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

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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 Scherer,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. 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.

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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 SiO₂ (55 to 78%), alumina Al₂O₃ (<10%) and modifying alkaline oxides such as sodium oxide Na₂O, potassium oxide K₂O and more rarely lithium dioxide Li₂O. 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). These had better mechanical properties with a flexural strength of 100–120 MPa.18 The Vita Mark II blocks (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/onlays19,20 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 Fradeani and Redemaqnì,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 (Li₂SiO₅)

In this category, the main component that constitutes the vitreous matrix is silicon dioxide SiO₂. Other elements are also present such as lithium oxide Li₂O, potassium oxide K₂O, magnesium oxide MgO, aluminum oxide Al₂O₃ and phosphorus pentoxide P₂O₅.

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

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). 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...
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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 (Al₂O₃)**

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. 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 to 92% for the crowns that are located posteriorly.

According to Rinke et al., 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 (MgAl₂O₄)**

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. Its use has been limited to the infrastructures of the anterior single-unit crowns with a survival rate of 91.7% after 5 years.

**InCeram Zirconia (Al₂O₃-ZrO₂)**

The association of zirconium dioxide (ZrO₂) with alumina (Al₂O₃)in the respective proportions of 33% and 67% allows the InCeram Zirconia (Vita Zahnfabrik) to acquire a flexural strength of about 700 MPa, which places it at the top of the ranking in terms of mechanical resistance for the glass-infiltrated ceramics.

This material is characterized by an intense opacity and low translucency. It expresses an efficient masking power in the level of the anterior sector to 92% for the crowns that are situated in the posterior region is frequently caused by 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 CeO₂, MgO, CaO or Y₂O₃. 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 Y₂O₃, 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

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, their modified versions that are very bioactive and very close to the elasticity module of the dentine,56 thus favoring a decrease of constraints at the tooth/crown interface level.

Obtaining a material that is easier to mill and adjust, such 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.
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(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 prosthodontics 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 |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| **Clinical**                    | **Indications**                 | **Veneer**                      | **Single-unit crown**           | **3-Unit bridge**               |
| Types of milled ceramics       |                                 | 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**            | **Bonding**                     | **Auto-adhesive resin**         | **CVI**                        | **CVIMAR**                      |
| Types of restorations           |                                 |                                 |                                 |                                 |
| Veneer                          | Vitreous                        | +                               | _                               | +                               | +                               |
|                                 | Glass-infiltrated ceramic network | +                               | _                               | +                               | +                               |
|                                 | Glass-infiltrated               | +                               | +                               | +                               | +                               |
|                                 | Polycrystalline                 | +                               | +                               | +                               | +                               |
|                                 | 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.
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