Review Article

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Current Status of All-Ceramic Systems in Esthetic Dentistry

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Abstract

Currently, patient increased esthetic demands have dramatically led to the rapid development of all-ceramic materials. The purpose of this article is to understand classification, mechanical and clinical aspects of all-ceramic systems in esthetic dentistry. To make a clear understanding, this review article classifies all-ceramic systems into four 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.

Keywords: All-Ceramic Materials; Esthetic Dentistry; Clinical Performance; Feldspathic; Glass-ceramic, Alumina-based; Zirconia-based system.

Introduction

Restorative dentistry has modified in several aspects due to the number of choices for indirect restorations that has evolved over the past few decades, especially pertaining to ceramics [1,2,3]. All-ceramic crowns with high crystalline content are increasingly very popular amongst patients and clinicians due to superior esthetics, high fracture resistance, biocompatibility and improved physical properties in comparison with metal frameworks of porcelain fused to ceramic (PFM) crowns[4,5,6].

Ceramics can be defined as solid compounds composed primarily of inorganic nonmetallic materials and are made by mixing the solid components together with the application of heat to form crystalline solid structures. Generally, ceramics are strong, inert, and stable at high temperature, and posses' good optical properties for esthetics.[7]

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Today the applications of ceramics in dentistry have expanded considerably due to the unmatched mechanical properties of partially stabilized zirconia. Even though it was estimated in 2005 that more than 50% of all indirect dental restorations fabricated in the lab were metal-ceramics [8], the current trend is toward the development of all-ceramic systems.

Composition of Dental Ceramics

The two structural components of ceramics are glass (responsible for esthetics) and the refractory phase (responsible for high mechanical strength). The refractory phase is made of particles of metallic oxides like silica and alumina. Silica is quartz and alumina is corundum. When heated, these refractory particles fuse together at their points of contact by sintering.

Refractory materials in a ceramic body; provide crystalline structure; thereby provide and retain the shape of the body throughout all stages of ceramic production; whereas glass has no coherent internal structure of its own and seals the spaces between refractory and helps keep the refractory from falling apart [9].

Recently, dental ceramic substructures are made of sintered refractory materials; alumina or zirconia with little or no glass between the refractory particles. Such ceramic substructures are fused at very high temperatures and are very hard.

Classification Based on Composition

Glass Based Ceramics (Mainly Silica)

Feldspathic ceramics (SiO_2-Al_2O_3-Na_2O-K_2O) which contains mainly glassy phase and 15 - 25 % of leucite (SiO_2-Al_2O_3-K_2O) crystal as fillers is used as veneering ceramics for porcelain-fused to metal (PFM) restorations [10]. Feldspar is resistant to crystallization (devitrification) during firing. The amount of leucite is adjusted such that the coefficient of thermal contraction of the ceramic is slightly lower than that of the metal, to place the ceramic under slight compression, which leads to improved bond strength between metal and ceramic and reduced the incidence of chipping.

Leucite is obtained by incongruent melting of feldspar at temperatures between 1150°C and 1530°C. Incongruent melting is a process in which one material does not uniformly melt and forms a different material.

The mechanical properties of feldspathic porcelains are the lowest amongst the ceramic materials used in dentistry due to the large amount of glassy phase [11]. Also, the esthetic outcome of PFM crowns especially on the anterior teeth are less than satisfactory due to the lack of translucency [12] and grayish discoloration at the cervical third of the restoration due to thinness of ceramic in this area and reflection of light meeting the opaque substrate of PFM restoration and thin gingival tissues [13].

Thus, for two reasons; demand for improved esthetics and the concern regarding the biocompatibility of the metal, led to the introduction of all-ceramic restorations.

Since the size and amount of the refractory component determines the mechanical and physical properties of all-ceramics [10], machinable feldspathic ceramic was developed with superior mechanical properties compared to the conventional feldspathic ceramic [14]. Vita Mark II (VITA Zahnfabrik, Germany), a machinable feldspathic porcelain was introduced in 1991 for the CEREC 1 system, with improved strength and finer grain size (4 -10ìm) primarily composed of SiO_2 and Al_2O_3. The finer grain size improved the particle packing and its firing at 1170°C, resulted in, a homogenous dense strong block with nearly pore-free microstructure [15] which led to the enhanced fracture strength of Vitabloc Mark II. Clinical applications of Vitabloc Mark II are for fabricating monolithic all-ceramic restorations including single crowns, inlays, and onlays.

