CAD/CAM ceramics, hybrid ceramics and resins - A new era (non-metal tooth replacement options) - A Review

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***Abstract*: Micro structure of dental restorative materials along with elastic constants gives an intuition of mechanical behaviour of the materials. Accuracy, quick esthetic restoration delivery, strength and durability made ceramics as the most chosen material of esthetic importance. The combination duo of CAD/CAM and numerous advanced ceramic materials ameliorated the esthetics, precision milling making ceramics as the best choice of prosthesis delivery chair side. Newer breakthrough ceramics with more mechanically resistant properties, softer materials with higher fracture resistance have evolved that made milling more rapid and error free which included adhesive ceramic, high strength ceramic, resin reinforced ceramic and many more. The objective of this article is to classify chairside CAD/ CAM materials and to define their characteristics and indications.**

***Keywords*: hybrid ceramics, resins, Lithium disilicates, zirconia-reinforced lithium silicates, feldspathic porcelain, nano ceramics, zirconia**

INTRODUCTION

The first chairside CAD/CAM[1] produced inlay was made in 1985 using a ceramic block comprising fine grain feldspathic ceramic (Vita Mark I, Vita Zahn Fabrik).[2] Since the 80's, different systems have been developed, such as known CEREC. Systems have evolved through a series of software and hardware.[3,4] The current systems offer a three-dimensional (3-D) design program and can fabricate inlays, onlays, veneers, crowns, as well as three unit bridges and custom lithium disilicate implant abutments.[5] Initially, materials had to be mechanically strong but also easily machinable. Feldspathic ceramics were well adapted for small occlusal inlays (CEREC I).[2] Then, the desire to extend the indications of CAD/CAM restorations (onlays, crowns) has driven the practitioner to work with more mechanically resistant materials. Therefore, reinforced ceramic has been developed. To maintain rapid milling, some of them are offered at a pre-crystallized stage. A post-milling crystallization will be necessary to access the final shade and mechanical strength. The idea to propose softer materials less susceptible to brittle fracture was also developed. This is the resin class, much less mechanically resistant but which has the property of deforming before fracture, unlike ceramics.[6,7] The next step was to increase the mechanical properties of these resins with the incorporation of ceramic particles. Currently, manufacturers try to combine the advantages of these two families of materials by providing a ceramic network infiltrated with resin polymers. Metal blocks are also available, but their existence and their use are today almost anecdotal. Nowadays, manufacturers propose more than 20 blocks for a chairside use. Blocks are available in different size, shade, and translucence and can require a post milling treatment, which would be different according to the type of material. Practitioners may encounter problems choosing the right material for the clinical situation among this large range of material and the related commercial communication.

The objective of this article is to classify chairside CAD/ CAM materials and to define their characteristics and indications.

CAD/CAM materials for chairside processing in a single appointment may be categorized based on material composition for ease in understanding their properties and clinical applications (Table 1).[8-11]

Table 1. CAD/CAM materials for chairside processing

Material category	Description	Brand	Manufacturer
Adhesive Ceramic	Feldspathic glass	Vitablocs Mark II CEREC Blocs	Vita Zahnfabrik Dentsply Sirona
	Leucite-reinforced glass	IPS Empress CAD	Ivoclar Vivadent
High-strength Ceramic	Lithium disilicate	IPS e.max CAD	Ivoclar Vivadent
	Zirconia-reinforced lithium silicate(precrystallized)	Celtra Duo	Dentsply Sirona
Resilient Ceramic	Nanoceramic	Lava Ultimate Cerasmart	3M GC America
	Hybrid ceramic (PICN)	Enamic	Vita Zahnfabrik
	Bis-GMA composite	Paradigm MZ100 Brilliant Crios	3M Coltene/whaledent

Resins	nano-hybrid CAD/CAM composite block	Tetric CAD	Ivoclar Vivadent
	PMMA	Telio CAD	Ivoclar Vivadent
Zirconia	Presintered zirconia	CEREC Zirconia e.max ZirCAD Katana Zirconia	Dentsply Sirona Ivoclar Vivadent Kuraray Noritake Dental

