Dental Ceramics: Part II – Recent Advances in Dental Ceramics

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Abstract Over the last decade, it has been observed that there is an increasing interest in the ceramic materials in dentistry. Esthetically these materials are preferred alternatives to the traditional materials in order to meet the patients' demands for improved esthetics. Dental ceramics are usually composed of nonmetallic, inorganic structures primarily containing compounds of oxygen with one or more metallic or semi-metallic elements. Ceramics are used for making crowns, bridges, artificial denture teeth, and implants. The use of conservative ceramic inlay preparations, veneering porcelains is increasing, along with all-ceramic complete crown preparations. The earlier ceramics are very fragile and can not with stand the high tensile forces. Several modifications have been made in ceramics in order to address this quandary. This article is a review of dental ceramics; divided into two parts such as part I and II. Part I reviews the composition, structure and properties of dental ceramics from the literature available in PUBMED and other sources from the past 50 years. Part II reviews 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.

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1. Introduction

In dentistry, ceramics represents one of the four major classes of materials used for the reconstruction of decayed, damaged or missing teeth. Other three classes are metals, polymers, and composites. The word Ceramic is derived from the Greek word "keramos", which literally means 'burnt stuff', but which has come to mean more specifically a material produced by burning or firing [1]. A ceramic is an earthly material usually of silicate nature and may be defined as a combination of one or more metals with a non-metallic element usually oxygen. The American Ceramic Society had defined ceramics as inorganic, non-metallic materials, which are typically crystalline in nature, and are compounds formed between metallic and nonmetallic elements such as aluminum & oxygen (alumina - Al_2O_3), calcium & oxygen (calcia - CaO), silicon & nitrogen (nitride- Si_3N_4) [2]. In general, ceramics are used for pottery, porcelain glasses, refractory material, abrasives, heat shields in space shuttle, brake discs of sports cars, and spherical heads of artificial hip joints [1,3]. In dentistry, ceramics are widely used for making artificial denture teeth, crowns, bridges, ceramic posts, abutments, and implants and veneers over metal substructures [1,4]. Ceramics are characterized by their refractory nature, hardness, chemical inertness, biocompatibility [5,6,7] and

susceptibility to brittle fracture [8,9]. Our previous article reviewed the composition, structure and properties of dental ceramics from the literature available in PUBMED and other sources from the past 50 years [10]. This article is Part II of dental ceramics which reviews 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.

Dental ceramics are usually referred to as nonmetallic, inorganic structures primarily containing compounds of oxygen with one or more metallic or semi-metallic elements like aluminum, calcium, lithium, magnesium, phosphorus, potassium, silicon, sodium, zirconium & titanium [1,11]. The term porcelain is referred to a specific compositional range of ceramic materials made by mixing kaolin, quartz and feldspar in proper proportioning and fired at high temperature [1,10,12]. Porcelain is essentially a white, translucent ceramic that is fired to a glazed state [7].

The first All Ceramic crown was introduced by Land in 1903. All ceramic anterior restorations appear very natural. Unfortunately, the ceramics used in these restorations are brittle and subject to fracture from high tensile stress. All metal restorations are strong and tough but from esthetic point of view they are acceptable for posterior restorations. Research aimed at better understanding of materials and innovative processing methods to develop better ceramics. Fortunately, the esthetic qualities of porcelain can be combined with strength and toughness of metal to produce

