REVIEW ARTICLE

All-ceramic Computer-aided Design and Computer-aided Manufacturing Restorations: Evolution of Structures and Criteria for Clinical Application

Elie Nasr[1], Anne-Christelle Makhlouf [2], Elie Zebouni[3], Joseph Makzoumé[4]

Abstract

Background: At a time when esthetics is becoming increasingly important in society, the metal-ceramic system, although clinically reliable in the long term, no longer grants satisfaction in terms of mimicry and biocompatibility. Over the last two decades, the growth of computer-aided design and computer-aided manufacturing (CAD/CAM) systems has promoted the development of new all-ceramic materials. However, the abundance and diversity of the suggested materials involved in fixed prosthetic rehabilitation place the practitioner in a situation of conflict regarding the choice of selecting the type of restoration appropriate to the clinical situation presented to him/her.

Aim: The aim of this article is to classify the different types of milled ceramics according to their microstructure, to review the clinical indications of each, and to indicate whether they should be cemented or bonded.

Results: The diverse sorts of milled ceramics using the CAD/CAM procedures are classified into four categories according to their chemical nature. Therefore, the large constitutional and structural variety of the all-ceramic materials will define the esthetic and mechanical properties of each group.

Conclusion: The all-ceramic CAD/CAM restorations are witnessing a well-deserved rise, knowing that none of those milled ceramics has a universal clinical application.

Clinical significance: Given the abundance and diversity of the new machined ceramics materials, it is necessary to familiarize with their properties as well as with their mode of assembling to the dental structures to ensure the success and durability of the restoration.

Keywords: All-ceramic, Classification, Clinical indications, Computer-aided design and computer-aided manufacturing.

The Journal of Contemporary Dental Practice (2019): 10.5005/jp-journals-10024-2549

Introduction

The fixed metal-ceramic crowns, even though imperfect in terms of mimicry and biocompatibility, have been used successfully for decades.[1,2] It is proven that 95% of these restorations remain intact after 11 years of use in the mouth.[3] The innovations in biomaterials, the rise of the CAD/CAM systems, as well as the increase of the demand on esthetics has led to the development of the ceramo-ceramic systems.[4] However, several complications are currently reported at the level of these restorations, including the chipping, fissuring, and fracture of the cosmetic ceramic.[5,6] These complications are observed more frequently at the level of the posterior sector,[2,7] and bridges are much more subject to fractures than the single-unit crowns.[8]

The fragility of the ceramic has always been a matter of concern. Already in 1965, aiming to strengthen the feldspathic ceramic, McLean and Hughes suggested the addition of aluminum oxide to its composition. Thereafter, both professionals and industrials kept on ameliorating its physical and esthetic properties.[9] Nowadays, the clinical longevity of an all-ceramic fixed restoration remains unpredictable, since it was put on the market without being really tested *in vivo*.[10,11] Scharer,[12] suggested that clinical tests must be executed before commercializing a new ceramic, which should display a survival rate of 95% for at least 3 years or even 5 years for optimal results.

Diverse sorts of milled ceramics using the CAD/CAM procedures are put on the market today. A survey estimated that in 2017, all-ceramic materials will be used for the fabrication of about 42% of the fixed dental restorations.

According to their chemical nature, milled ceramics are classified into four categories:

[1-3]Department of Fixed Prosthesis and Occlusodontics of the Faculty of Dentistry at Saint Joseph University, Beirut, Lebanon

[4]Department of Removable Prosthesis and Dean of the Faculty of Dentistry at Saint Joseph University, Beirut, Lebanon

Corresponding Author: Elie Nasr, Department of Fixed Prosthesis and Occlusodontics of the Faculty of Dentistry at Saint Joseph University, Beirut, Lebanon, Phone: +961 3 393 439, e-mail: elie.nasr1@usj.edu.lb

How to cite this article: Nasr E, Makhlouf AC, Zebouni E, Makzoumé J. All-ceramic Computer-aided Design and Computer-aided Manufacturing Restorations: Evolution of Structures and Criteria for Clinical Application. J Contemp Dent Pract 2019;20(4):516-523.

Source of support: Nil

Conflict of interest: None

1. Vitreous ceramics,
2. Glass-infiltrated ceramics,
3. Polycrystalline ceramics,
4. Polymer-infiltrated ceramic-network.

The type of an all-ceramic restoration is defined by the number of ceramics that compose the prosthetic piece. A dual restoration (double, bicomponent or ceramo-ceramic) involves two types of chemically different, but complementary ceramics, on both mechanical and esthetic levels. The infrastructure is obtained by milling a solid block made of a type of ceramic, using the CAD/CAM procedures. The collected infrastructure will then be covered with a cosmetic ceramic using the conventional technique of stratification in which, a mixture of ceramic powder and liquid will be applied in layers to the infrastructure level to obtain the final form and esthetics.

