All-ceramic systems in Esthetic Dentistry: A review

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Abstract

Currently, patient esthetic demands increase dramatically and drive the rapid development of all-ceramic materials. The purpose of this article is to summarize the mechanical and clinical aspects of all-ceramic systems in esthetic dentistry and give the trend idea of the future development. To make a clear understanding, this review article classifies all-ceramic systems into three major categories based upon their major composition, which are feldspathic and glass-ceramic, alumina-based, and zirconia-based system. Even though all-ceramic restorations have been reported to be a successful treatment option for patients, some critical limitations have to be considered such as veneer fracture, broken of the connecter, and loss of retention. The selection of these materials requires basic knowledge regarding material properties and case selection. All-ceramic restoration can be an alternative treatment option for patients especially in esthetically demanding cases.

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Introduction

Ceramics can be defined as solid compounds composed in large part of inorganic nonmetallic materials and are made by mixing the solid components together with the application of heat to form crystalline solid structures.[1, 2] The properties of ceramics are basically determined by crystal contents and chemical compositions. Generally, ceramics have high resistance to compressive stress, good chemical resistance, and high temperature stability.[3] Because of their advantages, they have been used in wide range of industries including biomedical engineering and biomaterial science.[4] In dentistry, ceramics have been used as restorative material for many years. Land, in 1886, introduced the first all-porcelain crown to restore extensively damaged teeth.[5] Due to low fracture resistance and high failure rate of ceramic jacket crowns, the idea of fabricating a metal substructure to support brittle feldspathic porcelain was originated.[6]

A porcelain-fused to metal crown consists of a metal substructure covered with esthetic veneering porcelain to mask the grayish color of metal and improve the esthetics. Although porcelain-fused to metal crowns have been successfully used in patients, the mismatch of thermal expansion coefficient between feldspathic porcelain and a metal substructure can cause chipping of the veneering part. Later, McLean introduced leucite-containing feldspathic porcelain to overcome chipping problem. The leucite crystals help in crack deflection, as a consequence, the energy required for crack propagation in ceramic body increases. Controlled amount of high-expansion leucite were added to raise thermal expansion coefficient of the porcelain to a slightly lower value than the thermal expansion coefficient of metal. The advantage of having slightly different thermal expansion coefficient between metal and porcelain is the improved bond strength between metal and porcelain caused by compressive pressure in porcelain. As a result, less chipping occurred compared to the conventional feldspar.[7] However, fracture of brittle veneering porcelain cannot be totally eliminated. In most cases, fracture of veneering porcelain requires replacement.[8-10]

Currently, patient esthetic demands increase dramatically. Porcelain-fused to metal crowns have esthetic limitation because the lack of translucency affects in esthetic outcome especially on the anterior teeth and implants.[11] As a result, the development of metal-free restorative materials is growing rapidly. The purpose of this article is to summarize the mechanical and clinical aspects of all-ceramic systems in restorative dentistry and give the trend of the future development. There are numbers of all-ceramic systems available in dentistry and they are different in structures, compositions, fabrication process and properties. To make a clear understanding, this review article classifies all-ceramic systems into three major categories based upon their major composition, which are feldspathic and glass-ceramic, alumina-based, and zirconia-based system. Common all-ceramic systems available in the market and their clinical applications recommended by manufacturers are listed in Table 1.

Feldspathic and Glass-ceramic system

Glass-ceramic system contains mainly glassy matrix of silicon dioxide with some amounts of alumina and ceramic crystal as fillers. Mechanical and physical properties of glass-containing all-ceramics are determined by size and amount of the crystal component.[12] Feldspathic porcelain, which contains mainly glassy phase and less than 50 % of leucite crystal as fillers, was originally used for fabricating porcelain jacket crown by

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Table 1 Lists of common all-ceramic systems and their clinical applications