restorations that have both a natural tooth-like appearance and very good mechanical properties. Therefore, very good aesthetics and adequate mechanical properties can be obtained in a single restoration if a strong bond is attained between the porcelain veneer and a metal sub structure (Figure 1). Brittle fracture can be avoided or at least minimized. This kind of restoration is often termed as metal ceramic restoration or more popularly called as porcelain fused to metal [1]. On the other hand, numerous researchers have also tried with reinforcing the ceramics with different crystalline phases which significantly increased the mechanical properties. The mechanisms of strengthening of these crystalline reinforced ceramic materials were discussed in the literature [1,10] and which is summarized in Figure 2. However, the nature, amount, particle size, distribution and refractive index of crystalline phases influence the mechanical and aesthetic properties of ceramics [13].
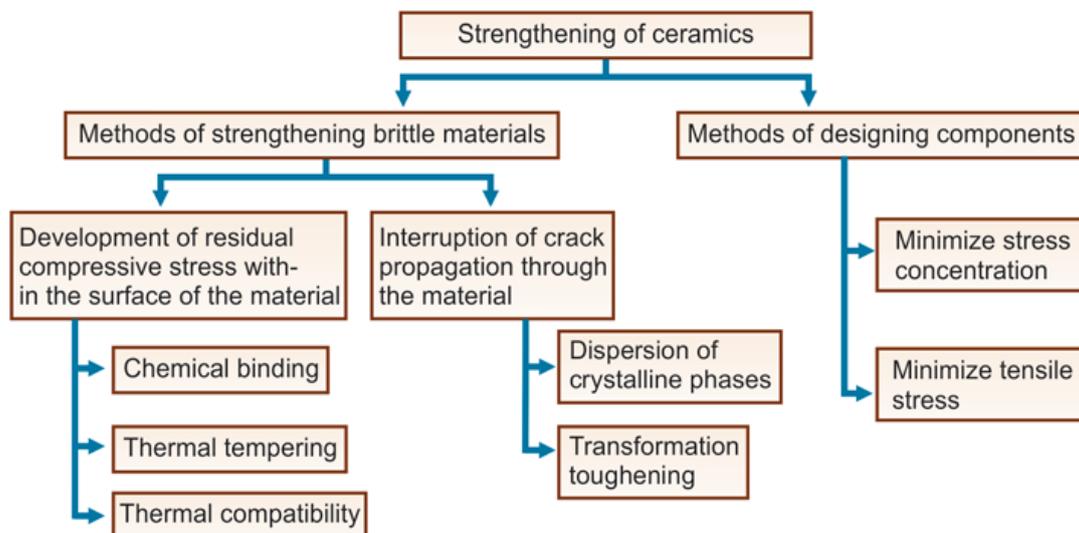

Figure 1. A 6-unit Metal-Ceramic bridge

Figure 2. Methods of strengthening dental ceramics

2. Porcelain Fused to Metal (PFM)

These restorations contain metal substructure where a ceramic veneer is applied over it. Various alloys can be used to fabricate the metal substructure including high gold alloys, low gold alloys, gold – palladium alloys and nickel – chromium alloys [1,11,12]. The composition of the ceramic generally corresponds to that of the glasses except for an increased alkaline content. Greater amount of alkali content such as soda and potash were added in order to meet the thermal expansion to a metal coping and also to reduce fusion temperature. The addition of glass/metal modifier (K_2O) results in the formation of high expansion leucite crystals. Leucite ($K\ Al_2\ Si_2O_6$) is potassium aluminum silicate with a large co-efficient of thermal expansion (COTE) which can increases the thermal expansion of porcelain, so that it could match to that of COTE of dental alloys [1,11,12,14,15]. Color pigments and opacifiers control the color and translucency of the restoration [1].

The success of the PFM restoration depends on the eminence of bond between the porcelain and metal substructure. The major problems associated with metal ceramic restorations are the failure of porcelain veneer, crazing, cracking and separation of the porcelain from the underlying substrate. A strong bond can be achieved by either chemical or mechanical or thermal (compression) bonding mechanisms [16]. The metal substructure is fabricated using conventional casting technique. The cast metal is subjected to several treatments in order to improve the bond strength with porcelain. The porcelain slurry is then applied on the cast metal surface and sintered. Sintering process is usually carried out under vacuum conditions in order to reduce the porosity in the final veneering ceramic [1,11,12,17,18]. However, the amount of porosity mainly depends on the sintering temperature, time, and viscosity of the melt [19]. Cheung et al [19] suggested that the shorter sintering time at higher temperature reduce the porosity. The properly made ceramic crown is stronger and more durable than PJC. The success of metal-ceramic restoration depends on the amount and size of crystalline phase and also on the skill of the technician [4]. However, there is a chance of appearance of metal at the cervical margins, discoloration of porcelain due to the presence of some alloying elements especially silver (imparts green color called as greening effect) and also possible disadvantage of the alloy being used [1]. In addition, the metal copings may be susceptible

to cohesive and adhesive ceramic failure due to insufficient framework and /or metal ceramic debonding [20,21]. Some metal ions may be released in to the gingival tissue and the gingival fluid may cause allergy and staining of gingival tissues [22,23,24,25]. These limitations of PFM restorations led to the development of all-ceramic restorations with the reinforcement of certain crystalline phases with innovative fabrication techniques.

