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Current CAD/CAM materials

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Abstract

Computer-aided design and computer-aided manufacturing (CAD/CAM) technologies have fundamentally reshaped restorative and prosthetic dentistry, streamlining both chairside and laboratory workflows while improving the speed, accuracy, and predictability of treatment. As the range of millable materials continues to expand, evidence-based, indication-specific selection has become increasingly challenging for clinicians and dental technicians alike. This review classifies and critically evaluates contemporary CAD/CAM materials according to their chemical composition—metal, ceramic, composite, polymer, and hybrid—and compares their performance to support rational treatment planning. Drawing on current literature, it surveys a broad spectrum of materials, including metal alloy blocks; feldspathic, leucite-reinforced, and lithium disilicate glass ceramics; glass-infiltrated and polycrystalline oxide ceramics (alumina and yttria-stabilized zirconia); resin nanoceramics; polymer-infiltrated hybrid ceramics; zirconia-reinforced lithium silicate; composite blocks; and polymer blocks such as PEEK and PMMA. For each group, mechanical strength, optical and esthetic properties, biocompatibility, clinical indications, advantages, and limitations are presented within a comparative framework, and the influence of production strategy—chairside versus centralized fabrication and hard versus soft milling—on restoration fit and longevity is discussed. Reported flexural strength ranged from approximately 150 MPa for feldspathic ceramics to well above 1000 MPa for high-strength zirconia, revealing consistent trade-offs between mechanical performance and translucency, most evident as the cubic phase of zirconia increases. Lithium disilicate and zirconia emerged as leading options balancing esthetics and durability, whereas PEEK and composite materials offered advantages in biocompatibility, elasticity, and provisional applications. Overall, no single material is universally optimal; selection should be guided by the specific clinical indication, esthetic demand, and occlusal load, with ongoing advances in digital dentistry expected to further broaden material choice and clinical performance.

Keywords: CAD/CAM, block materials, metal alloys, ceramics, polymer blocks, digital dentistry

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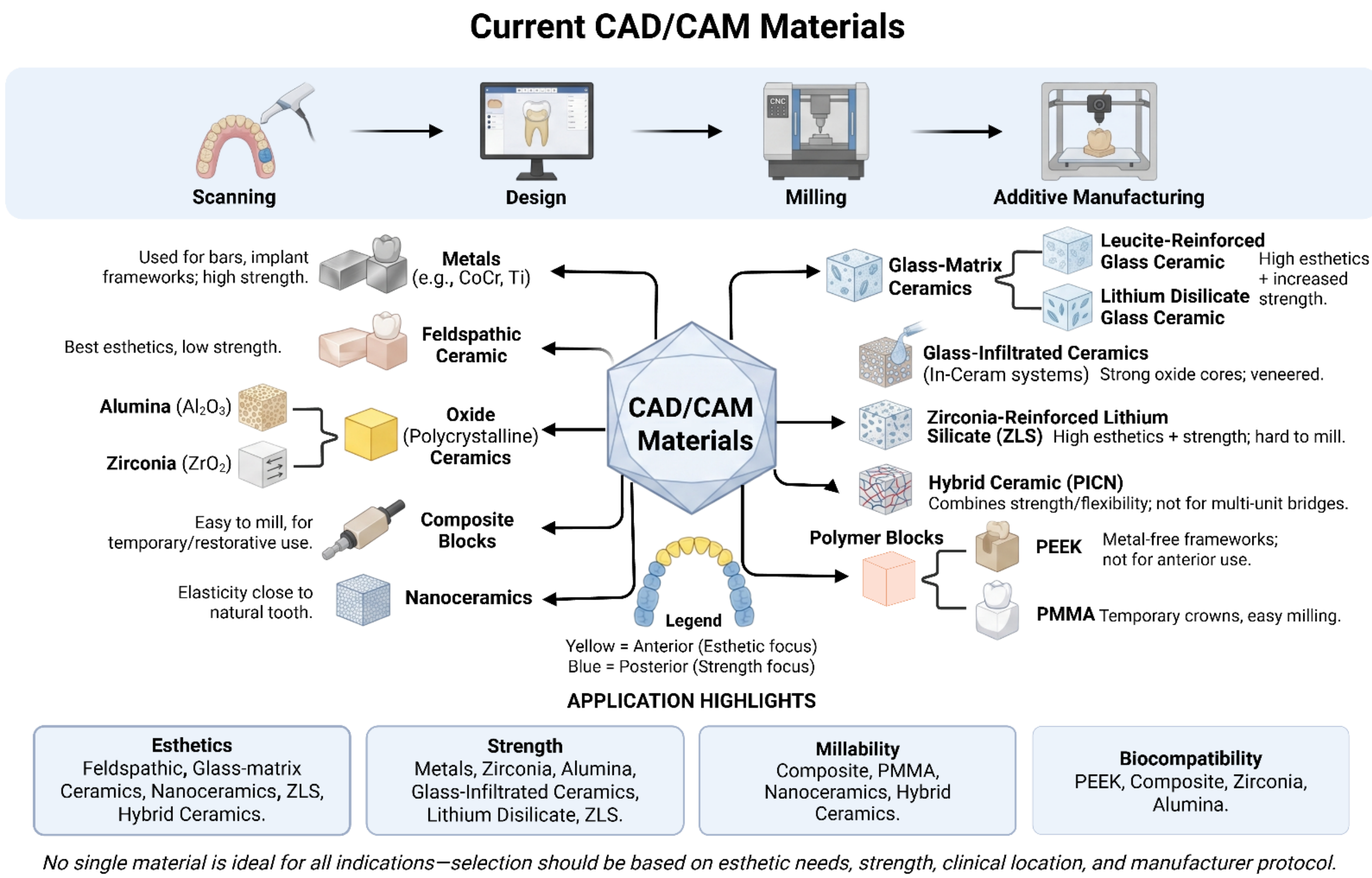
Graphical abstract