A monobloc restoration (simple, single-component or monolithic), is constituted of one type of ceramic and a simple surface makeup that ensures the esthetics. This type of restoration presents a large resistance and thus a higher rate of success in comparison to the dual restoration.[13]

The large constitutional and structural variety of the all-ceramic materials presents the practitioner with a dilemma since no material is ideal for all clinical situations.[14-16] Therefore, a good understanding of the esthetic and mechanical properties of the several types of milled ceramics is a fundamental necessity. The objective of this article is to classify the different types of milled ceramics according to their microstructure and review the clinical indications of each type.

Classification of Milled Ceramics

Vitreous Ceramics

Vitreous ceramics are inorganic materials that essentially contain silicon dioxide, also known as quartz or silica. Nowadays, vitreous ceramics are witnessing a well-deserved raise. In fact, this category of ceramics that is divided into two groups has been continually evolving throughout the years to meet the rational requirements of the patient seeking natural esthetics, comfort, and acceptable function. This category is divided into two groups.

Feldspathic Ceramics

Feldspathic ceramics have a biphasic structure: vitreous and crystalline. The vitreous matrix is mainly constituted of silica SiO_2 (55 to 78%), alumina Al_2O_3 (<10%) and modifying alkaline oxides such as sodium oxide Na_2O, potassium oxide K_2O and more rarely lithium dioxide Li_2O. As for the quartz, it composes the crystalline frame.

The first inlays that were conceived using the CAD/CAM procedures were manufactured in 1985 from completely sintered blocks made of fine-structured feldspathic ceramic: Vita Mark I blocks (Vita Zahnfabrik).[17] Their clinical performance proved to be unsatisfactory since they had low survival rate in the oral cavity. Consequently, in 1991, blocks of similar composition of feldspathic ceramic fine structure, but with a different machining technique, molding through extrusion, were introduced: the Vita Mark II (Vita Zahnfabrik) blocks. These have better mechanical properties with a flexural strength of 100–160 MPa.[18] The Vita Mark II blocks (Vita Zahnfabrik) are monochromatic but available in many shades, while the recent Triluxe, Triluxe Forte and Real Life (Vita Zahnfabrik) blocks contain multi-shade layers and allow a color gradient as well as better translucency (Fig. 1).

The feldspathic ceramics showcase a remarkable esthetic due to complex alchemy in which three main components intervene: luminosity, shade, and saturation. Based on the data of clinical trials that contain an irrefutable proof of success, these materials are recommended for the fabrication of veneers, inlays/onlays[19,20] and anterior single-unit crowns. However, their mechanical properties remain relatively weak to handle the posterior forces.

Reinforced Glass Ceramics

Unlike the feldspathic ceramics, reinforced glass ceramics contain minerals of different nature in their crystalline phase that reinforce the material. These glass ceramics are shaped in glass state, to undergo a controlled and partial crystallization thermal treatment which allows the nucleation and precipitation of the crystals in the vitreous matrix. After the crystallization, a structure that is similar to hydroxyapatite is obtained, i.e., a phase of individual crystals included in a vitreous matrix. Thereafter, this category is divided into three subgroups.

Leucite-reinforced Glass Ceramics (KAlSi2O6)

In 1998, the first block of leucite-reinforced glass ceramic block was introduced: the Empress ProCAD (Ivoclar Vivadent), which was ultimately substituted in 2006 by the Empress CAD (Ivoclar Vivadent) (Fig. 2). This new leucite-reinforced block in a percentage of 35 to 45%, with a finer size of particles (1–5 μm) displays a better resistance to defects during machining.[21]

Because of their low values of resistance to flexion (100 to 120 MPa), the leucite-reinforced ceramics would be recommended for the fabrication of the dental veneers and anterior single-unit crowns.[22] Several studies that were conducted during the last years underlined the remarkable clinical performances provided by this group of materials. In a retrospective long-term study (11 years) conducted by Fradeaniand Redemaqni,[23] the single-unit crowns in leucite-reinforced glass ceramics registered a survival rate of 98.9% in the anterior sector and 84.4% on the level of the posterior sector. According to Heintzeand Rousson,[24] the rate of the clinical fracture of these crowns is related to the type of the restored tooth. Indeed, it was found that these restorations that are cemented at the level of the incisors have showed a higher survival rate than those that are cemented on the molars.

Lithium Disilicate-reinforced Glass Ceramics (Li_2SiO_5)

In this category, the main component that constitutes the vitreous matrix is silicon dioxide SiO_2. Other elements are also present such as lithium oxide Li_2O, potassium oxide K_2O, magnesium oxide MgO, aluminum oxide $Al_2O_3$and phosphorus pentoxide P_2O_5.