3. Recent Advances in All-ceramic Restorations

Dental ceramics are composite materials [13,26]. The term 'all-ceramic' refers to any restorative material composed exclusively of ceramics, such as feldspathic porcelain, glass ceramic, alumina core systems and with any combination of these materials [27]. According to Kelly [28] the ceramic may be defined as a "composite" that means a composition of two or more distinct entities. All-ceramic systems use different types of crystalline phases which influence the physical, mechanical and aesthetic properties of all-ceramics. The nature, amount, particle size and coefficient of thermal expansion of crystalline phases influence the mechanical and optical properties of the materials [13,29]. In 1965 Mclean and Hughes [30] reported that the strength and fracture toughness of feldspathic glass can be significantly improved by the addtion of aluminium oxide particles (70 % vol). The castable glass-ceramic crown system [31] and "shrink free" [32] (Cerastore, coores Biomedical, Lake wood, Colo) ceramic systems were introduced in the 1980s with superior esthetics using new innovative processing techniques. Later, 100% polycrystalline substructure ceramics were introduced with superior mechanical properties. However, these 100% polycrystalline materials are highly opaque and their esthetic qualities are not up to the standard. So, it can be concluded that the increase in the crystalline phase would increase the mechanical properties substantially, with compromised aesthetic properties [33]. Therefore, it is necessary to optimize both the crystalline and glassy phases in order to attain adequate mechanical and aesthetic properties.

All ceramic restorations are more aesthetic and appear very natural. However, they are brittle and subject to fracture under high tensile stress. Numerous researchers have attempted reinforcing the ceramics with various crystalline materials using innovative fabrication techniques to improve the short comings of all-ceramic restorations. Kelly [28] classified all-cermaic restorations as predominantly glassy materials, particle filled glasses and polycrystalline ceramics. All the three materials consist of feldspathic glass as the main glassy phase with varying amounts of filler particles such as opacifiers, colorants and high-melting glass particles. In addition to these filler particles, filled glasses and polycrystalline ceramics contain leucite crystals with 17-25 mass% and 40-55 mas% respectively [28,33]. Based on their processing techniques all-ceramic restorations are widely classified into sintered porcelains, castable glass ceramics, machinable ceramics, slip-casted ceramics, heat pressed and injection molded ceramics. The detailed classification is mentioned in Table 1.

Table 1. All-ceramic restorative materials based on their processing technology

Name of Processing technique	Type of ceramic	Crystalline Phase	Brand & Manufacturer
Sintered porcelains	Leucite- reinforced Feldspathic porcelain	Sanidine	Optec HSP, Jeneric/Penetron Inc.,
	Alumina based porcelain	Alumina	Hiceram, Vident, Baldwin Park, CA.
	Magnesia based core porcelain	Forsterite	Vident, Baldwin Park, CA.
	Zirconia based porcelain	Mirage II	Myron International, Kansas City, KS
Castable glass ceramics	Mica based porcelains	Tetrasilicic fluoromica	DICOR, Dentsply International
	Hydroxyapatite based porcelains	Oxyapatite	Cerapearl, Kyocera, San Diego, CA.
	Lithia based porcelains	Lithium Disilicate	Vident, Baldwin Park, CA
Slip cast ceramics	Slip-Cast + Glass Infiltrated	Alumina	In-Ceram® Alumina, Vident, Baldwin Park, CA
	Slip-Cast + Glass Infiltrated	Spinel	In-Ceram® Spinell, Vident, Baldwin Park, CA
	Slip-Cast + Glass Infiltrated	12 Ce-TZP-alumina	In-Ceram® Zirconia, Vident Baldwin Park, CA
		3Y-TZP	Cercon®, Dentsply
Hot pressed, injection-molded ceramics	Leucite-based	Leucite	IPS Empress®, Ivoclar
	Lithium based	Lithium disilicate	IPS Empress® Eris, Ivoclar
	Cerestore	Spinel	Alceram, Innotek Dental Corp, Lakewood, CA.
Machinable ceramics	Cerec system	Tetrasilicic fluoromica	DICOR MGC, Dentsply International, Inc., York, PA
		Sanidine	Vitablocs®, Mark II Vident, Baldwin Park, CA.
	Celay system	Sanidine	Vita-Celay, Vident, Baldwin Park, CA
		Alumina	In-Ceram® AL, Vident, Vident, Baldwin Park, CA.
	Procera system	Alumina	Procera All Ceram, Nobel Biocare, USA
	CAD Based	Leucite	IPS Empress® CAD, Ivoclar
		Lithium disilicate	IPS e.max CAD, Ivoclar
	Lava CAD/CAM System	Y-TZP	Lava CAD/CAM, 3M ESPE, St. Paul, Minnesouta