Glass Based Systems (Mainly Silica with Fillers)

Filler particles (refractory phase) are added to the glass matrix to; improve mechanical properties; regulate thermal expansion / contraction behavior and control optical properties such as opalescence, color and translucency. Most commonly used fillers are; crystalline or particles of high-melting glasses, which are stable at the firing temperatures of the ceramic [16].

The filler particles can be a part of glass matrix by two methods; by adding mechanically during manufacturing as powder (Dispersion strengthening technique) or be precipitated from within the glass by special nucleation and growth heating treatments (Ceraming). These filler particles may be dissolved during etching to create micromechanical retentive features enabling bonding.

Leucite-reinforced glass ceramics

Leucite was the first filler to be used for strengthening feldspathic ceramic. There are many benefits of leucite as filler; it is added to create a veneering ceramic that could be successfully fired onto metal substructures for PFM. Leucite has its refractory index very similar to feldspathic glasses, which provides better translucency [17]. Leucite etches at a much faster rate than the base glass, and it is this ‘‘selective etching’’ that creates a myriad of tiny features for resin cements to enter, creating a good micromechanical bond. High leucite content of ceramic is also associated with the crack propagation strength. Greater leucite content means a lesser crack propagation [18]. Leucite-reinforced glass ceramics containing 40-55% mass of leucite crystals. They are available in two forms; pressable and machinable block.

Pressable commercial ceramics is pressed into molds at high temperature, e.g. IPS Empress (Ivoclar Vivadent, Liechtenstein) and Finesse All-Ceramic, (Dentsply Prosthetics, York, Pennsylvania). Microstructure of pressable ceramics shows less porosity in the material compared to conventional firing porcelain [19]. IPS Empress CAD is a machinable form of leucite-reinforced glass ceramics. Both IPS Empress and IPS Empress CAD are translucent enough for fabricating anterior monolithic restorations.

Lithium disilicate reinforced glass ceramics

This ceramic material contains 70% lithium-disilicate ($Li_2Si_2O_5$) crystals, which results in an increased flexural strength of approximately 360 MPa (IPS e.max Press, Ivoclar Vivadent, Amherst, N.Y., hot-pressed version) to 400 MPa (IPS e.max CAD, Ivoclar Vivadent, Amherst, N.Y., milled version) [20]. They are available in two forms; pressable (IPS e.max Press) and machinable block (IPS e.max CAD).

Their increased strength is due to the unique microstructure of lithium disilicate, which consists of many small interlocking plates like crystals that are randomly oriented. The lithium-disilicate crystals cause cracks to deflect or blunt, which arrests the propagation of cracks [21].

IPS e.max Press, introduced in 2005, is fabricated through a combination of the lost-wax and heat-pressed techniques. It is a second generation heat pressed ceramics, leucite reinforced being the first. The mechanical properties of this glass ceramic are far superior to that of the leucite glass ceramic. Flexural strength of IPS e.max Press is approximately 350 MPa. Therefore, it has been suggested for fabricating inlays, onlays or single crowns in the anterior and posterior region [22]. The machinable lithium disilicate blocks, IPS e.max CAD, are exposed to two-stage crystallization. After first firing stage, lithium metasilicate crystals (60 %wt) and lithium disilicate crystals (40 %wt) are formed and the blocks are blue in color with the flexural strength of approximately 130 to 150 MPa, which can facilitate machining process [22].

The final crystallization of lithium disilicate occurs at 850°C after which it exhibits the flexural strength up to 417 MPa [23], because of its moderately high strength, posterior monolithic crown can be fabricated successfully [24].

Glass-ceramics (special subset of particle-filled glasses)

The filler particles are made to grow inside the glass prosthesis or pellet. Under special heat treatment, precipitation and growth of crystallites takes place within the glass. This process is called "ceraming". These fillers (crystals) are derived from the glass itself; therefore, the composition of the remaining glass is altered as well due to "ceraming". Such glass particle-filled composites are called glass-ceramics. Dicor (Dentsply), containing crystalline mica particle (55 vol%) as filler was the first commercial glass ceramic available for fixed prostheses [25].