Materials

Adhesive ceramics

The introduction in the 1980s of the first CAD/CAM systems ushered in a dramatic change in the fabrication of chairside restorations. Adhesive ceramic materials were the first millable materials developed for CAD/CAM systems. This category includes materials with a significant glass component, resulting in higher translucency; this provides a "chameleon" effect that allows the material to blend well with the existing tooth shade. Exhibiting a moderate flexural strength of 125 to 175 megapascals, these materials are not independently strong enough to be delivered with traditional cements. However, the glass component of the material can be etched with hydrofluoric acid to create micromechanical retention for adhesive bonding. Adhesive bonding not only provides dependable retention, but it also seals the internal aspect of the restoration against cracks and improves resistance to functional fracture.[12]

Feldspathic and leucite-reinforced materials:

Feldspathic ceramics are obtained by simply mixing powder and water. A plasticized ceramic mixture is pressed and extruded through a nozzle to give its form. The blocks are then dried over several days before sintering.[2] Glasses in dental ceramics derive principally from a group of mined minerals called feldspar and are based on silica (silicon oxide) and alumina (aluminium oxide), hence feldspathic porcelains belong to a family called aluminosilicate glasses. Glasses based on feldspar are extremely biocompatible.[14] Leucite-reinforced are particle-filled glasses. Their microstructures differ by the presence of fillers incorporated in the glassy matrix. The first fillers to be used in dental ceramics contained particles of a crystalline mineral called leucite.[14] There are two major benefits to use leucite as a filler choice for dental ceramics; the first intended and the second probably serendipitous. First, leucite was chosen because its index of refraction is very close to feldspathic glasses; an important match for maintaining some translucency. Second, 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.[13,14] Leucite-reinforced ceramics are formed in the glass state and then heat-treated to obtain a controlled and partial crystallization. This treatment allows the production of crystalline loads-controlled devitrification of chemically homogeneous glass matrix and gives a fine grain structure, very homogeneous. This process is called "ceraming".[14] Dental ceramics that best mimic the optical properties of enamel and dentin are predominantly glassy materials.[13] Feldspathic and leucite-reinforced ceramics have a significant proportion of glassy phase (55 to 70%), which gives them an important translucency, and thus, the aesthetic qualities superior to other ceramic.[15] However, these particularities do not allow proper hiding of a discoloration stump or a metal inlay-core. Mechanical properties of these ceramics are insufficient to withstand occlusal stresses in theory. Reconstructions machined into this material will be bonded to increase this force.[16,17]Two types of materials are marketed in this category.one group is composed of fine-grained feldspathic porcelain(vitablocs Mark II,Vita Zahnfabrik;Bad sackingen,Germany,and CEREC blocs,Dentsply sirona;York,PA)(Fig. 1),the other group is composed of leucite-reinforced ceramic(IPS Empress CAD,Ivoclar vivadent;schaan,liechten-stein)(Fig. 2).[18]These materials are available as monochromatic blocks in a variety of classic shades, as well as polychromatic blocks with a progression of chroma and translucency that simulates the shade transition from cervical to incisal in natural dentition. Adhesive ceramic materials may be either hand-polished or glaze-fired with custom characterization to influence their esthetic outcome. Hand polishing creates an optimally smooth surface for functional wear with antagonist teeth. This category of materials is indicated for single-tooth restorations (e.g., inlays, onlays, veneers, and crowns).