3.1. Sintered Porcelains

Sintering is the consolidation process of ceramic powder particles through heating at high temperatures which results in atomic motion. The sintering of porcelain promotes physical-chemical reactions responsible for the final properties of the ceramic products. The amount of porosity decreases in the last stage of sintering. The amount of porosity is mainly influenced by the sintering temperature, time, and viscosity of the melt [19,34].

3.1.1. Leucite-reinforced Feldspathic Porcelain

Conventional feldspathic porcelains were reinforced with approximately 45 vol% of tetragonal leucite crystals [13,35,36], which are responsible for high compressive strength and modulus of rupture. Optec HSP is the commercially available leucite-reinforced feldspathic porcelain. Vaidyanathan *et al* [37] reported that greater leucite content of porcelain compared with conventional feldspathic porcelain for metal-ceramics leads to a higher modulus of rupture and compressive strength. Numerous studies have reported that the large amount of leucite in the material also contributes to a high thermal contraction coefficient ($25 \times 10^{-6}/°C$) which is much more than the thermal contraction coefficient of the glassy matrix ($8 \times 10^{-6}/°C$) resulting in the development of tangential compressive stresses in the glass around the leucite crystals when cooled. These stresses can act as crack deflectors and contribute to increase the resistance of the weaker glassy phase to crack propagation [1,11,12,38]. Leucite reinforced ceramics are indicated to fabricate veneers due to their good optical properties [39]. The low refractive index of these crystals makes ceramic materials translucent even with high crystalline content [40] leading to improved flexure strength (160 - 300 MPa) [41] which also depends on the shape and volume of the crystals. The glass matrix is infiltrated by micron size crystals of leucite, creating a highly filled glass matrix [42].

3.1.2. Alumina-based Porcelain

Alumina (Al_2O_3) is the strongest and hardest oxide known [43] and can be reinforced into ceramics by a mechanism called "dispersion strengthening" [1,10,11,22,44,45,46,47]. Reinforcement of alumina imparts high mechanical properties as it has high modulus of elasticity (MOE); 350 GPa, and high fracture toughness, 3.5 to 4 MPa [1,13]. COTE is the same for both alumina and glass matrix [1,13].

3.1.3. Magnesia-based Porcelain

The flexural strength and COTE ($14.5 \times 10^{'}6/°C$) of magnesia (MgO) is very high and closely matches with that of the body and incisal porcelains designed for bonding to metal ($13.5 \times 10^{-6}/ °C$). The core material is made by reacting magnesia with a silica glass within the 1100-1150°C temperature range that results in the precipitation of forsterite (Mg_2SiO_4) crystals [48,49] which is responsible for strengthening of ceramics. The strength of these porcelains is further increased by glazing [1,49].

3.1.4. Zirconia-based Porcelain

Zirconia is a polycrystalline material reinforced into conventional feldspathic porcelain in order to strengthen them by a mechanism called "transformation toughening" [1,10,11,13,45,51]. Zirconia has cubic structure at its melting point (2680°C) and on cooling from this temperature results in crystallographic transformations such as tetragonal and monoclinic phase at 2370°C and 1170°C respectively [52,53,54]. This crystal transformation induces internal stresses as it is accompanied by a 3% - 5% volume expansion [53,54]. Stabilizing agents such as calcia, magnesia, yittria and ceria are added to partially stabilize the tetragonal phase at room temperature and to control the volume expansion as well [55]. This partially stabilized zirconia has high initial flexural strength and fracture toughness [55]. Application of tensile forces also induces crystallographic transformation from the tetragonal phase to monoclinic phase with an associated 3% - 5% localized expansion [56], which is responsible for toughening of ceramics. [1,52,55,56,57,58]. Yittria stabilized zirconia (YSZ) increase fracture toughness, strength and thermal shock resistance and decrease translucency and fusion temperature [1,11,13,58,59]. Most dental zirconia ceramics are opaque and copings need to be veneered for high aesthetics [1,3,11].

