Review Article

CAD-CAM and All Ceramic Restorations, Current Trends and Emerging Technologies: A Review

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Abstract

All-ceramic restorations have revolutionized the concept of esthetics in the practice of dentistry. The increasing use of polycrystalline alumina and zirconia as framework materials and the increasing popularity and variety of CAD-CAM systems seem to be mutually accelerating trends. In fact, CAD-CAM technology opens-up new vistas for increased esthetics. With ever emerging developments, it becomes more versatile and convenient. However, this comes at the expense of making the application more complicated. The present review gives an overview on the different materials available in ceramics used in dental CAD/CAM technology.

Keywords: All ceramic restorations, CAD-CAM technology, esthetics, polycrystalline alumina and zirconia

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] 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. Dr. Charles Land patented the first Ceramic crowns in 1903.[2] The use of all-ceramic prosthesis in restorative treatments has become popular and many of these restorations can be fabricated by both traditional laboratory methods and computer-aided design and computer-aided manufacturing (CAD/CAM) machination [Table 1].[3,4] 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. CAD/CAM might be a good alternative.[3] 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.[5] These materials have made possible the use of all-ceramic crowns and short span bridges in the posterior load-bearing regions of the jaws.[2,6,7] The present review gives an overview on the different materials available in ceramics used in dental CAD/CAM technology.

Glass Ceramics

Mica-Based Ceramics: The mica minerals are a group of sheet silicate (so-called phyllosilicate) minerals consisting of varying highly complexly configured compounds of Si, K, Na, Ca, F, O, Fe, and Al.[8] Dicor was launched in 1984. It was developed from a formulation of low thermal expansion ceramic used for cookware by Corning Glass Works and marketed by DENTSPLY International.[9] Further development of this material resulted in the introduction of Dicor MGC, a machinable glass ceramic. This was a higher quality product containing 70% by volume tetrasilicicfluormica which was crystallized by the manufacturers and provided as CAD/CAM blanks or ingot. The mechanical properties of MGC were similar to Dicor glass ceramic although it exhibited reduced translucency.[10] Although both Dicor™ and Dicor™ MGC were very well studied, the materials are no longer in the market.

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Access this article online

Quick Response Code:

Website: http://www.ijofr.org

DOI: 10.4103/ijofr.ijofr_16_17

How to cite this article: Gopal SV. CAD-CAM and all ceramic restorations, current trends and emerging technologies: A review. Int J Orofac Res 2017;2:40-4.

Table 1: Brands, composition, and manufacturers of ceramic materials with recommended clinical indications

Core material	System	Manufacturing techniques	Clinical indications
Glass ceramic			
Feldspathic (SiO_2-Al_2O_3-Na_2O-K_2O)	Vitablocs Mark II (VITA Zahnfabrik, Bad Sackingen, Germany)	Milled	Onlays, 3/4 crowns, crowns, veneers
	VITA TriLuxe Bloc (VITA Zahnfabrik)	Milled	Onlays, 3/4 crowns, crowns, veneers
	Vitablocs Esthetic Line (VITA Zahnfabrik)	Milled	Anterior crowns, veneers
Leucite (SiO_2-Al_2O_3-K_2O)	IPS Empress (Ivoclar Vivadent)	Heat pressed	Onlays, 3/4 crowns, crowns
	Optimal Pressable Ceramic (Jeneric Pentron, Wallingford, Conn)	Heat pressed	Onlays, 3/4 crowns, crowns
	IPS ProCAD (Ivoclar Vivadent)	Milled	Onlays, 3/4 crowns, crowns
Lithium-disilicate (SiO_2-Li_2O)	IPS Empress 2 (Ivoclar Vivadent, Schaan, Liechtenstein)	Heat pressed	Crowns, anterior FPDP
	IPS e.max Press (Ivoclar Vivadent)	Heat pressed	Onlays, 3/4 crowns, crowns, FPDP
	IPS™ e.max CAD (Ivoclar Vivadent)	Milled	Inlays, onlays, veneers, anterior and posterior crowns
Alumina			
Aluminum-oxide (Al_2O_3)	In-Ceram Alumina (VITA Zahnfabrik)	Slip-cast, milled	Crowns, FPDP
	In-Ceram Spinell (VITA Zahnfabrik)	Milled	Crowns
	Synthoceram (CICERO Dental Systems, Hoorn, The Netherlands)	Milled	Onlays, 3/4 crowns, crowns
	In-Ceram Zirconia (VITA Zahnfabrik)	Slip-cast, milled	Crowns, posterior FPDP
	Procera (Nobel Biocare AB, Goteborg, Sweden)	Densely sintered	Veneers, crowns, anterior FPDP
Zirconia			
Yttrium tetragonal zirconia polycrystals (ZrO_2 stabilized by Y_2O_3)	Lava (3M ESPE, St. Paul, Minn)	Green milled, sintered	Crowns, FPDP
	Cercon (Dentsply Ceramco, York Pa)	Green milled, sintered	Crowns, FPDP
	DC-Zirkon (DCS Dental AG, Allschwil, Switzerland)	Milled	Crowns, FPDP
	Denzir (Decim AB, Skelleftea, Sweden)	Milled	Onlays, 3/4 crowns, crowns
	Procera (Nobel Biocare AB)	Densely sintered, milled	Crowns, FPDP, implant abutments