1. Introduction

In recent decades, patients' increasing aesthetic expectations and the rapid digitalization of dental workflows have profoundly changed restorative and prosthetic dentistry (1). Computer-aided design/computer-aided manufacturing (CAD/CAM) technology, introduced to dentistry in the 1980s with the CEREC system developed by Mörmann and Brandestini, allows restorations to be designed on a computer and fabricated by automated production units, thereby shortening production time, reducing human error, and enabling treatment to be completed in a single appointment (2, 3).

A CAD/CAM system consists of three components: a scanner that digitizes the intraoral or model surface, design software used to plan the restoration, and a production unit that converts the digital design into the final restoration. The clinical success of restorations produced with these systems depends not only on the accuracy of the digital workflow but also, to a large extent, on the restorative material selected for the specific indication (4). Today, a wide range of materials, including metal alloys, feldspathic and glass ceramics, oxide ceramics, nanoceramics, hybrid materials, and polymers, are available in block form for CAD/CAM processing.

Therefore, knowledge of the microstructure, mechanical and optical properties, and indications of these materials is essential for both clinicians and technicians. This review summarizes current CAD/CAM materials and provides an overview of their classification, properties, advantages, limitations, and clinical indications.

2. CAD/CAM materials

The rapid development of digital dentistry has increased the use of CAD/CAM, making it much easier to use both chairside and in the laboratory (1). Computer-aided design (CAD) and computer-aided manufacturing (CAM) are aimed at using different materials that we choose according to the indication. Restorations such as endocrown, porcelain veneers, implant abutments, inlay, onlay, and bar systems are produced using these systems (2). With the development of technology, the properties of the materials used in these restorations have improved in terms of durability and aesthetics. We can examine CAD/CAM materials with a wide variety of classifications. The type of production, processing method, and material content are examples. Production methods are divided into additive, subtractive, and combined production methods. When classified according to the processing route, they can be divided into production performed in the clinic during the preparation session (chairside), production performed in the laboratory (lab-side concept), and centralized production by scanning the model and sending it to the center for superstructure (4, 5).

The selection of materials for CAD/CAM systems depends on several factors. Both the dentist and technician must evaluate the material's suitability for a specific indication, as well as its cost-effectiveness. The classification based on the material content can also guide the selection process.