Crystalline - Based Systems with Glass Fillers (Mainly Alumina)

Alumina-based all-ceramic system consists of two layers of ceramics. Coping (core) is fabricated of high strength alumina by slip casting technique, which is veneered with highly esthetic ceramic. Alumina-based all-ceramics are used to fabricate single unit as well as 3-unit fixed partial denture prostheses (FPDs) in the anterior teeth [10].

In slip cast technique, a porous infrastructure is produced by crystalline phase e.g. alumina oxide, sintered and later infiltrated with a lanthanum-based glass [26]. This kind of three-dimensional interconnected microstructure is composed of two interpenetrating continuous phases; the glassy phase and the crystalline phase [27]. This way the aluminum oxide (refractory, crystalline phase) content is raised to 70 vol %. The benefits of having interpenetrating phase microstructure are reduced porosity, increased strength, and limited potential sites of crack propagation of the ceramic materials [28]. For slip casting technique, three crystalline phases are available, namely alumina (Al_2O_3), spinell ($MgAl_2O_4$) and zirconia-alumina (12 Ce-TZP-Al_2O_3).

In-Ceram Alumina was introduced in 1989, for single-unit restoration and 3-unit anterior FPDs [29]. The fabrication of alumina core can be performed by slip-casting technique or milling from partially-sintered alumina block. The porous alumina is infiltrated with lanthanum glass to form a 3-dimensional interconnected microstructure. Alumina-based slip-cast ceramics contains; 68 vol % alumina, 27 vol % glasses and 5 vol % porosity [30].

In-Ceram Spinell is 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 but the spinell crystals create high translucency thus it is an esthetically acceptable material for crowns in the anterior region [15].

In-Ceram Zirconia is also an alumina-based ceramic. Zirconia oxide particles are incorporated to the alumina to further strengthen the material. Flexural strength of In-Ceram Zirconia is highest compared to In-Ceram Alumina and In-Ceram Spinell. It comprises 34% vol alumina and 33% vol of 12% mol ceria-stabilized zirconia (12Ce-TZP). The glass phase represents approximately 23 vol % of the final product, with about 8 % vol residual porosity [31]. Due to the high opacity of these three alumina-based ceramics, the alumina coping must be veneered with the compatible feldspathic porcelain such as VM7 (VITA Zahnfabrik, Germany) to improve esthetics [10].

Polycrystalline Solids (Alumina and Zirconia)

Polycrystalline, monophase ceramics (alumina and zirconia), are formed by directly sintering crystals together without any intervening matrix to form dense, air-free, glass-free, structure. All the crystals are densely packed and sintered [10] due to which dense crystal lattice network forms with high mechanical properties and reduced crack propagation. Hence, polycrystalline ceramics generally are much tougher and stronger than glass-based ceramics with irregular network of atoms.

For the same reason polycrystalline ceramics are more difficult to process to fabricate prosthesis and became feasible only after the availability of computer-aided manufacturing. Polycrystalline ceramic is relatively opaque by nature and is indicated for the fabrication of crown and bridge copings upon which a veneering ceramic is layered for the required aesthetic result [32].

Alumina based polycrystalline ceramics

The first fully dense, machinable all-ceramic system consisting of polycrystalline alumina coping and veneering porcelain (Procera AllCeram, Nobel Biocare, Sweden) was introduced in 1993 [10]. The core material contains more than 99.9% alumina with a flexural strength of about 600 MPa, which is sufficient for fabricating anterior and posterior single restorations.

For fabricating Procera crown, the die of the prepared tooth is scanned with precision for the finish. This digital information is used to generate a duplicate die, which is enlarged by a factor of 0.2 to compensate for the sintering shrinkage of aluminium oxide powder which is thin pressed using very high pressure to produce the dense inside surface of the coping. The outside of the coping is then contoured by milling to the programmed thickness and dimension, sintered and is then veneered with compatible aesthetic porcelain. The fully sintered alumina core shrinks approximately 15- 20% during sintering process [33].