FPDP: Fixed partial denture prosthesis

Feldspathic Ceramics

The traditional type of dental porcelain is based on feldspar and comprises of a tectosilicate mineral feldspar ($KAlSi_3O_8$), quartz (SiO_2), and kaolin ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$). The first CAD/CAM-produced inlay was fabricated in 1985 using a ceramic block comprising of fine grain feldspathic ceramic (Vita™ Mark I, Vita Zahnfabrik, Bad Sackingen, Germany).[11] Vita™ Mark II (Vita Zahnfabrik, Bad Sackingen, Germany) introduced specifically for CEREC (Cerec™ 1-Siemens GmbH, Bensheim, Germany) in 1991 exhibited better mechanical properties with a reported flexural strength from about 100 MPa-160 MPa when glazed.[3,12] Vita™ Mark II blocks are made of materials similar to the conventional feldspathic ceramics but produced in a different process known as extrusion molding.[13] Vita™ Mark II is monochromatic but available in multiple shades. The newer Vitablocs™ TriLuxe™, Triluxe™ Forte, and RealLife™ blocks (Vita Zahnfabrik, Bad Sackingen, Germany) contain multishade layers and offer a gradient of color and translucency. These feldspathic ceramic materials have excellent esthetic properties and have been recommended for use in fabricating veneers, inlays/onlays,[14,15] and single anterior restorations.[16] The material, however, is not considered to be strong enough for posterior load-bearing areas.[17]

Leucite-Reinforced Ceramics

Leucite-reinforced feldspathic porcelain contains 45% by volume tetragonal leucite which acts as a reinforcing phase.[18] The thermal contraction mismatch between leucite (22-25 × 10-6.°C-1) and the glassy matrix (8 × 10–6.°C-1) results in the development of tangential compressive stresses in the glass around the leucite crystals which can act as crack deflectors with increased resistance to crack propagation.[18] ProCAD™ (Ivoclar Vivadent, Schaan, Liechtenstein) was introduced in 1998 to be used with the CEREC™ in LAB (Sirona Dental Systems, Bensheim, Germany). It is a leucite-reinforced ceramic similar in structure to the heat-pressed ceramic Empress™ (Ivoclar Vivadent).[19] Empress™ CAD (Ivoclar Vivadent), introduced in 2006, is the successor to Empress™ ProCAD. Its main difference is in the optimizing manufacturing procedure, and it has about 45% leucite with a finer particle size of about 1–5 µm that helps resist machining damages.[20] It was developed for chairside single unit restorations and has a flexural strength of about 160 MPa. Clinically, it is recommended for single tooth restorations and is available in high translucency (Empress™ CAD HT), low translucency (Empress™ CAD LT), and polychromatic (Empress™ CAD Multi) blocks. The milled restorations, can, in the next step, be stained and glazed. Another example in this category is Paradigm™ C (3M ESPE, Seefeld, Germany).

Lithium Disilicate Reinforced Ceramics

A lithium disilicate CAD/CAM ceramic IPS™ e. max CAD (Ivoclar Vivadent) was introduced in 2006 and is a chairside monolithic restorative material. Lithium disilicate (Li2SiO5) ceramics have their flexural strength between 350 MPa-450 MPa. This is higher than that of leucite-reinforced dental ceramics.[21] The blocks are manufactured in a process based on the so-called pressure-casting procedure used in glass industry. They are available in A-D and Bleach shades as well as in 3 translucencies (one of which is of medium opacity) and are supplied in a precrystallized, so-called, blue state.[21,22] The material has been recommended for use in fabricating inlays, onlays, veneers, anterior and posterior crowns, and implant-supported crowns.[23]