3.2. Glass Ceramics

A glass ceramic is also called as castable glass ceramic as it is processed by using lost-wax pattern casting procedure. The first commercially available castable ceramic material for dental use is 'Dicor', which was developed by Dentsply international and supplied as silicon glass plate ingots containing MgF_2 [1,11,13,22]. A glass ceramic prosthesis is fabricated in a vitreous or non-crystalline state and then converted to crystalline state by controlled devitrification process using heat treatment called as ceramming. The process of ceramming takes place in two phases such as crystal nucleation and crystal growth, which results in increasing the strength and fracture toughness of glass ceramics by interrupting the crack propagation through them under masticatory forces [1,2,13,22,60,61,62]. The significant aspect of this ceramics is the Chameleon effect in which a part of color is picked up from adjacent tooth [2].

Fabrication of glass ceramic restoration involves investing the wax pattern in phosphate bonded investment material or leucite based gypsum bonded investment material followed by burnout of wax pattern. The molten ceramic material is casted with a motor driven centrifugal machine at 1380°C. After removal of sprue, the glass is invested again and heat-treated at 1075°C for 6 hours to produce crystallization of glass to form a mica-ceramic such as "tetrasilicic fluoromica crystals". This crystal nucleation and crystal growth process is called 'ceramming' [1,2,13,22,60,61,62]. These crystals increase strength, toughness, abrasion resistance, thermal resistance and chemical durability. The final shape is achieved by applying a thin layer of porcelain veneer of the required shape and fire [1]. Hydroxy apatite based porcelains are also belong to glass ceramic category in which oxyapatite can be transformed in to hydroxy apatite on exposed to moisture [13].

3.3. Slip-Cast Ceramics

Slip-casting involves the pouring of an aqueous porcelain slip on a refractory die. The porosity of the

refractory die helps condensation by absorbing the water from the slip by capillary action. Then it is fired at high temperature on the refractory die. During this heat treatment, the refractory die shrinks more than the condensed slip, and helps in easy separation. The resulting ceramic is very porous and must be either infiltrated with molten glass or fully sintered before veneering porcelain can be applied [13,63]. Ceramics processed by slip-casting technique exhibit reduced porosity, and higher toughness than conventional feldspathic porcelains. However, this method may be technique sensitive in dental operatory, and also it is difficult to have accurate fit [63,64,65,66].

These slip-casted ceramics contain two 3-dimensional interpenetrating phases such as core framework and infiltrated glass. The core is usually made up of alumina or zirconia or spinell and the infiltrated glass is usually lanthanum aluminosilicate glass with sodium and calcium. Lanthanum glass has less viscosity and promotes proper infiltration [66]. Based on the type of core material, slip-casted ceramics are classified into Inceram-Alumina, Inceram-Zirconia and Inceram-Spinel. Fabrication of these ceramics involves application of core slurry on the refractory die and heated at 120°C for 2 hours followed by sintering at 1120°C for 10 hours. Then apply lanthanum glass on the framework and fire at 1100°C for 4 hours [67,68,69]. Flexural strength of inceram-zirconia is very high compared to the other slip casted ceramics [4,70,71,72]. However these inceram-zirconia ceramics are highly opaque compared to others [1,73,74,75]. Properties of all the three types of slip casted ceramics are detailed in Table 2.

Table 2. Composition and Properties of glass infiltrated slip-cast ceramics

Property	Inceram-Alumina	Inceram-Spinell	Inceram-Zirconia
Composition	Alumina and Lanthanam Glass	MgO and Alumina	Alumina and Zirconia
Flexural Strength (MPa)	500	350	700
Translucency	Translucent	Highly Translucent	Opaque
Indications	Anterior and posterior crowns, Anterior 3-unit bridges.	Anterior crowns, inlays and onlays.	Posterior Crown and Bridgeds.