The blue block, provided at a pre-crystallized stage, can be easily milled (Fig. 3). The resulting restoration will be ultimately

Fig. 1: The different types of feldspathic ceramics milled blocks

Fig. 2: An Empress CAD milled block

Fig. 3: An IPS e.max CAD milled block provided at a precrystallized stage

crystallized in an empty oven at an 850°C temperature for 25 minutes. A shift from blue color to the shade and translucency of choice occurs. As for the resistance to the flexion, it increases to 360 MPa.[25] Therefore, and the lithium disilicate-reinforced glass ceramic will be composed of 70% by volume of needle-shaped crystals having an average size of 1.5µm.[26]

Laboratory tests conducted by Asai et al.,[27] have shown that lithium disilicate-reinforced glass ceramics (IPS e.max CAD - Ivoclar Vivadent) fracture load is significantly higher than that of leucite-reinforced glass ceramics(Empress ProCAD, Empress CAD - Ivoclar Vivadent). Moreover, several studies confirm that the monolithic crowns in lithium disilicate-reinforced glass ceramics (IPS e.max CAD - Ivoclar Vivadent) are more resistant to fatigue during the cyclic loading tests in comparison with the ceramo-ceramic crowns constituted of a feldspathic ceramic stratified on a zirconia base.[28,29]

With such promising characteristics, this glass ceramic reinforced with lithium disilicate is recommended for the confection of veneers, inlays/onlays, anterior and posterior single-unit crowns. Kern et al.,[30]evenrecommendits use for the fabrication of anterior bridges of 3 elements extending to the second premolar. In fact, favorable survival rates have been reported after 2 years, from 97.4 to 100% for the single-unit crowns,[31] and 93% for the anterior bridges of 3 elements.[32] However, the clinical trials having a long-term observation period must be carried out in order to provide more reliable proofs in order to draw a significant conclusion.

Zirconia-reinforced Lithium Silicate Glass Ceramics

In 2013, a lithium silicate-reinforced glass ceramic doped with zirconium dioxide was developed. It is composed of a vitreous matrix containing 8 to 12% of zirconium dioxide (ZrO_2) and a crystalline phase characterized by a fine and homogenous structure with a 0.5µm average size of lithium metasilicate (Li_2SO_3) and lithium disilicate ($Li_2Si_2O_5$).

Nowadays, only two blocks belonging to this category of ceramics exist on the market: the Celtra Duo (Dentsply) which is presented under a completely crystallized form and the Vita Suprinity (Vita Zahnfabrik) that is delivered at a partially crystallized phase (Fig. 4). Later, an additional crystallization treatment is required after machining.

From a clinical point of view, this variety of ceramics promises to conjugate the remarkable properties of the zirconium dioxide and lithium disilicate-reinforced glass ceramics.[33] In fact, according to Elsaka and Elnaghy,[34] this new glass ceramic proves to be much more mechanically resistant to the propagation of fissures in comparison with the lithium disilicate-reinforced glass ceramic following the inclusion of zirconia particles. Moreover, Awad et al.,[4] reported that the small size of the silicate crystals has led to a high content of the glass, which might lead to a better translucency in comparison with the lithium disilicate-reinforced glass ceramics. Therefore, this zirconia-reinforced lithium silicate glass ceramic finds its indication for the fabrication of veneers, inlays/onlays, anterior and posterior single-unit crowns.

Fig. 4: The only two milled blocks belonging to the zirconia-reinforced lithium silicate glass ceramics category: the Celtra Duo and the Vita Suprinity

Glass-infiltrated Ceramics

This category of ceramics was developed for the first time at the end of the 80s with the InCeram Alumina (Vita Zahnfabrik), followed by the InCeram Spinell (Vita Zahnfabrik) and In Ceram Zirconia (Vita Zahnfabrik).[22] However, the milled blocks belonging to this category and that are destined to be shaped using the CAD/CAM procedures were introduced only in 1993 (Fig. 5).

Divided into three groups, these glass-infiltrated ceramics that occupy an intermediate place between the silicate-based ceramics and polycrystalline ones allow the realization of the infrastructures

Fig. 5: The InCeram milled blocks

of crowns and bridges of 3 elements. Subsequently, these infrastructures will be covered by stratification of cosmetic ceramic (i.e., feldspathic ceramic) to obtain the final form and esthetics.

InCeram Alumina (Al_2O_3)

This category, which has been put on the market more than 20 years ago, shows resistance to the flexion which varies between 450 and 600MPa.[18,35,36] As a result, it is recommended for the confection of the infrastructures of single-unit crowns. In fact, over a five-year observation period, many clinical studies have reported a survival rate that varies from 96.9% for the restorations that are placed on the level of the anterior sector [37]to 92% for the crowns that are located posteriorly.[38]

According to Rinke et al.,[39] the fracture of the restorations that are situated in the posterior region is frequently caused by the chipping of the cosmetic ceramic. The manufacturer recently recommends the use of the InCeram Alumina (Vita Zahnfabrik) as an infrastructure of a 3-unit anterior bridge. Meanwhile, only clinical and in vitro studies will allow the approval of their use in the near future.