Name	Material	Manufacturer	Fabrication procedure	Clinical recommendation
Vitablocs System: Mark II, Triluxe, Reallife	Feldspathic ceramic	Vita Zahnfabrik, Germany	CAD/CAM	Inlays, onlays, veneers, anterior and posterior crowns
CEREC blocs	Feldspathic ceramic	Sirona, Germany	CAD/CAM	Inlays, onlays, veneers, anterior and posterior crowns
IPS Empress Esthetic	Leucite-reinforced glass-ceramic	Ivoclar Vivadent, Liechtenstein	Pressable	Inlays, onlays, veneers, anterior crowns
IPS Empress CAD	Leucite-reinfored glass-ceramic	Ivoclar Vivadent, Liechtenstein	CAD/CAM	Inlays, onlays, veneers, anterior and posterior crowns
IPS e.max Press	Lithium disilicate glass-ceramic	Ivoclar Vivadent, Liechtenstein	Pressable	Inlays, onlays, veneers, anterior and posterior crowns
IPS e.max CAD	Lithium disilicate glass-ceramic	Ivoclar Vivadent, Liechtenstein	CAD/CAM	Inlays, onlays, veneers, anterior and posterior crowns, anterior FPDs
In-Ceram Alumina	Glass-infiltrated alumina	Vita Zahnfabrik, Germany	Slip-casting, CAD/CAM	Onlays, anterior and posterior crowns, anterior FPDs
In-Ceram Spinell	Glass-infiltrated alumina (addition of MgO)	Vita Zahnfabrik, Germany	Slip-casting, CAD/CAM	Inlays, Onlays, anterior and posterior crowns
In-Ceram Zirconia	Glass-infitrated alumina (addition of ZrO)	Vita Zahnfabrik, Germany	Slip-casting, CAD/CAM	Onlays, posterior crowns, and posterior FPDs,
Procera AllCeram	Polycrystalline alumina	Nobel Biocare , Göteborg, Sweden	CAD/CAM	Anterior and posterior crowns
In-Ceram YZ	Polycrystalline zirconia (Y-TZP)	Vita Zahnfabrik, Germany	CAD/CAM	Posterior crowns, anterior and posterior FPDs.
Lava Zirconia	Polycrystalline zirconia (Y-TZP)	3M ESPE, USA	CAD/CAM	Anterior crowns (translucent zirconia), posterior crowns, anterior and posterior FPDs.
Cercon	Polycrystalline zirconia (Y-TZP)	Degudent, Germany	CAD/CAM	Posterior crowns, anterior and posterior FPDs.
Incoris TZI	Polycrystalline translucent zirconia (Y-TZP)	Sirona, Germany	CAD/CAM	Anterior crowns, posterior crowns, anterior and posterior FPDs.

conventional powder-liquid technique. High failure rate was reported in porcelain jacket crowns because of brittleness of porcelain itself.[12, 13] Twenty years ago, there was a study reporting the clinical use of machinable feldspathic porcelain.[14] Machinable feldspathic porcelain has been developed with superior mechanical properties compared to the conventional porcelain. Vitabloc Mark II (VITA Zahnfabrik, Germany), machinable feldspathic porcelain, is used to make a crown using a computer-assisted design/computer-assisted manufacture (CAD/CAM). It is fine-grain feldspathic porcelain with the grain size of approximately 4 to 10 μm and primarily composed of SiO_2 and Al_2O_3. The finer grain size improves the particle packing when forming a green compact. A homogeneous green compact is fired at 1170°C, as a result, a dense strong block with consistent and nearly pore-free microstructure is made, which is a typical characteristic of manufactured machinable ceramic blocks.[12, 15] The improved homogeneity of the microstructure contributes to the enhanced fracture strength of Vitabloc Mark II. The strength of this material is approximately 130 MPa when polished.[16] Clinical applications of Vitabloc MarkII are fabricating monolithic all-ceramic restorations including single crowns, inlays, and onlays. A study by Sjögren et al. showed the results after 5-year follow up of ceramic inlays fabricatd from Vitabloc Mark II. They reported the failure rate was as low as 3.4% of all ceramic inlays.[14] Gladys et al. reported the 100% clinical success of ceramic inlays after three years of service.[17] Bindl and Mörmann compared the survival rate of crowns made from Vitablocs Mark II and with Vita In-Ceram Spinell (VITA Zahnfabrik, Germany), a glass-infiltrated all-ceramic system. The survival probability was reported to be 91.7% for In-Ceram Spinell crowns and 94.4% of Vitablocs Mark II crowns after 44.7 ± 10.3 months.[18] Even though Vitabloc Mark II crowns showed good clinical success, the bulk fracture of an entire restoration still occurs. Magne et al. explained that the crack easily initiated in brittle nature material such as all-ceramics compared to higher ductile material such as machinable composite resins. The high tensile stresses in the central groove of a milled crown could not be withstood by the brittle ceramics.[19]