Classification of materials by content (6, 7)

1. Metal blocks
2. Glass ceramics
3. Feldspathic ceramics
4. Glass matrix reinforced ceramics
   a) Ceramics reinforced with leucite
   b) Ceramics reinforced with lithium disilicate
5. Glass-infiltrated ceramics
6. Polycrystalline ceramics (oxide)
   a) Aluminum oxide
   b) Zirconium oxide
7. Nanoceramics
8. Hybrid ceramics (glass ceramics in resin matrix)
9. Zirconia-reinforced lithium silicate glass ceramics (ZLS)
10. Composite blocks
11. Polymer blocks
    a) PEEK
    b) PMMA

3. Metal blocks

When a metal-supported veneer or full metal crown restoration is planned, various techniques can be used. These include the conventional lost-wax technique and CAD/CAM milling. In the conventional technique, the workmanship and experience of the technician are very important. The reduced labor required for CAD/CAM systems is a great advantage (8). Metal blocks are preferred in implant restorations using CAD/CAM systems, especially in bar construction (9).

According to a systematic review and meta-analysis by Yang and Li, conventional and CAD/CAM techniques were compared, and in terms of marginal fit in single crowns, the marginal fit of the restoration produced by the conventional lost wax technique was higher than that produced by CAD/CAM milling, but both obtained close values (10).

Metal alloy blocks are classified as fully sintered or semi-sintered. Fully sintered blocks are hard-milled to the final restoration size, while semi-sintered blocks are oversized milled and then sintered. This compensates for the shrinkage that occurs during the sintering process (1, 11, 12). The advantages of hard milling are that it does not require post-process sintering and is therefore dimensionally stable. However, the disadvantages are the faster wear of the cutters due to the hard material and the need for more powerful machines (13). In soft milling, tool wear is low and less costly, and less powerful machines can be used. However, the disadvantages are the extra time required for sintering after milling and the risk of dimensional change (14).

Again, Yang and Li compared hard-milled and soft-milled restorations in terms of marginal fit and reported that soft-milled restorations had a better fit margin (10).

4. Glass ceramics

With the growing emphasis on aesthetics and rising patient expectations, glass ceramics have gained popularity in dentistry due to their excellent aesthetics, biocompatibility, wear resistance, and chemical stability. They are composed of both glassy and crystalline phases. The glassy phase provides high optical performance and natural tooth-like translucency, and it is also the phase that is susceptible to hydrofluoric acid during surface roughening. In contrast, the crystalline phase enhances the mechanical strength of the material (15).

5. Feldspathic ceramics

This group of glass ceramics was the first material used in CAD/CAM systems for chairside applications. It contains different proportions of feldspar, quartz, and kaolin. Feldspar is an important crystal for the glassy phase. In addition to having excellent optical properties, it is the most fracture-prone and weakest material among glass-ceramics (16). It is indicated for use in laminate veneers, anterior and posterior crowns, partial crowns, and inlay and onlay restorations (17). Its brittle structure limits its use in bridge construction (18). The fracture strength and elastic modulus are approximately 150 MPa and 45-63 GPa, respectively (19). However, it is possible to make these restorations stronger with adhesive cementation. **VITABLOCS Mark II** (VITA Zahnfabrik, Bad Säckingen, Germany) blocks are produced for use in monolithic, i.e., single-layer restorations. **VITABLOCS TriLuxe** is produced in three layers (20). A superior aesthetic is achieved by using different color intensity and depth in each layer (21, 22). **CEREC Blocs C (Dentsply Sirona, Bensheim, Germany)** blocks are materials that can be processed in the CEREC unit. This material, which exhibits wear properties similar to natural enamel, also has high translucency due to the chameleon effect. It is indicated for inlay, onlay, veneer and full crowns. Its fast polishability has made it widely used in chairside applications.

CEREC Blocs C PC (Polychromatic): Allows for optimal adjustment to the color gradient of the restoration, as it has different layers based on different degrees of chroma (3).