Figure 1: fine-grained feldspathic porcelain

Figure 2: leucite-reinforced ceramic

High-Strength Ceramics

Lithium disilicates and zirconia-reinforced lithium silicates:

The introduction of ceramic materials with improved strength properties marked an important development in CAD/CAM materials.IPS e.max(Fig. 3) CAD was introduced in 2006 as a lithium disilicate material with a significantly greater flexural strength and fracture toughness than previous adhesive glass ceramics.[19,20]The block consists of 0.2-1.0 micron(µm) lithium meta-silicate crystals 40% by volume. The manufactured block is a blue-violet color, which accounts for the commonly used "blue block" description. This partially crystallized "soft" state (i.e.,140 MPa) allows the block to be milled easily without excessive diamond bur wear or damage to the material. Post milling, the restoration must be subjected to a two-stage firing cycle in a ceramic furnace at 850℃ under vacuum to complete the crystallization process. During crystallization, the meta-silicate crystals are dissolved, the lithium disilicate crystallizes, and the ceramic is simultaneously glazed. The restoration changes from the blue color to the chosen shade and achieves the material's maximum flexural strength potential (i.e., 500 MPa).the crystallization firing produces a glass ceramic restoration with a grain size of approximately 1.5µm with a 70% crystal volume incorporated in a glass matrix, as well as creates the optimum translucency for the material.[21]

Another example of a high strength CAD/CAM ceramic, Celtra Duo (Dentsply Sirona)(Fig. 4)was introduced in 2012 as a zirconia-reinforced lithium silicate (ZLS). The ZLS microstructure has a high content of ultra-fine glass ceramic crystals (i.e.,<1.0µm). Zirconium dioxide (10%) is unique to the composition of Celtra Duo and is completely diluted in amorphous glass.it creates a fine-grained structure that increases the material strength, yet allows the material to be readily machined. The manufacturer provides Celtra Duo in a fully crystallized state that may be either hand-polished or glaze-fired in a ceramic furnace prior to delivery. Hand polishing the restoration results in a material that has a flexural strength of 210 MPa, while glazing it in a porcelain oven results in a restoration with a flexural strength of 370 MPa.[21] both IPS e.max CAD and Celtra Duo are also available to dental laboratories as press-fit ingots.

The category of high-strength ceramic materials has become the most popular for chairside restorations. Clinicians appreciate the combination of the materials improved strength and good translucency with their ease of use in surface finishing to fabricate natural-looking restorations. Maximum strength is dependent on oven glazing for ZLS restorations and oven crystallization for lithium disilicate restorations. Clinicians apparently find these additional in-office processing steps acceptable, since they result in restorations with higher strength properties. This category of materials is indicated for single-tooth restorations (e.g., inlays, onlays, veneers, and crowns).lithium disilicate also is available in specifically designed blocks for short-span fixed partial dentures and the restoration of dental implants.

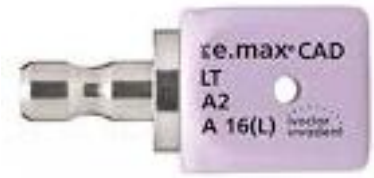

Figure 3; lithium disilicate

Figure 4: zirconia-reinforced lithium silicate

Resilient ceramics

This newer category of chairside CAD/CAM materials is designed to take advantage of the lower brittleness and greater fracture resistance properties of polymers, while combining the esthetic characteristics of glass ceramics. Resilient ceramic materials-also referred to as resin nanoceramics, hybrid ceramics, or polymer-infiltrated-ceramic network (PICN) materials in an attempt to specifically distinguish within the category-all contain a resin matrix structure and a lower modulus of elasticity may be considered more resilient and able to resist a higher functional load without brittle fracture. Since these materials are less dense than ceramics, they mill efficiently with less margin chipping.[23]

Nanoceramics:

Lava Ultimate (3M) is a nanoceramic(Fig.5) CAD/CAM material that contains silica particles OF 20 nanometre's(nm), zirconia particles of 4 to 11 nm, and agglomerated nano-sized particles of silica and zirconia, all embedded in a highly cross-linked polymer matrix with an approximately 80% ceramic load. According to the manufacturer, an advantage for the nanoceramic material over CAD/CAM composite blocks is the formers ability to retain a high gloss surface finish over time.[2]the manufacturer reports a flexural strength of 200 MPa for Lava Ultimate, which is greater than the flexural strength of the feldspathic and leucite-reinforced porcelain blocks, and of veneering porcelains for porcelain-fused-to-metal (PFM) CROWNS (i.e.,<100 MPa).[2]The manufacturer indicates it for veneers, inlays, and onlays, but not for crowns. Independent laboratory studies have reported flexural strength of 170 MPa for Lava Ultimate.[23,24]