Leucite-reinforced glass ceramics containing more than 50%wt of leucite crytals are available in two forms; pressable and machinable block. Pressable ceramic systems are fabricated by using a lost wax technique. They are available from manufacturers as prefabricated ingots made of crystalline particles distributed throughout a glassy matrix.[20] Microstructure of pressable ceramics shows less porosity in the material compared to conventional firing porcelain.[20, 21] IPS Empress (Ivoclar Vivadent, Liechtenstein) was a commercial product of leucite-based pressable system. A wax pattern was invested using a particular investment material and burnt off to creat a mould for melted ceramic to flow in. Empress ingot was heated and pressed into a mould. The pressed restoration was divested and finished.[22] In a previous study, flexural strength of Empress was higher than other pressable ceramics because a more homogeneous leucites distribution might help to improve the strength of this material.[23] Recently, IPS Empress Esthetic, a new generation of leucite-reinforced pressable ceramic, has been launched to replace Empress system.[24] IPS Empress CAD is a machinable form of leucite-reinforced glass ceramics. Both IPS Empress Esthetic and IPS Empress CAD are translucent enough for fabricating anterior monolithic restorations. Some studies reported increased failure rates of these materials when they are used in the posterior region.[25-27]

IPS e.max Press, introduced in 2005, is a

lithium-disilicate glass ceramic fabricated through a combination of the lost-wax and heat-pressed techniques. It is originally developed from the former IPS Empress 2 and consists of lithium disilicate crystal as IPS Empress 2 does. However, physical and optical properties of IPS e.max CAD are improved through a different firing process from IPS Empress 2.[28] Flexural strength of IPS e.max Press is approximately 350 MPa which has been suggested to resist destructive parafunctional movement.[22] Therefore, it has been suggested for fabricating inlays, onlays or single crowns in the anterior and posterior region.[12, 27] A study by Sjögren et al. on the clinical performance of heat-pressed ceramic crowns (IPS Empress) after 3 years of service showed the clinical success rate was at 92% form 110 crowns. There were no significant differences in the fracture rates found between anterior and posterior crowns.[29] However, Fradeani et al. reported the significantly higher survival rate of anterior IPS empress crowns compared to the posterior crowns.[30] IPS e.max CAD is a machinable lithium disilicate glass-ceramic containing lithium disilicate crystal in the SiO_2-Li_2O-K_2O-ZnO-P_2O_5-Al_2O_3-ZrO_2 system. Unlike pressable lithium disilicate, the machinable lithium disilicate blocks are exposed to a two-stage crystallization. After first firing stage, lithium metasilicate crystals (60 %wt) and lithium disilicate crystals (40 %wt) are formed. At this stage, the blocks are presenting in blue color with the flexural strength of approximately 130 to 150 MPa, which can facilitate machining process.[27] The final crystallization of lithium disilicate occurs at 850°C. The flexural strength of fully crystalized lithium disilicate could exhibit up to 417 MPa.[31] Because of its moderately high strength, posterior monolithic crown can be fabricated from IPS e.max CAD successfully.[32] IPS e.max CAD exhibits slightly more opacity than IPS Empress Esthetic because of its higher crystalline phase.[33] A previous clinical study reported that CAD/CAM-fabricated lithium disilicate crowns performed well after two years of clinical service.[34]

Alumina-based system

Alumina-based all-ceramic system consists of two layers of ceramics. High strength alumina is fabricated as a coping and veneered with highly esthetic porcelain. Alumina-based all-ceramics are used to fabricate not only single restorations but also 3-unit fixed partial denture prostheses (FPDs) in the anterior teeth.[27] In-Ceram Alumina, introduced in 1989, was the first alumina-based system available for single-unit restoration and 3-unit anterior FPDs.[35] The fabrication of alumina core can be performed by slip-casting technique or milling from partially-sintered alumina block. The shaped alumina core was then fired to get a sintered porous alumina. The porous alumina is infiltrated with lanthanum glass to form a 3-dimensional interconnected microstructure classified as an interpenetrating phase ceramic. The benefits of having interpenetrating phase microstructure are reduced porosity, increased strength, and limited potential sites of crack propagation of the ceramic materials.[36, 37] In-Ceram Spinell is also an alumina-based ceramic with the addition of magnesium oxide to form the spinel crystal ($MgAl_2O_4$). Flexural strength of In-Ceram Spinell is lower than In-Ceram Alumina resulting from different crystal structure. However, spinell crystals create high translucency thus it is an esthetically acceptable material for crowns in the anterior region.[15, 38] In-Ceram Zirconia is not purely zirconia oxide but it is an alumina-based ceramic with the addition of 35%wt of zirconia oxide particles to the slip composition. The purpose of incorperaing zirconia oxide particles to the alumina is to strengthen the material.