Stabilized zirconia based polycrystalline ceramics

Zirconia is also known as ceramic steel because of their superior mechanical properties compared to other available all-ceramic systems. Zirconia in its unalloyed state is a polymorphic and has three crystallographic forms depending on the temperature. At room temperature, pure zirconia presents in monoclinic (M) phase having about 4.5% larger volume of crystal size compared to tetragonal (T) and cubic (C) [34]. Monoclinic zirconia is transformed to the smaller crystal structures when heated, tetragonal phase (at 1170^{0}C to 2370^{0}C), and cubic phase (at 2370^{0}C up to the melting point) [35]. On cooling, smaller tetragonal phase, transforms to larger monoclinic phase. This transformation induces the internal stress which may cause catastrophic failure [36]. In order to prevent this kind of fracture, cerium oxide (CeO_2), magnesium oxide (MgO) or yttrium oxide (Y_2O_3), are added to zirconia as phase stabilizers. Yttrium-oxide partially stabilized zirconia (Y-TZP) appears in tetragonal phase at room temperature because of the addition of yttrium oxide. 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. Manufacturing of Y-TZP coping is performed with CAD / CAM system. Partially sintered Y-TZP is milled to form an oversize coping and then fully sintered to achieve the final dimensions [36].

Any progressive crack in zirconia generates tensile stresses that induce a change of configuration from a tetragonal to monoclinic, and a localized volume increase of 3% to 5%. This induces compression stress at the tip of the crack. These compressive forces counter the external tensile forces and stop the further advancement of the crack [37]. This mechanism is called transformation toughening and it effectively hinders (i.e., arrests) the crack propagation. This accounts for the material's low susceptibility to stress fatigue and high flexural strength of 900 MPa to 1200 MPa which is almost double of alumina based ceramics [38].

An oversized coping from a partially sintered block of zirconia-oxide material (ZirCAD, Ivoclar Vivadent; Lava Zirconia, 3M ESPE) are machined, which is then fired to full sintering temperature to cause predictable shrinkage to fit the die. Y-TZP shrinks approximately 25% during sintering process. Milling is usually done of partially sintered zirconia which helps in reducing milling time and damage to the machine [36]. Zirconia copings have highest opacity among other all-ceramic system because of its polycrystalline nature. Zirconia dioxide can be used as a monolithic restoration or a substructure with veneering porcelain.

Classification Based on Processing Technique

Ceramics can also be classified by the method in which they are processed. Processing technique has a very large impact on strength and, thus, clinical performance. This includes powder / liquid building, slip casting, heat pressing, and additive and subtractive computer-aided design / computer-aided manufacturing (CAD / CAM).

Powder/Liquid

The ceramic powder is mixed with liquid (deionized water) to form slurry, which is then veneered and condensed on the metal or ceramic framework (coping). The slurry is condensed by vibration to remove excess liquid, which comes to the surface and is blotted away by an absorbent tissue. After condensation of the ceramic buildup it is vacuum fired at a selected temperature. Vacuum firing further removes the moisture and condenses the ceramic through a process called “sintering.” During the sintering process, fusion occurs at the particles’ points of contact, which results in shrinkage by viscous flow when the glass particles reach their firing temperature [39]. Usually, all restorations are over contoured by 25% to allow for shrinkage during the firing cycle. As a general rule, powder / liquid system (used with conventional feldspathic ceramic) have much lower strength than pre-manufactured blocks because of a much larger amount of bubbles and flaws in the finished restoration.

Slip Casting

In the slip-casting fabrication method, a porous core is sintered which is then infiltrated with a lanthanum-based glass, producing two interpenetrating continuous networks: a glassy phase and a crystalline infrastructure. The crystalline infrastructure could be alumina (Al_2O_3), spinell ($MgAl_2O_4$), or zirconia-alumina (12 Ce-TZP-Al_2O_3) [40]. Restorations produced by slip casting tend to have fewer defects of processing and have greater strength than conventional feldspathic ceramic.

Pressable Ceramic

This method is similar to lost wax technique; the desired shape of the restoration is created in the wax and burnt out [41]. Heat-press involves the use of a special ceramic furnace with a pneumatic ram, which presses the ceramic material into the mold at high temperatures under vacuum.

Initially, only ceramics containing high amounts of leucite glass were used for this process. Vitabloc Mark II for the CEREC and pressable and machinable versions of IPS Empress are the primary materials available in this classification. These materials are ideally suited for inlay and onlay restorations, anterior crowns and veneers. Lithium disilicate became the second generation of materials to be used by this method [42]. E.max Press has higher strength and fracture toughness (roughly double that of IPS Empress), thus, it has the potential to be used for any type of single restoration anywhere in the mouth [43].