InCeram Spinell ($MgAl_2O_4$)

It is characterized by the lowest mechanical resistance (350MPa) but presents better optical properties, such as high translucency and optimal diffusion of light in comparison with the other glass-infiltrated ceramics.[22]Its use has been limited to the infrastructures of the anterior single-unit crowns with a survival rate of 91.7% after 5 years.[40]

InCeram Zirconia (Al_2O_3-ZrO_2)

The association of zirconium dioxide (ZrO_2) with alumina (Al_2O_3)in the respective proportions of 33% and 67% [41]allows the InCeram Zirconia (Vita Zahnfabrik) to acquire a flexural strength of about 700 MPa,[18] which places it at the top of the ranking in terms of mechanical resistance for the glass-infiltrated ceramics.[42]

This material is characterized by an intense opacity and low translucency.[36]It expresses an efficient masking power in the presence of dark colors or discolored teeth, but remains maladjusted to the situations in which an elevated esthetic result is primordial.[22] Its application must be consequently restrained to the posterior region as an infrastructure of single crowns and 3-unit bridges.[43]

Several studies have evaluated the clinical performance of the InCeram Zirconia (Vita Zahnfabrik) as an infrastructure of a 3-unit posterior bridge. Survival rates of 94.5% [44] and 93.6% [45] have been reported for the respective observation periods of 3 and 10 years.

Polycrystalline Ceramics

Integrally composed of oxides, this category of ceramics is divided into two groups and does not include a vitreous matrix. Thus, their dense network of crystals opposes the propagation of fissures, which results in excellent mechanical properties.

Alumina-based Polycrystalline Ceramics

The first polycrystalline ceramic was introduced by Andersson and Odén,[46] in 1993: the Procera AllCeram.This material, composed of more than 99.9% of aluminum oxide (Al_2O_3), has a flexural strength of 600 MPa.[47,48]

These ceramics (InCeram AL blocks –Vita Zahnfabrik, are not to be confused with the InCeram Alumina blocks -Vita Zahnfabrik) (Fig. 6) are recommended for the confection of the infrastructures of the anterior and posterior crowns as well as of the anterior bridges of short range. Then, the obtained infrastructures are to be laminated by a corresponding cosmetic ceramic. The survival rates of the Procera AllCeram crowns is 97% after 5 years,[49]and 93.5% after 10 years.[50]

Zirconia-based Polycrystalline Ceramics

Zirconia is a polymorphic material having three crystallographic phases: monoclinic (from room temperature to 1170°C), tetragonal (from 1170°C to 2370°C) and cubic (from 2370°C to 2716°C, the fusion point).

When the pure zirconia is sintered at a temperature exceeding 1170°C, the tetragonal phase is generated. While it cools, the phenomenon reverses: passing from the tetragonal to the monoclinic phase. This change of crystalline structure is accompanied by a volume expansion of 3 to 5% that provokes the appearance of significant stresses within the sintered material that leads to its fracture. It is then advisable to force the structure to maintain its quadratic structure until room temperature. This phenomenon is obtained by supplying stabilizing oxides such as CeO_2, MgO, CaO or Y_2O_3. The material will be then stabilized partially (i.e., PSZ: Partially Stabilized Zirconia), and composed largely of quadratic structured crystals and in a small part of monoclinic structured crystals. However, the addition of 3% mol of yttrium oxide Y_2O_3, has allowed us to obtain a monophasic material containing tetragonal structured crystals only (i.e., TZP: Tetragonal Zirconia Polycrystal).

The Y-TZP zirconia is the most common in dental application. It is composed of a tetragonal phase that is thermodynamically metastable and is characterized by very elevated mechanical properties. The multiple crystallographic forms of the zirconia have allowed it to develop singular behaviors vis-à-vis the external factors. In fact, Garvie et al. demonstrated in 1975 that the zirconia has a reinforcement mechanism by phase transformation(i.e., transformation toughening) that allows it to resist the propagation of cracks. Thus, when cracking appears in the material, the tetragonal particles will be transformed into monoclinic particles under the effect of the constraint that is applied by the propagating crack. This phase transformation is accompanied by a volume augmentation from 3% to 5% of the monoclinic crystals, which stimulates a compression at the peak of the crack, which is stopped and "squeezed". We are talking about an auto-reparation capacity. This mechanism allows the zirconia to be the most rigid ceramic.

The resistance of the zirconia to the flexion reaches extremely elevated limits of 900 to 1200 MPa in comparison to other ceramic materials. It also allows the fabrication of long-range prosthetic pieces in zirconia, which are conceived with sections of adapted connexions.