Flexural strength of In-Ceram Zirconia is the highest value compared to In-Ceram Alumina and In-Ceram Spinell. Due to the high opacity of those three alumina-based ceramics, the alumina coping must be veneered with the compatible feldspathic porcelain such as VM7 (VITA Zahnfabrik, Germany) to improve esthetics.[12, 39] Procera Alumina (Nobel Biocare, Sweden) is a machinable all-ceramic system consisting of polycrystalline alumina coping and veneering porcelain. The fabrication procedure for Procera crown starts with scanning the die of the prepared tooth using the Procera Scanner. After scanning, the technician defines the finish line with extreme precision. The final design enhancements of the coping are completed. This digital information is sent to the Procera production facility where the fabrication of Procera coping is taking place. At the work station, a die model is precision milled by a computer-controlled milling machine. High-purity aluminium oxide powder is thin pressed using very high pressure to produce the dense inside surface of the coping. The outside of the coping is then milled to the desired design of the coping before the final sintering process. The semi-translucent core is then completed and the veneering porcelain is added to complete the restoration. The fully sintered alumina core shrinks approximately 15-20% during sintering process.[40] The compensation for this shrinkage in the Procera system is different from other system by designing and milling an enlarged die before designing alumina core. Strength value of Procera alumina is approximately 600 MPa, which is sufficient for fabricating anterior and posterior single restorations.[12, 41] Fradeani et al. reported a 96.7% survival rate of Procera crowns after 5-years follow up.[42] The use of alumina-based ceramic has been declining popularity since zirconia-based all-ceramic system was introduced.

Zirconia-based system

Zirconia has been widely used in dentistry because of their superior mechanical properties compared to other available all-ceramic systems. Zirconia is a polycrystalline solid material that occurs in 3 phases of crystal structures; monoclinic, tetragonal and cubic phase depending on the temperature. At room temperature, pure zirconia presents in monoclinic phase having about 4.5% larger volume of crystal size compared to tetragonal and cubic. Monoclinic zirconia is transforming to the smaller crystal structure, tetragonal phase, when it is heated up above 1170°C. At temperature above 2370°C up to the melting point, crystal structure changes to the smallest size, cubic phase.[43-45] In the cooling phase, smaller zirconia crystal, tetragonal phase, transforms to larger zirconia crystal, monoclinic phase. This transformation can induce the internal stress, which is sufficient to cause the catastrophic failure.[43] To prevent fracture, the addition of phase stabilizer to zirconia is essential. Yttrium-oxide partially stabilized zirconia (Y-TZP) appears in tetragonal phase at room temperature because of the addition of yttrium oxide as a phase stabilizer.[46] Y-TZP has chemical and dimensional stability, high flexural strength and fracture toughness. It is suggested for fabrication of all-ceramic FPDs, especially, in the posterior teeth.[43, 47] Manufacturing of Y-TZP coping is usually performed with a sophisticate CAD/CAM system.[47] Partially sintered Y-TZP is milled to form an oversize coping and then fully sintered to achieve the final dimensions. Shrinkage from sinering process is approximately 25% for Y-TZP. Milling the partially sintered zirconia helps in reducing milling time and machining damage.[47] Zirconia copings have highest opacity among other all-ceramic system because of its polycrystalline nature. Therefore, the compatible esthetic ceramic is recommended to be veneered on the zirconia.[48]

However, recently developed high translucent zirconia has been introduced. This material can be milled to form a full-contoured crown without veneering ceramic. Shade and characterization of the restoration can be modified with external staining. An in vitro study showed that full-contoured zirconia caused less wear of the opposing materials than veneered zirconia crowns.[49]

Zirconia restorations have been reported high clinical success rate. Örtorp et al. studied the fracture resistance of core-veneered zirconia crowns after 3 years of service and the result showed none of zirconia core fractured. However, four cases of veneering porcelain chipping were observed.[50] Other studies showed the survival rates of zirconia single crowns ranged from 91.7% to 100 % after being used for 2-5 years.[18, 51, 52] Fracture of the veneering porcelain is the most commonly reported complication in Y-TZP-based restorations.[53] Veneer fracture rates were reported at 2% to 9% for single crowns after 2 - 3 years and 3% to 36% for FPDs after 1 – 5 years.[27] The mismatch of thermal expansion coefficient between zirconia coping and veneering porcelain has been discussed as a contributing factor for fracture of veneering porcelain.[27, 54] Residual stress in core-veneered crowns can be associated with the developing thermal gradients inside the structure during cooling. The low thermal conductivity of zirconia in core-veneered all-ceramic system results in the large temperature differences and therefore, high residual stress. In addition, thick layers of veneering ceramics on zirconia cores are highly susceptible to residual tensile stress resulting in cracking or chipping.[54] Frequently, delamination, chipping and cracking of veneering porcelain were defined as minor complications in which the replacing of a restoration was not required. Depending on the size and location, cracks leading to veneer fractures can severely compromise the esthetics and function of restorations, eventually; the restorations have to be replaced. Nowadays, zirconia-based crowns are the most frequent used materials among the other core-veneered all-ceramics.