3.4. Pressable Ceramics

Fabrication of the pressable ceramics involves the application of external pressure at elevated temperatures to obtain sintering of the ceramic body. So, based on the processing technology these ceramics are also called as "hot-pressed" ceramics or "heat-pressed" ceramics. This fabrication technique prevents the porosity, and extensive grain growth or secondary crystallization in ceramics with associated increase in density and superior mechanical properties [4,13]. Pressable ceramics are catogerized in to two generations including the first generation of heat-pressed dental ceramics contains leucite as reinforcing crystalline phase (IPS Empress 1) and the second generation is lithium disilicate-based (IPS Empress2) [4].

First generation heat-pressed ceramic such as IPS Empress1 is dispersed with 35 to 45 vol % leucite crystalline phase [36]. The strengthening mechanism involves the dispersion strengthening of leucite crystals [76,77], formation of stable tetragonal phase at processing temperature and also involves in the development of tangential compressive stresses around the crystals upon cooling, due to the difference in thermal expansion coefficients between leucite crystals and glassy matrix [78]. However, the strength and fracture toughness may be diminished when the micro cracks joins with each other results in decoupling the crystals from the glass matrix [79]. The amount of porosity is approximately about 9% [77]. Dong et al [80] suggested that that the flexural strength of these ceramics can be significantly improved after additional firings, due to additional leucite crystallization.

Second generation heat-pressed ceramic such as IPS Empress2 contains about 65 vol % lithium disilicate as the main crystalline phase [4,77]. Numerous studies have revealed that it forms two different phases such as lithium metasilicate (Li_2SiO_3) and cristobalite (SiO_2) during the crystallization process, prior to the growth of lithium disilicate ($Li_2Si_2O_5$) crystals [81]. The final microstructure consists of highly interlocked lithium disilicate crystals and layered crystals which contribute to strengthening. The mismatch in COTE between lithium disilicate crystals and glassy matrix is also likely to result in tangential compressive stresses around the crystals, potentially responsible for crack deflection and strength increase [82]. Crack propagation can takes place easily in directions parallel to crystal alignment and has high resistance to crack propagation in the direction perpendicular to crystal alignment [77,83,84]. IPS Empress2 ceramics were characterised with about 1% porosity [77]. Properties of two types of pressable ceramics are detailed in Table 3.

Table 3. Properties of pressable ceramics

Property	IPS Empress1	IPS Empress2
Flexural Strength (MPa)	112 ± 10	400 ± 40
COTE (ppm /^{0}C)	15 ± 0.25	10.6 ± 0.25
Pressing Temperature (^{0}C)	1150 – 1180	890 – 920
Veneering Temperature (^{0}C)	910	800

More recently, IPS e.max Press (lithium disilicate glass-ceramic ingot for the press technique) and IPS e.max ZirPress (fluorapatite glass-ceramic ingot for the press-on technique) ceramic systems were developed by Ivoclaur vivadent. IPS e.max Press is processed in the dental laboratory with the known Empress pressing equipment. This equipment is distinguished for providing a high accuracy of fit. The microstructure of IPS e.max Press is characterized as needle-like lithium disilicate crystals, which are embedded in a glassy matrix. The flexural strength of IPS e.max press is more than IPS Empress, comparatively [85].

The "shrink-free" Cerestore system was introduced with injection-molded technology. The commercial material available with this system is Alceram (Innotek Dental Corp, Lakewood, CO) which contains a magnesium spinel ($MgAl_2O_4$) as the major crystalline phase [86]. This material has the excellent marginal fit of the restorations [87].

3.5. Machinable Ceramics

The evolution of CAD-CAM (Computer aided design and Computer aided machining) technology for the production of machined inlays, onlays, and crowns led to the development of a new generation of machinable ceramics. The advantages of this system include; impressions are not needed, which saves the dentist chair time and also avoids cross-contamination between the patient-dentist operational field and the dental technician [88,89,90,91]. Dr. Duret was extensively worked on the development of CAD-Cam System [92]. He has developed Sopha system, which had led to the development of CAD-CAM system in dentistry [91]. Most popular systems available for machining all-ceramic restorations include CEREC (Siemens, Bensheim, Germany) system, Celay (Mikrona Technologie, Spreitenbach, Switzerland) system and Procera Alceram (Noble Biocare, USA) system.