Thus, the zirconia-based ceramics, in particular, Y-TZP, are clinically available as an alternative to metallic infrastructures. The fabrication of Y-TZP infrastructures can be achieved by milling a solid block using the CAD/CAM procedures. However, the modeling of feldspathic ceramic on the zirconia infrastructure, combined with the expertise of an experienced and talented operator allows to obtain esthetic restorations that are estimated to be among the best, in comparison with other all-ceramic systems.

The long-term success of the ceramo-ceramic crowns made of a zirconia frame-laminated ceramic is a critical problem. In fact, these restorations underline a high percentage of fracture of the cosmetic ceramic. The in-vivo fracture rate of the stratified ceramic reaches 15% after 24 months, 25% after 31 months, and only 2,9% after 36 months for the ceramo- metallic restorations.[51]The location of the interface as a flaw of origin has been reported, which suggests that the link between the stratification ceramic and the zirconia infrastructure is the weakest link of this type of restoration.[52]

In order to solve the problems of bilayer structure, monolithic crowns made of polychromatic zirconia were put on the market (Katana-Kuraray) (Fig. 7). They are characterized by a fine and homogenous structure and are shaped using the CAD/CAM procedures. This new variety is proven to be promising at the esthetic and mechanical levels. Studies that were conducted by Johansson et al.[53] and Sun et al.,[54] have shown that the fracture resistance of zirconium dioxide monolithic crowns is considerably higher than that of lithium disilicate and zirconia frame-laminated ceramic restorations.

Polymer-infiltrated Ceramic Network (PICN)

In 2013, the first hybrid dental ceramic doted of a double network was introduced. It was a glass ceramic in an interpenetrating polymer network.

According to Gracis et al.,[55] this category of ceramics that comprises a resinous matrix was developed following three objectives:

- Obtaining a material that is very close to the elasticity module of the dentine,
- Obtaining a material that is easier to mill and adjust,
- Facilitating the reparation or modification of the ceramic by composite resin.

From a constitutional point of view, the inorganic content of ceramic is 86% in weight, whereas the organic content of the polymer is only 14% in weight. In fact, the ceramic part that constitutes 75% of the weight is composed of silica SiO_2 (58-63%) and alumina Al_2O_3 (20-23%), whereas the polymer part, which constitutes 25% of the volume, is composed of urethane dimethacrylate (UDMA) as well as triethylene glycol dimethacrylate (TEGDMA). However, this hybrid glass ceramic is not as resistant as the other milled ceramics but has an elasticity module that is very similar to that of the dentine,[56] thus favoring a decrease of constraints at the tooth/crown interface level.

Moreover, based on the promising results of the recent in vitro studies, this category of ceramics which is not yet commercialized on the dental market is recommended for the realization of the veneers and single-unit crowns situated at the level of the anterior or posterior regions. However, only the clinical studies will constitute the best means of judgment, thus the validation of the indications advocated for above (Table 1).

Assembling Modes

One of the factors of the longevity of the crystalline matrix restorations depends on the quality of their assembly for dental preparation. The choice between cementing or bonding should be made in accordance with the retentive potential between the restoration and the tooth. Thus, in the presence of good mechanical retention, it is recommended to cement, whereas a weaker intrinsic retentive power of the preparations, directs the choice towards bonding, implying a clean and dry operating field.

Among the cementing materials, the conventional glass-ionomer cements (CVI) such as Fuji II (GC) present mechanical and physicochemical properties that are particularly interesting. In addition to their very satisfying sealing and solubility, these materials are also very bioactive, since they allow the release of fluorides. Their modified version made by adding resin (CVIMAR) such as the Fuji Plus (GC) presents ameliorated mechanical properties and stronger resistance. Their implementation is very easy and practical since they are commercialized in pre-dosed capsules.

Among the bonding materials, such as the SuperBond (Morita) and the Panavia (Kuraray)that have adhesive potential, should be used after the application of a self-etching adhesive system at the level of the surfaces of the tooth and prosthetic intrados. As for the auto-adhesive bonding materials such as the RelyX Unicem

Fig. 6: The InCeram AL milled block

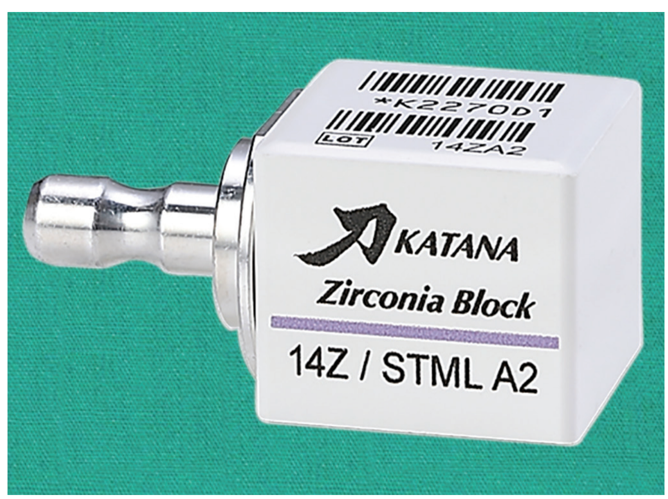

Fig. 7: A zirconia multi-layered milled block

(3M ESPE), their use does not require any prior treatment. They present good mechanical qualities that allow them to ensure strong adhesion of the dento-prosthetic complex.