CAD/CAM (Mostly All-Crystalline Alumina- or Zirconia-Based Systems)

With CAD / CAM technology, it became possible to scan, design, and mill either a full-contoured restoration or a single- or multiple-unit framework by a computer.

In the mid 1990s, Nobel Biocare produced the first CAD / CAM substructure using a core consisting of 99.9% alumina on which a feldspathic ceramic was layered [42]. Currently, two different CAD / CAM methods are in use. The first is rapid prototyping (additive method) in which an electro-deposition of powdered material is applied layer by layer to a conductive die through an electrical current [44]. The other more commonly used method (subtractive method), in which a substructure or full-contour restoration is milled from a solid block of ceramic material. For the subtractive CAD / CAM processing silica-based ceramics, infiltration ceramics and lithium-disilicate ceramics materials blocks and polycrystalline ceramics are available [45]. For example, lithium disilicate is milled as lithium metasilicate and fired at 820°C which converts it into disilicate crystals and increases the grain size from 0.5 ìm to 5 ìm. This crystallization process changes the physical composition and strength [46].

CAD / CAM restorations have become more popular over the conventional ceramic processing techniques, as this technique eliminates the need for the traditional impression-making, laboratory-shipping and laboratory steps including model-pouring, articulation, die sectioning, casting and subsequent ceramic layering, thus saving enormous amount of time and manpower. However, the superiority of this system over the conventional ones with effect to marginal discrepancy is not clearly established in the literature.

CAD / CAM technology has become popular as an in-office procedure too; as it saves time of the clinician as well as the number of visits of the patient.

Advantages of All-Ceramic Systems

All ceramic systems provide better esthetic advantage than PFM restorations, when the light-blocking metal is replaced by an opaque ceramic because a wide range of translucency-opacity (value) can be achieved with commercially available ceramic systems. All ceramics restorations are more kind to soft tissues, as the quantity of plaque, adhering to ceramic surface is far less in comparison to any alloy. Even the intra-oral plaque of a qualitatively healthier composition forms on ceramic surfaces [47]. Lastly, the emergence profiles are over contoured with PFM because a thicker layer of porcelain is required to mask the opaque-metal surface. However, this is not the case with all ceramic system. For the same reason, it often is acceptable to leave the margin of all-ceramic prostheses supragingival or at the gingival margin, with the added benefit of more predictable and less traumatic impression making.

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.

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

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

This review article aimed to summarize the currently available all-ceramic products used in dentistry (Table 1). 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 [10]. Glass-ceramics such as leucite reinforced and lithium disilicate glass-ceramics were reported to have superior mechanical properties compared to feldspathic porcelain [48].

CAD/CAM fabricated monolithic feldspathic 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 [10,15].

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 [49].

Zirconia-based ceramics has attracted 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 [50,51]. Further investigations on the translucency, wear properties and fatigue resistance of monolithic zirconia should be performed.

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.

Conclusion

Successful application of these materials will depend upon the clinician's ability to select the appropriate material, manufacturing technique, and cementation procedures, to match intraoral conditions and esthetic requirements.

The selection criteria are different depending on individual judgment of dentists and case selection. If clinical judgment is judiciously used All-ceramic restoration can be the treatment option for patients especially in esthetically demanding cases.