6. Glass matrix reinforced ceramics

a) Glass ceramics reinforced with leucite

Some crystals were added to the glass ceramics to strengthen them. Leucite, one of the most successful fillers in dental glass ceramics, is the first of these. Leucite-reinforced glass ceramics are mainly composed of silicon oxide (SiO_2), aluminum oxide (Al_2O_3), and potassium oxide (K_2O). The addition of leucite to the matrix not only increases the strength of the material but also provides it with a high coefficient of thermal contraction. However, despite this, due to its low flexural strength (106-160 MPa), it is more commonly used in single-member veneer, inlay, and onlay restorations. The negative aspect of glass ceramics reinforced with feldspathic porcelain or leucite is their low flexural strength (FS). IPS Empress is the commercial name of a leucite-reinforced glass ceramic material (23).

In addition to the IPS Empress material produced using the pressing technique, IPS Pro CAD is a type of leucite-reinforced glass ceramic used in CAD/CAM systems. However, these blocks were later replaced with IPS Empress CAD (Ivoclar Vivadent, Schaan, Liechtenstein) blocks. Two options are available: high translucency (HT) and low translucency (LT) (20).

Color options include monochromatic or polychromatic (IPS Empress CAD Multiblocs) blocks. Adhesive systems should be preferred for cementation of restorations made of this material to increase their fracture strength (24). 5% HF acid should be used for 20 seconds to etch leucite-reinforced CAD/CAM ceramics. The acid acts on the glassy phase and provides roughening (16).

b) Glass ceramics reinforced with lithium disilicate

The addition of lithium disilicate to glass ceramics has significantly increased the fracture strength compared to earlier CAD/CAM ceramics, with bending strengths exceeding 360 MPa. Although lithium disilicate-reinforced ceramics offer excellent aesthetics, their mechanical strength is still lower than that of polycrystalline ceramics, which limits their use in long-span posterior restorations (25).

IPS e.max CAD material is an example of this group of CAD/CAM blocks. The chemical structure of these bluish colored blocks is identical to those of the IPS e.max Press blocks. In the Empress blocks, the size of the lithium disilicate crystals is larger (26).

IPS e.max CAD was the only lithium disilicate material available in CAD/CAM systems. However, with recent studies, other companies, such as **Rosetta SM** (Hass) and T-lithium (Shenzhen Upcera Dental Technology) have started to produce it. Although these materials are similar to IPS e.max CAD in terms of mechanical strength and other optical properties, sufficient studies and comparative tests have not yet been conducted (27). Tavares et al. compared IPS e.max CAD and Rosetta SM groups in a study and reported that both materials have similar values in terms of properties such as density, porosity, and fracture strength (28).

Zaniboni et al. conducted a study comparing lithium disilicate materials from five different companies: EM (E.max CAD), RT (Rosetta SM), EV (Evolith), PM (ProtMat Smile-Lithium CAD), and HS (HaHaSmile). XRD analysis showed that the experimental materials were identical to the control group (IPS E.max CAD), regardless of heat treatment, with similar peak intensities and crystal positions. SEM images revealed that the EM and RT ceramics had similar crystal structures, whereas the other three groups showed distinct morphologies, although they were similar to each other. No significant differences in bending strength were observed between the groups in the 3-point bending test (29).

7. Glass-infiltrated ceramics

It is obtained by infiltrating molten glass particles into a sintered oxide substrate. This is known as the In-Ceram system. The first material used in this system was **In-Ceram Alumina** containing alumina. Giordano et al. measured the flexural strength and reported that In-Ceram Alumina is three times more durable than feldspathic ceramics (30). The process of lanthanum glass infiltration in In-Ceram Alumina significantly increases the strength of the material (31). The lanthanum in the glass facilitates infiltration by reducing the viscosity and also improves its translucency. Its bending strength is 450-600 MPa (32). In addition to this strength, Vita, a feldspathic ceramic, is coated on the In-Ceram substructure to provide an aesthetic appearance (33).

In-Ceram Spinell, another material, contains magnesium aluminum oxide (7). The presence of the main crystal phase, $MgAl_2O_4$ (magnesium aluminate), is highly effective in the aesthetic development of the material (34). Therefore, it is especially preferred in anterior region rehabilitations (21). When examined in terms of bending strength, its strength is lower than that of In-Ceram Alumina, and its value is 350 MPa (32, 35).