The choice of the assembling method and material shall be made following a rigorous analysis of the clinical parameters. The bonding technique, if it presents qualities of retention and reinforcement of the dento-prosthetic joint, requires a rigorous and fastidious assembling protocol. So, one shall not deprive oneself of the comfort of using materials such as CVIMAR as the first intention. In fact, they have good adherence potential and a certain ease of implementation (Table 2).

Conclusion

The increasing demand of esthetic restorations that reproduce the natural teeth as accurately as possible, as well as the concerns about the metallic restorations, have been the driving force behind the development and evolution of new materials and techniques in the field of fixed prosthetics in odontology.

Nowadays, all-ceramic crowns are witnessing a well-deserved raise. In fact, the high-resistance ceramics and the associated CAD/CAM techniques have largely increased the clinical indications of the metal-free prosthetics, showing more favoring towards the mechanical characteristics in comparison with the precocious ceramic materials.

Given the abundance and diversity of the new suggested material, the practitioner finds himself/herself facing a dilemma with regards to the choice of the type of restoration to use in a clinical case. It is then necessary to familiarize with these new machined ceramics as well as with their mode of assembling to the dental structures to ensure the success and durability of the restoration.

Table 1: The clinical indications of the diverse types of milled ceramics

Indications / *Clinical* / *Types of milled ceramics*			*Veneer*	*Single-unit crown*		*3-Unit bridge*		*Long range bridge*
				Anterior	*Posterior*	*Anterior*	*Posterior*	
Vitreous	Feldspathic		+	+				
	Reinforced	L*	+	+				
		LD*	+	+	+	+		
		LSZ*	+	+	+			
Glass-infiltrated	In ceram alumina			+	+	+		
	In ceram spinell			+				
	In ceram zirconia				+		+	
Polycrystalline	Alumina-based			+	+	+		
	Zirconia-based			+	+	+	+	+
Polymer-infiltrated-ceramic-network			+	+	+			

L: Leucite
LD: Lithium disilicate
LSZ: Lithium silicate doped with zirconium dioxide.

Table 2: The assembling modes used for each type of restoration according to the type of ceramic

Assembling modes / *Types of restorations*		*Bonding*		*Cementing*	
		Adhesive resin	*Auto-adhesive resin*	*CVI **	*CVIMAR ***
Veneer	Vitreous	+	–	–	–
	Polymer-infiltrated ceramic network	+	–	–	–
Single-unit crown	Vitreous	+ +	+ +	+	+ +
	Glass-infiltrated	+	+ +	+ +	+ +
	Polycrystalline	+	+ +	+ +	+ +
	Polymer-infiltrated ceramic network	+ +	+ +	–	+ +
Bridge	Vitreous	+ +	+ +	+	+ +
	Glass-infiltrated	+	+ +	+ +	+ +
	Polycrystalline	+	+ +	+ +	+ +

++ : Highly recommended
+ : Recommended
– : Contraindicated
** : Glass-ionomer cement
** : Glass-ionomer cement modified by addition of resin.