References

1. Conrad HJ, Seong W, Pesun IP. Current ceramic materials and systems with clinical recommendations: a systematic re-view. J Prosthet Dent. 2007; 98(5): 389-404.
2. Frankenberger R, Kramer N, Petschelt A. Technique sen-sitivity of dentin bonding: effect of application mistakes on bond strength and marginal adaptation. Oper Dent 2008; 25(4): 324-30.
3. Kumbuloglu O, Lassila LVJ, User A, Toksavul S, Vallittu PK. Shear bond strength of composite resin cements to lith-ium disilicate ceramics. J Oral Rehabil. 2005; 32(2): 128-33.
4. Kokubo Y, Ohkubo C, Tsumita M, Miyashita A, Vult Von Steyern P, Fukushima, S. Clinical marginal and internal gaps of Procera All Ceram crowns. Journal of Oral Rehabilitation. 2005; 32: 526-30.
5. Bindl A, M¨ormann WH: Marginal and internal fit of all-ceramic CAD/CAM crown copings on chamfer preparations. J Oral Rehabiltation. 2005; 32: 441-47.
6. Strub, JR, Rekow D, Witkowski S. Computer-aided design and fabrication of dental restorations. Current systems and future possibilities. The Journal of the American Dental Association. 2006; 137: 1289-96.
7. Roesler J, Harders H, Baeker M. Mechanical Behaviour of Engineering Materials: metals, ceramics, polymers, and composites. New York: Springer; 2010.
8. Holand W, Schweiger M, Rheinberger VM, Kappert H. Bioceramics and their application for dental restoration. Adv. Appl. Ceram. 2009; 108: 373-80.
9. Martin S Spillar, https://dentallearning.org/course/Ceramics/Dental_Ceramics.pdf.
10. Giordano RA, McLaren EA. Ceramics overview: classification by microstructure and processing methods. Compend Contin Educ Dent. 2010; 31: 682-4.

11. Seghi RR, Daher T, Caputo A. Relative flexural strength of dental restorative ceramics. Dent.Mater. 1990; 6: 181-84.

12. Gallucci Go, Grütter L, Nedir R, Bischof M, Belser UC. Esthetic outcomes with porcelain-fusedto-ceramic and all-ceramic single-implant crowns: a randomized clinical trial. Clin Oral Implants Res. 2011; 22: 62-9.

13. Raptis NV, Michalakis KX, Hirayama H.: Optical behavior of current ceramic systems. Int J Periodontics Restorative Dent. 2006; 26: 31-41.

14. Sjögren G, Molin M, Bessing C. A clinical examination of ceramic (CEREC) inlays, Acta Odontol Scan. 1992; 50: 171-8.

15. Giordano RA. Materials for chairside CAD/CAM-produced restorations. J Am Dent Assoc. 2006; 137: 14s-21s.

16. Denry IL. Recent advances in ceramics for dentistry. Crit Rev Oral Biol Med. 1996;7(2): 134-143.

17. Martinez Rus F, Pradies Ramiro G, Suarez Garcia MaJ, Rivera Gomez B. Dental ceramics: classification and selection criteria. RCOE. 2007; 12(4):253-263.

18. Cesar PF, Gonzaga CC, Miranda Júnior WG, Okada CY. Correlation between fracture toughness and leucite content in dental porcelains. J Dent. 2005; 33(9): 721-729.

19. Cattell MJ, Chadwick TC, Knowles JC, Clarke RL, Lynch E. Flexural strength optimization of a leucite reinforced glass ceramic. Dent Mater. 2001; 17: 21- 33.

20. Della Bona A, Mecholsky JJ Jr, Anusavice KJ. Fracture behavior of Lithia disilicate and leucite based ceramics. Dent Mater. 2004; 20(10): 956-62.

21. Shenoy A, Shenoy N. Dental ceramics: an update. J Conserv Dent. 2010; 13(4):195-203.

22. Guess PC, Schultheis S, Bonfante EA, Coelho PG, Ferencz JL, Silva NR. All-ceramic systems: laboratory and clinical performance. Dent Clin North Am. 2011; 55: 333-52.

23. Zogheib LV, Bona AD, Kimpara ET, McCabe JF. Effect of hydrofluoric acid etching duration on the roughness and flexural strength of a lithium disilicate-based glass ceramic. Braz Dent J. 2011; 22: 45-50.

24. Guess PC, Zavanelli RA, Silva NR, Bonfante EA, Coelho PG, Thompson VP. Monolithic CAD/CAM lithium disilicate versus veneered Y-TZP crowns: comparison of failure modes and reliability after fatigue. Int J Prosthodont. 2010; 23: 434-42.

25. Grossman DG. Cast glass-ceramics. Dent Clin North Am. 1985; 29:719–23.

26. Yang L, Hong J, Santerre JP, Pilliar RM. Synthesis and characterization of a novel polymer-ceramic system for biodegradable composite applications. J Biomed Mater Res. 2003; 66: 622-32.

27. He LH, Purton D, Swain M. A novel polymer infiltrated ceramic for dental simulation. J Mater Sci Mater Med. 2011; 22: 1639-43.