The survival rate of this material over 2-5 years was reported as 91.7% (36, 37).

Finally, the **In-Ceram Zirconia** material in this group is glass-infiltrated zirconia reinforced with alumina. It is the strongest of the glass-infiltrated ceramics (38). It contains approximately 33% zirconium oxide and 67% aluminum oxide by weight (39). Its bending strength is up to 700 MPa (32). In addition to this high strength, In-Ceram zirconia is not considered aesthetically successful due to its highly opaque structure. Therefore, its use is mostly indicated in posterior teeth (40, 41, 42).

According to a translucency comparison of six all-ceramic systems, Heffernan et al. concluded that In-Ceram Zirconia is similar in opacity to metal ceramic alloys, while In-Ceram Alumina is more translucent (42).

8. Polycrystalline ceramics (oxide)

Polycrystalline ceramics, such as alumina and zirconia, do not have a glassy phase, and all crystals are densely packed in regular arrays and sintered (43). The crystal lattice in these materials prevents crack propagation, resulting in significantly higher mechanical strength than glass ceramics. This makes them ideal for posterior crown and bridge restorations under high occlusal forces.

a) Aluminum oxide blocks (Alumina)

It has a flexural strength of 600 MPa, and its most important member is Procera AllCeram (44). Composed of 99.9% alumina, this material is used for crowns, inlays, onlays, and veneers in non-discolored teeth (4, 45). It is enlarged by 20% before sintering (4) and veneered with low-temperature porcelain. Procera AllCeram showed 97.7% survival at 5 years and 93.5% at 10 years (46, 47).

b) Zirconium oxide blocks (Zirconia)

The most common molecular form of zirconium, which is not found in pure form in nature, is zirconium dioxide (zirconia). Zirconia is widely used in dentistry as a substructure material in crown and bridge construction, endodontic posts, orthodontic brackets, and abutments in implant rehabilitation (48). This material is processed in CAD/CAM systems using either semi-sintered or fully sintered techniques. Semi-sintered blocks are milled before the final sintering to prevent stress-related phase changes. Fully sintered blocks, such as DC Zirconia (DCS Dental AG, Switzerland), are milled directly and offer high strength with translucency close to lithium disilicate. DC Zirconia is available in three types: Premium, T, and HT, with Premium having the highest flexural strength (45). The hardness present in full sinterization makes it difficult to shape and causes deformation of the abrasive bits used in the milling unit. Two different systems, Denzir (cadesthetic AB) and DC-Zirconia (DCS Dental AG), are used in hard milling (49, 50).

Blocks such as Lava All-Zirconia, Zirkonzahn, and BruxZir are used in monolithic restorations (21). IPS e.max ZirCAD and Lava Zirconia are yttrium-stabilized zirconia blocks, available in different translucency levels (45). Higher yttrium content improves aesthetics but reduces mechanical strength by increasing the cubic phase and decreasing the tetragonal phase, as shown in the fracture toughness and flexural strength comparisons (51). Translucent zirconia products are commonly classified by cubic content as low (below 30% by volume), moderate (30-50%), and high (above 50%), and those with higher cubic content show a significant decrease in fracture toughness and flexural strength. This is because cubic zirconia has a more stable structure and does not undergo the stress-induced transformation toughening described by Hannink et al. (52). Due to its lower durability, high-cubic-phase zirconia is less suitable for posterior use (53). An example of this more aesthetic but fragile type is the DD Cube X2 (Dental Direkt GmbH, Germany) (1).

9. Nanoceramics

Nanotechnology was first used in dentistry in 1997 to improve material properties, achieving elasticity values close to natural teeth (54). Nanoceramic blocks have an elasticity modulus of 10-20 GPa, absorbing more stress than glass ceramics (55). They also cause less wear on opposing teeth (56) and are easier to polish due to nano-sized particles, enhancing both aesthetics and oral health by preventing plaque retention (57).