The CEREC system was developed by Dr. Moermann [93]. CEREC stands for *"Chair side Economic Restoration of Esthetic Ceramics"* and it was the first fully operational CAD-CAM ceramic. There are two commercial materials available in this system. They are Vita Mark II (Vident, Balsdwin Park, CA) and Dicor MGC (Dentsply International, Inc., York, PA). Vita mark II contains sanidine ($KAlSi3O8$) as a major crystalline phase. Sanidine imparts more opacity to the ceramic. Dicor MGC is a machinable glass ceramic similar to Dicor, with the exception in the fabrication technique. This material contains 70 vol% of tetrasilicic fluoromica crystals. This higher vol% of crystalline phase is addresses its superior mechanical properties [94]. The fabrications of ceramic prosthesis involve the scanning of prepared tooth structure and digitize the information in to the computer. Design the restoration in the computer and activate the milling machine to cut the ceramic into the required shape. Adhesive resin cements are most commonly suggested for luting of these all-ceramic crowns to improve the fracture resistance [16, 95,96,97]. However, numerous studies have shown that the overall fracture resistance of Dicor MGC was independent of cement film thickness [98].

The Celay system uses a copy milling technology to manufacture ceramic inlays or onlays from resin analogs. This system is a machinable device based on pantographic tracing of resin inlay or onlay fabricated directly on to the prepared tooth or die. Commercially available Celay system material is Vita-Celay (Vident, Baldwin Park, CA). Sanidine is the major crystalline phase in this material. Recently, In-Ceram pre-sintered slip cast alumina blocks (Vident, Baldwin Park, CA) have been developed and they can be machined with the Celay copy-milling system. This material is mainly used to make crowns and fixed partial dentures [99].

Procera All Ceram System (Nobel Biocare, USA) was introduced by Dr. Andersson [100], it was the first system which provided outsourced fabrication using a network connection. The master die is scanned and the scanned images are sent to processing center/laboratory through an internet. In the processing center/laboratory, an oversized die is milled to compensate the firing shrinkage. The die is milled by a computer controlled milling machines using scanned images. Aluminum oxide powder is compacted on the die and coping is milled by a computer controlled milling machines [100,101].

Other systems developed using milling technique were DCS Precident system with a laser scanner, Cercon System with no CAD component, and CICERO (Computer integrated crown reconstruction) system. More recently, Lava CAD/CAM System (3M ESPE, St. Paul, Minnesouta) was introduced. It is used for fabrication of zirconia framework for all ceramic restorations using yttria stabilized tetragonal zirconia poly crystals which have greater fracture resistance than conventional ceramics. Lava system uses a laser optical system to digitize information. The Lava CAD software automatically finds the margin and suggests a pontic and CAM produces an enlarged framework to compensate shrinkage [101].

The machinable ceramic prostheses can be delivered to patient with in a single appointment. However, the drawbacks of this system include; requires expensive equipment and also the dentist/technician should have the adequate knowledge to use and operate the system [91]. Most dental zirconia ceramics are opaque and copings need to be veneered for high aesthetics [1,3,11]. The color difference between zirconia core and adjacent natural tooth should be reduced through layering technique for the veneering porcelain [102,103]. Appropriate shade selection also plays an important role in the defining of final aesthetic properties [104]. Bona et al evaluated the color differences between various CAD-CAM ceramic restorations and suggested that adjustments should be made carefully to the final shade of CAD-CAM ceramic restorations to reach a clinically acceptable shade match [105].

Various surface treatments have been suggested in the literature to improve the bond strength between ceramic and the natural tooth. Various surface treatments include abrasion/sand blasting [106], a diamond stone bur [106, 107], sand paper disks [108], LASERS [16], etching [109], atmospheric plasma, UV, and treatment with ceramic primer [110].

4. Conclusion

The evolution in fabrication technology of dental ceramics has been outstanding over the past few decades; tremendous progress has been made in terms of mechanical performance, with a ten-fold increase in flexural strength and fracture toughness. These new generations of all-ceramic materials present interesting options, both in terms of material selection and fabrication techniques. Success of the ceramic restoration depends on clinician's ability to select the appropriate material to match intraoral conditions and esthetic demands.

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