28. Chaiyabutr Y, Giordano R, Pober R. The effect of different powder particle size on mechanical properties of sintered alumina, resin- and glass-infused alumina. J Biomed Mater Res B Appl Biomater. 2009; 88: 502-8.

29. Haselton DR, Diaz-Arnold AM, Hillis SL. Clinical assessment of high-strength all-ceramic crowns. J Prosthet Dent. 2000; 83: 396-401.

30. Guazzato M, Albakry M, Ringer SP, Swain MV. Strength, fracture toughness and microstructure of a selection of all-ceramic materials. Part I. Pressable and alumina glass infiltrated ceramics. Dent. Mater. 2004; 20: 441-48.

31. Guazzato M, Albakry M, Ringer SP, Swain MV. Strength, fracture toughness and microstructure of a selection of all-ceramic materials. Part II. Zirconia-based dental ceramics. Dent. Mater. 2004; 20: 449-56.

32. Kelly JR, Benetti P. Ceramic materials in dentistry: historical evolution and current practice. Aust Dent J. 2011; 56(Suppl. 1): 84–96.

33. Rekow ED, Zhang G, Thompson V, Kim JW, Coelho P, Zhang Y: Effects of geometry on fracture initiation and propagation in all-ceramic crowns. J Biomed Mater Res B Appl Biomater. 2009; 88: 436-46.

34. Manicone PF, Iommetti PR, Raffaelli L. An overview of zirconia ceramics: Basic properties and clinical applications. J Dent. 2007; 35: 819-26.

35. Liu PR, Essig ME. Panorama of dental CAD/CAM restorative systems. Compend Contin Educ Dent. 2008; 29:482–8.

36. Denry I, Kelly JR. State of the art of zirconia for dental applications. Dent Mater. 2008; 24: 299-307.

37. Helvey GA. Zirconia and computer-aided design/computer-aided manufacturing (CAD/CAM) dentistry. Inside Dentistry. 2008; 4(4): 72-79.

38. Raigrodski AJ. Contemporary all-ceramic fixed partial dentures: a review. Dent Clin North Am. 2004; 48(2): 531-44.

39. Sakaguchi RL, Powers JM, Craig's Restorative Dental Materials, Elsevier, Mosby, Philadelphia, 2011, 12th Edition, 327-48.

40. Denry I, Holloway JA. Ceramics for dental applications: a review. Materials. 2010; 3(1): 351-68.

41. Gorman CM, McDevitt WE, Hill RG. Comparison of two heat-pressed all ceramic dental materials. Dent Mater. 2000 Nov; 16(6): 389-95.

42. Helvey GA. A history of dental ceramics. Compend Contin Educ Dent. 2010; 31(4): 1-3.

43. Yeo IS, Yang JH, Lee JB. In vitro marginal fit of three all-ceramic crown systems. The Journal of Prosthetic Dentistry.2003; 90: 459-64.

44. Beuer F, Schweiger J, Edelhoff D. Digital dentistry: an overview of recent developments for CAD/CAM generated restorations. Br Dent J. 2008; 204(9): 505-11.

45. Silva NR, Witek L, Coelho PG, et al. Additive CAD/CAM process for dental prostheses. J Prosthodont. 2011; 20(2):93-96.

46. Helvey GA. Chairside CAD/CAM: lithium disilicate restoration for anterior teeth made simple. Inside Dentistry. 2009; 5(10): 58-67.

47. 47 . Kawai K, Urano M. Adherence of plaque components to different restorative materials. Oper Dent. 2001; 26: 396–400.

48. Ritter RG. Multifunctional uses of a novel ceramic-lithium disilicate. J Esthet Restor Dent. 2010; 22: 332-41.

49. Manicone PF, Iommetti PR, Raffaelli L. An overview of zirconia ceramics: Basic properties and clinical applications, J Dent. 2007; 35: 819-26.

50. Beuer F, Stimmelmayr M, Gueth JF, Edelhoff D, Naumann M. In vitro performance of full-contour zirconia single crowns. Dent Mater. 2012; 28(4): 449-56.

51. Kontos L, Schille C, Schweizer E, Geis-Gerstorfer J. Influence of surface treatment on the wear of solid zirconia. Acta Odontol Scand. 2013; 71(3-4): 482-7.