Its manufacturer describes Cerasmart (GC America; Alsip, IL) (Fig. 6) as a flexible nanoceramic with a resin matrix containing homogeneously distributed nanoceramic filler particles. The material, which is radiopaque, is a high-density composite resin with 71% silica and barium glass nanoparticles filler by weight.[23]the reported flexural strength of cerasmart is 230 MPa and it is indicated for single-tooth restorations (e.g., veneers, inlays, onlays, and crowns).[23]

Figure 5: nanoceramic

Figure 6: flexible nanoceramic

PICN hybrids:

Introduced in 2013, enamic (vita) (Fig.7) is described as a PICN. It is a resin-based (14% by weight) hybrid ceramic comprising an interpenetrating structure of a leucite-based and zirconia-reinforced ceramic network (86% by weight).[23] The materials mechanical properties are intermediate to those of adhesive ceramics and highly filled composites.[25]the ceramic network may improve wear resistance; however, it may make the material more brittle and susceptible to fracture. The polymer network can improve the materials fracture resistance due to its capability of undergoing plastic deformation.[26]this material is indicated for inlays, onlays, and crowns, and the manufacturer reports a flexural strength of 150 MPa .The latter is consistent with the results of an independent study, which reported the flexural strength to be approximately 135±25 MPa.[24] A more recent introduction, Enamic is based on identical chemistry, but comes in a block design specific for milling implant restorations.

Resilient CAD/CAM materials offer a very good combination of fast and accurate milling with efficient finishing and polishing to minimize processing time for chairside restorations. While hand polishing quickly results in surface smoothness comparable to ceramics, shade modification is limited to the use of visible light-cured (VLC) surface tints and glazes. This category of materials does not exhibit the inherent strength to be cemented and must be adhesively bonded to the tooth structure.

Figure 7: **PICN hybrids:**

Resins

Bis-GMA composite

Introduced in 2000, composite resin CAD/CAM materials for chairside applications have not been particularly popular. However, recent developments in the ease of use and efficiency of CAD/CAM technology have led to an increased use of composite materials. Development of accurate occlusion, desired proximal contacts, and avoidance of postoperative sensitivity can prove problematic when using sectional matrices for the placement of large, multi-surface direct composite restorations. The chairside CAD/CAM workflow may offer a more predictable result while avoiding postoperative sensitivity using monolithic composite blocks, as there is no polymerization shrinkage to the milled restoration.

Paradigm MZ100 (3M) was the first composite block introduced. It is radiopaque, has zirconia-silica filler particles, and is 85% filled by weight with an average particle size of 0.6µm.[26] A proprietary processing technique is used to maximize the degree of cross-linking in the Bis-GMA composite.[27] paradigm MZ100's reported flexural strength is 157±30 MPa, which is similar to the flexural strength of adhesive ceramic materials.[23]

Brilliant Crios (coltene/whaledent; Cuyahoga Falla, OH)(Fig.8), which was introduced in 2016, is a reinforced composite containing amorphous silica particles (<20 nm) and barium glass ceramic particles (<1.0µm) in a cross-linked methacrylate matrix. The manufacturer reports a filler weight of 70.7% and filler volume of 51.5% with a flexural strength of 198 MPa and a modulus of elasticity of 10.3 GPa. The modulus of elasticity, similar to that of dentin, is suggested to minimize stress concentration in the restoration and avoid brittle fracture.