Nanoceramics combine the ease of processing of resins with the mechanical strength of porcelain. Composed of 80% nanoceramic particles and 20% resin, with a filler size under 100 nanometers, they require no milling and are compatible with traditional bonding procedures (58). Lava Ultimate (3M ESPE, St. Paul, MN, USA) and Cerasmart (GC Corporation, Tokyo, Japan) are examples of resin nanoceramic blocks. Lava Ultimate consists of 80% ceramic (zirconia and silica monomers) and 20% composite, offering advantages such as no milling requirement and easy intraoral adaptation. Its elastic modulus is 10-20 GPa, and flexural strength is 204 MPa. Cerasmart, a flexible nanoceramic with 71% silica and 29% composite, excels in minimal preparations and vertical resizing, with a bending strength of 231 MPa.

10. Hybrid ceramics (Glass ceramics in resin matrix)

This material integrates a glass ceramic structure with a polymer network, in which the polymer phase consists of 66% urethane dimethacrylate (UDMA) and 33% triethylene glycol dimethacrylate (TEGDMA) (59, 60). The polymer network reduces crack propagation, improving the fracture resistance (150-160 MPa), though its durability is lower than nanoceramic blocks, limiting its use in multi-unit bridges (61). Its elasticity, similar to natural teeth, also results in lower opposing tooth abrasion (62). This material enables minimally invasive preparation, reduces chairside application time with fast milling and easy polishing, and offers good edge conformity and the ability to create thin edges with minimal preparation (60). VITA ENAMIC, a hybrid ceramic material with 86% ceramic content, is the world's first polymer-infiltrated ceramic (PICN). It combines the strength of ceramic with the flexibility of composite, offering better wear resistance than composite blocks (63). In a study by Coldea et al., 3-point bending tests were conducted on Y-TZP, glass-infiltrated alumina, lithium disilicate, feldspathic porcelain, and PICN materials. Y-TZP showed the highest bending resistance (1358 MPa), while feldspathic porcelain had the lowest (137 MPa). PICN exhibited the second-lowest bending resistance at 158 MPa (64).

11. Zirconia-reinforced lithium silicate glass ceramics (ZLS)

Zirconia-reinforced lithium silicate (ZLS) is created by adding 10% zirconium oxide to glass-ceramics, combining the positive properties of both materials. This allows restorations to meet aesthetic expectations while providing enhanced durability. However, some studies have shown that the machinability of ZLS is inferior to that of lithium disilicate (LS2), leading to its description as "the most difficult of the glass ceramics to process" (65). Indications include inlays, onlays, laminate veneers, anteroposterior and implant-supported crown prostheses. Its use is not recommended in parafunction and inadequate oral hygiene. In a study by Elsaka et al., zirconium-oxide-reinforced lithium silicate (ZLS) restorations outperformed lithium disilicate in terms of fracture strength, bending resistance, and elastic modulus (66).

To combine these beneficial properties, zirconia-reinforced lithium silicate (ZLS) was introduced in two forms for CAD/CAM systems: fully sintered and semi-sintered, produced by different companies. The first to be introduced were the semi-sintered **VITA Suprinity** blocks (VITA Zahnfabrik, Bad Säckingen, Germany), which require final firing after production. However, if the fully sintered **Celtra Duo** (Dentsply Sirona, Bensheim, Germany) is used in the restoration, there is no single method in the final stage. It has been reported that mechanical polishing is sufficient, but the aesthetic and mechanical properties of the material are much better if an additional final firing is performed (65).

In a study by Riquieri et al., the fired Celtra Duo (cfir) exhibited the highest fracture strength (251.25 MPa) and hardness (693.33 ± 10.85 MPa). Unfired Vita Suprinity (sunf) had the lowest fracture strength (106.95 MPa) and hardness (597.53 ± 33.97 MPa) (67).

12. Composite blocks

These materials are clinically easy to apply and mill. They are polymerized at a much higher density, under higher pressure and temperature than conventional composite resins, resulting in superior wear resistance. When comparing direct composite applications to millable composite CAD/CAM blocks, the blocks are free from common issues, such as polymerization shrinkage and residual monomers (24). Their elastic modulus is close to that of a real tooth, and the wear caused on the opposing tooth is considerably less than that caused by ceramics (68). Restorations milled from composite blocks can be used as temporary crowns with a service life of up to 3 years. The flexural strength is 80 MPa (58).