References

1. Guess PC, Schulheis S, Bonfante EA, Coelho PG, Ferencz JL, Silva NR: All-ceramic systems: Laboratory and clinical performance. Dent Clin North Am 2011;55:52-333
2. Wang X, Fan D, Swain MV, Zhao K: A systematic review of ceramic crowns: Clinical fracture rates in relation to restored tooth type. Int J Prosthodont 2012;25:50-441
3. Leempoel PJ, VanRossum GM, DeHann AF: Survival studies of dental restorations: Criteria, methods and analysis. J Oral Rehabil 1989;16:94-387
4. Awad D, Stawarczyk B, Liebermann A, Ilie N: Translucency of esthetic dental restorative CAD/CAM materials and composite resins with respect to thickness and surface roughness. J Prosth Dent 2015;113:534-540
5. Sax C, Hammerle CH, Sailer I: 10-year clinical outcomes of fixed dental prostheses with zirconia frameworks. Int J Comput Dent 2011;14:183-202
6. Raigrodski AJ, Hillstead MB, Meng GK, Chung KH: Survival and complications of zirconia-based fixed dental prostheses: A systematic review. J Prosthet Dent 2012;107:7-170
7. Pjetursson BE, Sailer I, Zwahlen M, Hammerle CH: A systematic review of the survival and complication rates of ceramic and metal-ceramic reconstructions after an observation period of at least 3 years. Part I: Single crowns. Clin Oral Implants Res 2007;18:73-85
8. DellaBona A, Kelly JR: The clinical success of all-ceramic restorations. J Am Dent Assoc 2008;139:8-13
9. Denry I, Kelly JR: Emerging ceramic-based materials for dentistry. J Dent Res 2014;93:42-1235
10. Kelly JR: Clinically relevant approach to failure testing of all-ceramic restorations. J Prosthet Dent 1999;81:61-652
11. Dhima M, Carr AB, Salinas TJ, Lohse C, Berglund LJ, Nan KA: Evaluation of fracture resistance in aqueous environment under dynamic loading of lithium disilicate restorative systems for posterior applications. Part II. J Prosthodont 2014;23:57-353
12. Scharer P: All-ceramic crowns systems: Clinical research versus observation in supporting claims. Signature 1997;4:1
13. Zhao K, Wei YR, Pan Y, Zhang XP, Swain MV, Guess PC: Influence of veneer and cyclic loading on failure behavior of lithium disilicate glass-ceramic molar crowns. Dent Mater 2014;30:71-164
14. Conrad HJ, Seong WJ, Pesun IJ: Current ceramic materials and systems with clinical recommendations: A systematic review. J Prosthet Dent 2007;98:389-404
15. Rosentritt M, Behr M, Thaller C, Rudolph H, Feilzer A: Fracture performance of computer-aided manufactured zirconia and alloy crowns. Quintessence Int 2009;40:62-655
16. Manso AP, Silva NR, Bonfante EA, Pegoraro TA, Dias RA, Carvalho RM: Cements and adhesives for all-ceramic restorations. Dent Clin North Am 2011;55:32-311
17. Mörmann WH, Bindl A: All-ceramic, chair-side computer-aided design/computer-aided machining restorations. Dent Clin North Am 2002;46:405-426
18. Giordano R: Materials for chairside CAD/CAM-produced restorations. J Am Dent Assoc 2006;137:14-21
19. Zimmer S, Gohlich O, Ruttermann S, Lang H, Raab WHM, Barthel CR: Long-term survival of Cerec restorations: A 10-year study. Oper Dent 2008;33:484-487
20. Morimoto S, Rebello De SampaioFBW, Braga MM, Sesma N, Özcan M: Survival rate of resin and ceramic inlays, onlays, and overlays: A systematic review and meta-analysis. J Dent Res 2016;95:985-994
21. Giordano R., McLaren EA: Ceramics overview: Classification by microstructure and processing methods. Compend Contin Educ Dent 2010;31:682-688
22. Zarone F, Russo S, Sorrentino R: From porcelain-fused-to-metal to zirconia: Clinical and experimental considerations. Dent Mater 2011;27:83-96
23. Fradeani M, Redemagni M: An 11-year clinical evaluation of leucite-reinforced glass-ceramic crowns: A retrospective study. Quintessence Int 2002;33:503-510
24. Heintze SD, Rousson V: Fracture rates of IPS Empress all-ceramic crowns: A systematic review. Int J Prosthodont 2010;23:129-133.
25. Aboushelib MN, Sleem D: Microtensile bond strength of lithium disilicate ceramics to resin adhesives. J Adhes Dent 2014;16:547-552.
26. Culp L, McLaren EA: Lithium disilicate: The restorative material of multiple options. Compend Contin Educ Dent 2010;31:716-725.
27. Asai T, Kazama R., Fukushima M, Okiji T: Effect of overglazed and polished surface finishes on the compressive fracture strength of machinable ceramic materials. Dent Mater J 2010;29:661-667.
28. Guess PC, Zavanelli RA, Silva NRFA, 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;23:434-442.
29. Silva NRFA, Bonfante EA, Martins LM, Valverde GB, Thompson VP, Ferencz JL, CoelhoPG: Reliability of reduced-thickness and thinly veneered lithium disilicate crowns. J Dent Res 2012;91:305-310.
30. Kern M, Sasse M, Wolfart S: Ten-year outcome of three-unit fixed dental prostheses made from monolithic lithium disilicate ceramic. J Am Dent Assoc 2012;143:234-240.
31. Fasbinder DJ, Dennison JB, Heys D, Neiva G: A clinical evaluation of chairside lithium disilicate CAD/CAM crowns. J Am Dent Assoc 2010;141:10-14.
32. Esquivel-UpshawJF, Anusavice KJ, Young H, Jones J, Gibbs C: Clinical performance of a lithia disilicate-based core ceramic for three-unit posterior FPDs. Int J Prosthodont 2004;17:469-475.
33. Sen N, Us YO: Mechanical and optical properties of monolithic CAD-CAM restorative materials. J Prosthet Dent 2018;119:593-599.
34. Elsaka SE, Elnaghy AM: Mechanical properties of zirconia reinforced lithium silicate glass-ceramic. Dent Mater 2016;32:908-914.
35. Yilmaz H, Aydin C, Gul BE: Flexural strength and fracture toughness of dental core ceramics. J Prosthet Dent 2007;98:120-128.
36. Chen YM, Smales RJ, Yip KHK, Sung WJ: Translucency and biaxial flexural strength of four ceramic core materials. Dent Mater 2008; 24:1506-1511
37. Kokubo Y, Tsumita M, Sakurai S, Suzuki Y, Tokiniwa Y, Fukushima S: Five-year clinical evaluation of In-Ceram crowns fabricated using GN-I (CAD/CAM) system. J Oral Rehabil 2011;38:601-607.
38. Bindl A, MörmannWH: An up to 5-year clinical evaluation of posterior In-ceram CAD/CAM core crowns. Int J Prosthodont 2002;15:451-456
39. Rinke S, Tsigaras A, Huels A, Roediger M: An 18-year retrospective evaluation of glass-infiltrated alumina crowns. Quintessence Int 2011;42:625-633.
40. Bindl A, Mörmann WH: Survival rate of mono-ceramic and ceramic-core CAD/CAM-generated anterior crowns over 2-5 years. Eur J Oral Sci 2004;112:197-204.
41. Raigrodski AJ: Contemporary materials and technologies for all-ceramic fixed partial dentures: A review of the literature. J Prosthet Dent 2004;92:557-562.
42. Chong KH, Chai J, Takahashi Y, Wozniak W: Flexural strength of In-Ceram alumina and In-Ceram zirconia core materials. Int J Prosthodont 2002;15:183-188.
43. Heffernan MJ, Aquilino SA, Diaz-Arnold AM, Haselton DR, Stanford CM, Vargas MA. Relative translucency of six all-ceramic systems. Part II: Core and veneer materials. J Prosthet Dent 2002;88:10-15.
44. Suárez MJ, Lozano JFL, Paz Salido M, Martinez F. Three-year clinical evaluation of In-Ceram Zirconia posterior FPDs. Int J Prosthodont 2004;17:35-38.
45. Chaar MS, Passia N, Kern M: Ten-year clinical outcome of three-unit posterior FDPs made from a glass-infiltrated zirconia reinforced alumina ceramic (In-Ceram Zirconia). J Dent 2015;43:512-517.
46. Andersson M, Odén A: A new all-ceramic crown: A dense-sintered, high-purity alumina coping with porcelain. Acta Odontol Scand 1993;5:59-64.
47. Zeng K, Odén A, Rowcliffe D: Flexure tests on dental ceramics. Int J Prosthodont 1996;9:434-439.
48. Brunton PA, Smith P, McCordJF, Wilson NH: Procera all-ceramic crowns: A new approach to an old problem? Br Dent J 1999;186: 430-434.
49. Odman P, Andersson B: Procera AllCeram crowns followed for 5 to 10.5 years: A prospective clinical study. Int J Prosthodont 2001;14:504-509.

