited higher values of flexural strength of up to 900–1200 MPa and fracture toughness of 9–10 MPa Christel et al.[9]

PRESSABLE CERAMICS

Ceramic ingot are melted at 1180 °C and then pressed into a mould using the lost wax technique. There are various types of pressable ceramics which are available; IPS Empress, IPS ProCAD, IPS Empress 2 and IPS e.max Press (Ivoclar Vivadent, Schaan, Liechtenstein). IPS Empress, a leucite crystal. High crystallinity of leucite results in high opacity with improved strength with slight compromise aesthetics. The IPS Empress system is designed for the fabrication of single crowns,inlays, onlays, and veneers[10]

IPS ProCAD was introduced in 1998 which similar to IPS Empress. It has a fine leucite particle size, therefore it is designed to be used with the CEREC inLab system (Sirona Dental Systems, Bensheim, Germany) and is available in numerous shades to achieve better aesthetic.

IPS Empress 2 comprises lithium disilicate (Li2Si2O5) crystal-reinforced glass ceramic. It contains 60–70 wt% of crystalline fillers. IPS Empress can resist 148 MPa, whereas IPS Empress 2 can resist 340 MP.The fracture toughness of IPS Empress and IPS Empress 2 was 13 MPa·m1/2 and 33 MPa·m1/2 respectively. Hence, the IPS Empress 2 has been recommended for the construction of FPDs in the anterior and premolar regions.

Lastly, IPS e.max Press is developed in 2005 as an improved press-ceramic material compared to IPS Empress 2 its physical properties and translucency are improved through a different firing process. Therefore, IPS Empress 2 has now been replaced by IPS e.max Press.

GLASS-INFILTRATED CERAMICS

In-Ceram (Vita Zahnfabrik, Germany) and Turkom-Cera TM-fused alumina (Turkom-Ceramic). Addition of high alumina content with infiltration in glass ceramics improved the fracture strength of the current all-ceramic fixed prostheses. In-Ceram core particles that are made from alumina, spinell, or zirconia.(VITABLOCS) feldspathic porcelain to improve the aesthetic traits. Glass-infiltrated oxide ceramics are commercially available in four different compositions as described below.

IN-CERAM ALUMINA

Vita In-Ceram alumina was first introduced in 1990. This material consists of 75 wt% polycrystalline alumina and 25% infiltration glass. It has high strength and fracture toughness of 500 MPa and 3.1 MPa·m1/2 respectively, with medium translucency, which makes it suitable for posterior crowns and anterior bridges.[11]

IN-CERAM SPINELL

Vita In-Ceram spinell was developed in 1994. This material consists of 78 wt% magnesium aluminum oxide (MgAl2O4) and 22 wt% infiltration glass. Compared with other In-Ceram materials. It has flexural strength and fracture toughness of 400 MPa and 2.7 MP am1/2, respectively but It exhibits the highest aesthetic requirements. Therefore, In-Ceram spinell is only recommended for inlays and anterior crowns.

IN-CERAM ZIRCONIA

In-Ceram zirconia was introduced in 1999. This material is based on In-Ceram alumina of 67 wt% with the addition of CeO2 stabilized zirconia of 33 wt%. It consists of 56 wt% polycrystalline alumina, 24 wt% polycrystalline zirconia, and 20 wt% infiltration glass. It a flexural strength and fracture toughness of 600 MPa and 4.8 MPa·m1/2 respectively It is currently the strongest material of the In-Ceram. The material is also opaque, so it is recommended for crowns and posterior three-unit bridges.

TURKOM-CERA™

Turkom-Cera™ fused alumina (Turkom-Ceramic, Puchong, Selangor, Malaysia) consists of two components, namely, alumina gel (99.98% Al2O3) and the crystal powder of lanthanum oxide-based glass. It has flexural strength and hardness of 506 MPa and 10 GPa, respectively. This material used as a core material for all-ceramic anterior and posterior crowns.[12]

MACHINABLE (CAD/CAM) CERAMICS

Machinable ceramics are supplied as ceramic ingots in various shades suitable to bothh precision copy-milling concept and CAD/CAM systems. Machining process reduce the considerable time involved in the fabrication of all-ceramic Restorations. Fabrication method can be either centralised, chair-side, or it can involve laboratory processing.[13]

CAD/CAM (CEREC SYSTEM)

Industrial ceramic blocks are milled under optimum and controlled conditions. Since its development in 1980, Cerec system (Sirona Dental Systems, Bensheim, Germany) has undergone several technical modifications.[14]

The first generation system was Cerec 1 (2D image), (1987) using a chairside fabrication of intra-oral restorations such as onlays, inlays, and/or veneers. Subsequently, Cerec 2 (2D image) was introduced in 1994 with the software and hardware designed to fabricate complete crowns and intra-coronal restorations.[15]

In 2003, Cerec 3 system showed remarkable improvement compared with the Cerec 2 system with enhanced intra-oral optical camera was utilised to reproduce fine details and improve software capability for recording 3D images for fast preparation.

In 2005 Cerec inLab MC XL CAD/CAM system (InLab 3D software, Sirona Dental GmbH, Germany) was established to fabricate a variety of restorations including crown copings, long-span bridge frameworks, full-contoured crowns, inlays, onlays, temporaries and veneers with a high-end milling machine. According to the manufacturer, this machine could significantly reduce fabrication times of crown copings, fully fabricated crowns and (up to) 10-unit frameworks.[16]

Currently, a highly translucent zirconia VITA YZ-Cerec (VITA Zahnfabrik, Bad Säckingen, Germany) are utilized to fabricate single crown, multi-unit substructures and fully anatomical dental restorations in the anterior and posterior regions. This system also possesses flexural strength of approximately 1200 MPa, Weibull modulus of 14 and excellent light refraction.[17] VITA YZ-Cerec showed minimal marginal discrepancy with significantly smaller marginal gap values before cementation when compared from the Digitising computer and Procera systems.