Alumina-Based Ceramics: The In-Ceram Alumina system (Vita Zahnfabrik, Bad Sackingen Germany) was developed by Sadoun in 1984 and uses the addition of alumina to feldspathic glass to create high temperature-sintered alumina glass-infiltrated copings.[24] InCeram Alumina has a flexural strength of 236–600 MPa.[25-27] Clinically, InCeram Alumina can be used to fabricate anterior and posterior crowns. The materials can, also, be fabricated by CAD/CAM machination since 1993. CAD/CAM InCeram™ Alumina has been recommended for single anterior and posterior crowns. In-Ceram Spinel, a magnesium aluminate ($MgAl0_4$) spinel, replaces alumina as the major crystalline phase with traces of alumina improving the translucency of the final restoration because of the crystalline structure of the spinel and a relatively lower index of refraction compared with alumina.[28] In-Ceram Spinell, therefore, has superior esthetics over InCeram Alumina; however, it is not as strong as the alumina-based material. The flexural strength is lower at 377 MPa, and the clinical indications are for inlays only.[29] In-Ceram Zirconia (VITA Zahnfabrik) is, also, a modification of the original In-Ceram Alumina system with an addition of 35% partially stabilized zirconia (PSZ) oxide to the slip composition to strengthen the ceramic.[30] It exhibits a flexural strength of 421–800 MPa.[25-27] It has been successfully used for posterior three-unit-fixed bridges.[31,32] With the advent of technology, newer polycrystalline ceramics have been developed such as alumina and zirconia which have no intervening etchable glassy matrix and all the crystals are densely packed into regular arrays and then sintered improving the mechanical properties.[5,20] Procera/AllCeram (Nobel Biocare, Goteborg, Sweden) was first described by Andersson and Odén.[33] The Procera AllCeram crown is composed of densely sintered, high-purity aluminum oxide core combined with compatible AllCeram veneering porcelain.[34] This ceramic material contains 99.9% alumina, and its hardness is one of the highest among the ceramics used in dentistry.[35] Procera AllCeram can be used for anterior and posterior crowns, veneers, onlays, and inlays. A unique feature of the Procera system is the ability of the Procera scanner to scan the surface of the prepared tooth and transmit the data to a milling unit to produce an enlarged die through a CAD/CAM process, thus, compensating for the sintering shrinkage.[35] Some studies confirm that Procera restorations have high strength and excellent longevity.[36] The mean flexural strength for Procera alumina and zirconia is 639 and 1158 MPa, respectively.[37] A similar CAD/CAM ceramic is the Vita™ InCeram AL cubes (Vita Zahnfabrik, Bad Sackingen, Germany) introduced in 2005. However, it should be differentiated from InCeram™ Classic Alumina which has, also, been referred to as InCeram™ or InCeram™ Alumina in that this is glass-free polycrystalline in structure and manufactured by a different process.[38]

Zirconia-Based Ceramics

Zirconia was first discovered by a Chemist Martin Klaproth in 1789.[39] Zirconia does not occur in nature in a pure state. It can be found in conjunction with silicate oxide with the mineral name Zircon ($ZrO_2 \times SiO_2$) or as a free oxide (ZrO_2) with the mineral name Baddeleyite.[40] ZrO_2 is a polymorphic material and occurs in three forms: monoclinic, tetragonal, and cubic. The monoclinic phase is stable at room temperatures up to 1170°C, tetragonal at temperatures of 1170°C–2370°C, and the cubic at over 2370°C.[41] With the addition of stabilizing oxides such as ceria (CeO_2), magnesia (MgO), or yttria (Y_2O_3), a multiphase material known as PSZ is formed at room temperature with cubic crystals as the major phase and monoclinic and tetragonal crystals as the minor phases.[40] However, when zirconium oxide is heated, noticeable changes in volume occur due to transformation of zirconium oxide from monoclinic to tetragonal phase with this transformation leading to 5% decrease in the volume; conversely, a 3%–4% increase in the volume is observed during the cooling process.[42] This mechanism is known as transformation toughening.[40]

Yttria-Partially Stabilized Tetragonal Zirconia Polycrystal (3Y-TZP): Yttria-Partially Stabilized Tetragonal Zirconia Polycrystal (3Y-TZP) consists of an array of PSZ with a 2–4 mol% yttria oxide. In 1977, it was reported that ZrO_2 fine grain (usually ≤0.05 mm) with small concentrations of Y_2O_3 stabilizers could contain up to 98% of the metastable tetragonal phase after sintering. The main feature of this microstructure is to be formed by tetragonal grains of uniform diameter in the order of nanometers, sometimes, combined with a small fraction of the cubic phase. Yttria-Partially Stabilized Tetragonal Zirconia Polycrystal was first applied in the medical field of orthopedics with significant success due to its good mechanical properties and biocompatibility.[40] In dental applications, it is fabricated with microstructures containing small grains (0.2–0.5 mm in diameter) depending on the sintering temperature which avoids the phenomenon of structural deterioration or destabilization in the presence of saliva slowing the growth of subcritical cracks.[39]

Magnesium Partially Stabilized Zirconia

The microstructure of Mg-PSZ consists of an array of cubic zirconia partially stabilized by 8–10 mol% of magnesium oxide. Due to difficulty in obtaining free silica Mg-PSZ precursors (SiO2), magnesium silicates can form a low content of magnesia favoring the transformation from tetragonal to monoclinic phase resulting in lower mechanical properties and stability of the material.[39] The material has not been widely used and an example is the Denzir-M™ (Dentronic, Skellefteå, Sweden) for hard machining.

Ceria Stabilized Zirconia/Alumina Nano-Composite (Ce-TZP/A): Recently, a tough and strong material, Ce-TZP/A, has been developed.[43] This material has an interpenetrated intragranular nanostructure in which either nanometer-sized Ce-TZP or Al_2O_3 particles are located within the submicron-sized Al_2O_3 or Ce-TZP grains, respectively. Several studies have reported that the Ce-TZP/A has shown significantly higher mechanical strength than Y-TZP[25,40,44-46] and has complete resistance to low-temperature aging degradation in water-based conditions such as the oral environment.[47]

Conclusion

Advances in digital dentistry and CAD/CAM technology have catalyzed the development of esthetic all ceramic restorations with superior biomechanical properties. Although none of these materials exhibit ideal clinical properties, 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

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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