Figure 8: reinforced composite

Nano-Hybrid CAD/CAM composite block

Tetric CAD(Fig 9) is an esthetic hybrid ceramic resin block for the efficient fabrication of indirect single-tooth restorations by means of the CAD/CAM technology. Tetric CAD is based on the proven Tetric technology and is the digital supplement to the direct restoratives of the Tetric Evo-Line. Due to the pronounced chameleon effect, Tetric CAD restorations blend in with the residual tooth structure in an optically pleasing manner. The restoration is polished after milling and then seated using an adhesive cementation protocol. This processing technique is very efficient and leads to an esthetic result quickly and easily. Indications – Veneers – Inlays – Onlays (e.g. occlusal veneers, partial crowns) – Crowns in the anterior and posterior region .[10]

Figure 9: Nano-Hybrid composite block

Telio CAD

Telio CAD is a block made of polymethyl methacrylate (PMMA) (Fig 10) and is used to mill both full contour single-tooth and multiple-unit temporary restorations using CAD/CAM technology. This block enables restorations to be milled both in the laboratory (labside) and the dental practice (chairside). Additional layering materials and stains can be used to enhance the esthetic appearance of the milled restorations.[11]

Figure 10: polymethyl methacrylate block

Zirconia

Zirconia has the particular property to change its crystallographic form under stress. The transition phase is accompanied by a substantial increase in volume sufficient to lead to a catastrophic failure. The transformation allows to stop crack propagation, leading to high toughness.[28-30] The mechanical properties of zirconia are the highest ever reported for any dental ceramic. This may allow the realization of posterior FPD (Fixed Partial Denture) and permit a substantial reduction in core thickness. These capabilities are highly attractive, when strength and aesthetics are paramount.[30] However, due to its microstructure, this ceramic cannot be bonded with conventional techniques. Chairside CAD/CAM zirconia blocks are yttrium cation-doped tetragonal zirconia polycrystals (3Y-TZP) (Fig.12). The restorations are processed either by soft machining of presintered blocks followed by sintering at high temperature, or by hard machining of fully sintered blocks.[31] However, only pre-sintered blocks can be milled by chairside milling units, less sophisticated than those used in laboratory. Restorations produced by soft machining are sintered at a later stage, this process prevents the stress-induced transformation from tetragonal to monoclinic and leads to a final surface virtually free of monoclinic phase unless grinding adjustments are needed or sandblasting is performe.[30]

Figure 12: Zirconia

Indications

Full zirconia restorations, milled chairside, are very recent. There is limited clinical experience on this kind of restoration. It seems possible to realize crowns or small bridges (maximum 3 items). The microstructure of this material does not allow a conventional bonding protocol. Currently, no consensus exists regarding the best adhesion protocol for zirconia used in dentistry. MDP-based resin cements tend to present higher results than those of other cements[32].

For manufacturers, this material requires a support, having no sharp corners, to avoid the risk of fractures. *In vitro* studies show that the surface condition is the main factor of antagonist abrasion. A polished zirconia piece would not be more abrasive than other dental ceramics.[33] However, the aesthetics of this material is limited by the low translucency due to its microstructure and the absence of glassy matrix, and the risk of breakage of the dental support due to its very high mechanical properties is significant. However, some monolithic zirconia may present an acceptable degree of translucency.[34] Mean grain size influences translucency through the number of grain boundaries. Smaller grain sizes is leading to decreased translucency due to the larger number of grain boundaries. A larger grain size is therefore beneficial to mechanical properties but decreases the resistance to low-temperature degradation (LTD). The grain size is depending on sintering temperature and will also determine the amount of cubic phase and yttrium distribution, which has been shown to directly influence resistance to LTD.[35]

Implementation and finish

The prosthetic workpiece is machined slightly oversized to compensate the shrinkage during sintering. The computer software (CAD) manages the oversizing according to the information supplied by the manufacturers. This sintering lasts about 400 minutes in a sintering furnace that reach 1500°C. A glaze may then be necessary to characterize the prosthesis.

Summary

Understanding the material categories and their differing properties and handling characteristics will play an influential role in selecting a specific material for a particular clinical situation. A significant amount of clinical evidence supports the premise that attention to the unique properties and features of the various categories of CAD/CAM materials can result in excellent clinical outcomes.

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