Novel developing all-ceramic materials

Since brittle ceramics undergo fracture during function, there are many attempts to toughening the brittle ceramics. Fabrication of interpenetrating phase ceramic composites (IPCs) having three-dimentional interconnected microstructure can enhance fracture resistance of the ceramics.[55, 56, 57] The invention of polymer-ceramic IPCs has become interesting in dentistry. A novel interpenetrating network material in which porous feldspathic porcelain infused by a resin-based polymer has been developed.[58] Toughening mechanism in the polymer-infiltrated ceramics occurs because the ceramic phase will provide the elastic stiffness prior to failure and the polymeric phase will provide a crack bridging effect after ceramic cracking.[58, 59] An in vitro study reported that the polymer-infiltrated ceramic had higher fracture toughness than the pre-sintered ceramics preforms. However, the hardness values were lower than those in conventional porcelain.[60] A study by Yada et al. investigated the biaxial flexural strength and fracture toughness of resin-infused alumina versus glass-infused alumina (In-Ceram Alumina). The results showed that resin-infused alumina lower fracture toughness and flexural strength on the biaxial test than glass-infused alumina. Authors discussed that the effect of aging the resin-infused alumina could cause water absorption and a breakdown of silane coupling agent.[59] Recently, a dental hybrid ceramic, Vita Enamic (VITA Zahnfabrik, Germany), was released to the market. It is an interpenetrating phase ceramic composing of porous ceramic core infiltrated with resin. This material

combines positive characteristics of a ceramic and a composite resulting in a great strength, high reliability, precise and accurate restoration. The manufacturer recommends that Vita Enamic can be used for fabricating single crowns, inlays, onlas, and veneeres.[61] Additional in vitro and in vivo studies are required for this material.

Discussion

The demand for aesthetics in restorative dentistry has risen dramatically in the last few decades. Nowadays, some patients desire that their restorations should resemble natural tooth structure. Many attempts by manufacturers try to produce all-ceramic materials that could be restored extensively damaged tooth with the acceptable mechanical and physical properties. This review article aimed to summarize the currently available all-ceramic products used in dentistry and the future development of the esthetic restorative materials which have superior mechanical and physical properties. Feldspathic porcelain was reported to be used successfully for fabricating monolithic all-ceramic veneers, inlays, and crowns in the anterior teeth. However, the chipping and bulk fracture of the restorations were the major complication found in this material. [12, 16] Glass-ceramics such as leucite-reinforced and lithium disilicate glass-ceramics were reported to have superior mechanical properties compared to feldspathic porcelain. [28-30] CAD/CAM fabricated monolithic feldsparthic porcelain and glass-ceramics showed higher mechanical properties compared to the conventional fabricated ceramics. It is because the improved homogeneity of the microstructure in CAD/CAM ceramic block contributes to the enhanced fracture strength of the materials. [12, 15]

Alumina-based and zirconia-based ceramics has been used to fabricate a coping for the core-veneered all-ceramic system. The mechanical properties of those two materials were reported to be remarkably higher than other ceramic systems in dental application. [41, 42, 45] Zirconia-based ceramics has been interested by many researchers to develop this material for fabricating high strength esthetic crowns. Nowadays, studies on zirconia-based ceramic are focusing on the development of esthetic monolithic zirconia restorations. [62, 63] Further investigations on the translucency, wear properties and fatigue resistance of monolithic zirconia should be performed. In addition, a novel IPCs ceramics have been developed for fabricating dental restorations. This material showed high fracture toughness that can resist to the brittle fracture of ceramic restorations. [55, 56, 57] However, further investigations regarding the use of this material are required.

There are many available all-ceramic systems that cause a lot of confusion in restorative dentistry. This article classifies all-ceramic depending on the major composition that can simplify the understanding in material properties and clinical applications. Even though all-ceramic restorations have been reported to be successful treatment options for restoring severely damage teeth, some critical limitations have to be considered such as veneer fracture, broken of the connecter, and loss of retention. The selection criteria are different depending on individual judgment of dentists and case selection. All-ceramic restoration can be an alternative treatment option for patients especially in esthetically demanding cases.

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