50. Fradeani M, D'amelio M, Redemagni M, Corrado M: Five-year follow-up with Procera all-ceramic crowns. Quintessence Int 2005; 36:105-113.
51. Ozkurt Z, Kazazoglu E, Unal A: In vitro evaluation of shear bond strength of veneering ceramics to zirconia. Dent Mater 2010;29: 138-146.
52. Durand JC, Jacquot B, Salehi H, Fages M, Margerit J, Cuisinier FJ: Confocal raman microscopic analysis of the zirconia/feldspathic ceramic interface. Dent Mater 2012;28:661-671.
53. Johansson C, Kmet G, Rivera J, Larsson C, Vult Von Steyern P: Fracture strength of monolithic all-ceramic crowns made of high translucent yttrium oxide-stabilized zirconium dioxide compared to porcelain-veneered crowns and lithium disilicate crowns. Acta Odontol Scand 2014;72:145-153.
54. Sun T, Zhou S, Lai R, Liu R, Ma S, Zhou Z, LongquanS: Load-bearing capacity and the recommended thickness of dental monolithic zirconia single crowns. J Mech Behav Biomed Mater 2014;35:93-110.
55. Gracis S, Thompson VP, Ferencz JL, Silva NRFA, Bonfante EA: A new classification system for all-ceramic and ceramic-like restorative materials. Int J Prosthodont 2015;28:227-235.
56. Della Bona A, Corazza PH, Zhang Y: Characterization of a polymer-infiltrated ceramic-network material. Dent Mater 2014;30:564-569.