COPY-MILLING TECHNIQUE (CELAY SYSTEM)

The milling technique is a central and important aspect of CAD/CAM technology. High milling accuracy reduces the time needed to adapt the work-piece, and provides restorations with better longevity and aesthetic aspect. The Celay system (Mikrona Technologies, Spreitenbach, Switzerland) is a divergence of the direct–indirect restoration concept, but a dental technician is not needed. After completing tooth preparation, a precision imprint chemical or light-cured dental composite is loaded directly in the prepared teeth or indirectly on the master cast. This mould is adjusted for the occlusal relationship and marginal integrity, thereby making the material cured. The mould is then removed from the patient's mouth and mounted on one side of the Celay (the scanning side). This serves as a prototype model, whereas the ceramic blocks are reproduced on the other side using the milling duplicating technique. In the Celay system, the type of ceramic blocks used is similar to those available for the CAD/CAM system. In-Ceram alumina and spinell blocks can also be used to fabricate single and multiple units of In-Ceram cores to produce all-ceramic crowns and bridges. The milling technique for In-Ceram material is dramatically better than that for glass-infiltrated In-Ceram restorations. This result is due to the shorter time needed to produce prosthesis by eliminating slip fabrication, reducing sintering cycle, and decreasing the glass infusion time. The Celay core needs 40 min for glass infiltration compared with the 4 h required by the conventional In-Ceram prosthesis. Hwang and Yang showed that the fracture strength of copy-milled In-Ceram prosthesis is 10% higher than that of conventional glass-infiltrated In-Ceram restorations.

PROCERA ALL-CERAM CAD/CAM SYSTEM

The ceramic core consists of more than 99.9% of pure Al2O3 that is sintered at 1600 °C to produce a dense translucent material. The burning process leads to a large shrinkage of alumina of about 15%–20% 2. The Procera system utilizes the concept of the CAD/CAM system.The computer enlarges die to accommodate the burning shrinkage. The flexural strength and fracture toughness of Procera AllCeram material are 687 MPa and 4.48 MPa·m1/2 respectively. However, it is only indicated for single-unit restorations/veneers because the currently available system is unable to compensate the complex shrinkage of a multi-unit prosthesis.[18]

STRENGTHENING OF DENTAL CERAMICS

There are different typical methods available for reinforcing dental ceramics through the creation of residual compressive stresses within the surface of the restorations that deflect and arrest crack propagation in the ceramic frameworks[19]

A) Chemical or ion exchange strengthening

This is a process that creates a thin surface layer of high compressive stress by exchanging the small glass monovalent ions with the larger ones.The exchange of large potassium ions for surface sodium ions in feldspathic porcelain will increase the viscosity during cooling stresses that are generated in the surface layer due to the congestion of potassium ions in place of the smaller sodium ions. Ion exchange produces a state of compression to a limited depth from the surface varying from 30 to 100 µm and this will lead to a small improvement in biaxial strength of the materials.

B) Thermal treatment strengthening

During sintering, the outer layer solidifies first and then cools rapidly due to poor thermal conductivity of the material. However the inner part of the material shrinks and remains liquid for some time. Consequently, it introduces a compressive stress in the outer layer.One of the advantages of thermal treatment is the stress profiles that extend much deeper in the ceramic materials to a depth of 150 µm, when compared to chemical treatment

C) Dispersion strengthening

Leucite/Alumina fillers (at concentrations of around 40-55 wt%) are also used for dispersion strengthening of all-ceramic restorations by Empress technique into moulds at high temperature.

D) Fine microstructures strengthening

Reinforcing feldspathic dental ceramics by using fine microstructure materials that provide strength and translucency to the dental ceramics. These materials include; alumina-leucite fibers, leucite glass ceramics, fluorapatite glass ceramics, fluormica glass ceramics, and lithium disilicate glass ceramics. In addition, other materials are glass infiltrated oxide ceramics; glass infiltrated spinell (MgAl2O4), glass-infiltrated alumina or the glass infiltrated zirconia polycrystals (3y-Tzp).

E) Nano-composite strengthening

Use of silicon carbide or alumina/zirconia with reduced size to level of nano particles in Nano-composite ceramics materials have been receiving much attention due to their significantly enhanced mechanical properties. These improvements occurred due to the reduction in the interparticle spacing, whereas the average internal stresses remain unaffected. Y2O3-stabilized ZrO2 powder in the Al2O3/ZrO2 nano-composites is a strengthening and toughening agent, where the maximum strength and toughness of the composites were 1000 MPa and 10 MPa·m1/2, respectively. Improvement in the mechanical behavior of the nano-composite ceramic material was not due small size of the particles, but it is a result of stresses generated by mismatch of thermal expansion coefficient between Al2O3 and Mo metal. Ceria Stabilized Zirconia/ Alumina Nano-Composite (Ce-TZP/A): Recently, a tough and strong material, Ce-TZP/A, has been developed.[20]

CONCLUSION

As seen, there is no single material and/or system that possess all the characteristics of ceramic existing in clinical situations. Intense research is under way to promote the strength, esthetics, dimensional accuracy and the ability of these restorations to reliably bond to varying dental substrates Historical review of the development of all-ceramic restorative materials and their applications shows the current limitations and many challenges which still need to be tackled.

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