Composite CAD/CAM blocks first appeared in the market under the name **Paradigm MZ100** (3M ESPE, St. Paul, MN, USA). They are easily conformable to the mouth. It contains 85% zirconium silica fillers by mass. The flexural strength is 157 MPa (20). In addition to Paradigm MZ100, other composite blocks available on the market include Tetric CAD (Ivoclar Vivadent, Liechtenstein), **LuxaCam Composite** (LUXA) (DMG; Hamburg, Germany), and **Grandio Blocks** (VOCO GmbH, Cuxhaven, Germany). **Tetric CAD blocks** were filled with 70% barium glass and silicon dioxide particles. The flexural strength is 273.8 MPa. They are usually offered as HT, high-translucency blocks. They are preferred for small permanent restorations. The flexural strength of **LuxaCam Composite** material is 164 MPa. They are preferred for long-term, permanent restorations. Grandio Blocks, on the other hand, contain a high percentage of nanohybrid filler, 86% (16). In other words, **Grandio Blocks** is a CAD/CAM composite block with the highest filler ratio. Compared to Paradigm MZ100, it offers significantly better aesthetic performance. In terms of elastic modulus, it has a more rigid structure than other composite blocks.

13. Polymer blocks

a) PEEK

Polyether ether ketone (PEEK) is increasingly used with CAD/CAM technology due to its versatility. It is suitable for various applications, including frameworks for fixed prostheses (up to two units), posts, implant-supported restorations, abutments, healing caps, and bars for implant prostheses (69, 70). In addition to being lightweight and durable, the fact that it is metal-free enhances its aesthetic acceptability among patients. This material, which is reported to be non-allergenic, is also used in skeletons produced using CAD/CAM technology (71). Its color in pure form is grayish brown. Although color stabilization can be achieved by adding various fillers, it is not recommended for anterior restorations (72).

Other PEEK blocks on the market include **Copra Peek** (Whitepeaks Dental Solutions, Wesel, Germany), **Ceramill PEEK** (Amann Girrbach, Koblach, Austria), and **BIOHPP** (bredent GmbH & Co. KG, Senden, Germany).

b) PMMA blocks

This material consists of filler-free methacrylate monomers and has low mechanical strength. Therefore, it is used to make temporary crowns that can be used for 6 months to 1 year (73). It is easy to produce using CAD/CAM systems. Since it is a soft material, milling is much faster than with other materials (58). Telio CAD (Ivoclar Vivadent, Liechtenstein) and Sintodent (Sintodent S.r.l., Rome, Italy) are the most common manufacturers of PMMA blocks (1).

In dentistry, CAD/CAM enables faster, more reliable, and aesthetically pleasing results. Various CAD/CAM materials stand out in different aspects. Ceramics such as zirconia and lithium disilicate draw attention with their aesthetic and mechanical properties, while PEEK and composite materials offer significant advantages in terms of biocompatibility. With the continuously evolving technology in digital dentistry, the variety and performance of CAD/CAM materials will further increase, and innovations in this field will significantly improve both patient satisfaction and clinical efficiency.

14. Conclusion

Advances in CAD/CAM technology have profoundly changed restorative and prosthetic dentistry, and clinicians today can choose from a broad spectrum of block materials, ranging from metal alloys and feldspathic ceramics to polycrystalline oxide ceramics, nanoceramics, hybrid ceramics, and zirconia-reinforced lithium silicate glass ceramics. No single material is ideal for every clinical situation: glass-based ceramics stand out with their superior optical properties in the anterior region and low-stress areas, whereas high-strength polycrystalline ceramics are preferred for posterior restorations and long-span frameworks, and hybrid materials, whose elastic moduli are closer to that of dentine, offer advantages in terms of millability, repairability, and reduced wear of the antagonist teeth. Therefore, successful clinical outcomes depend on selecting the material based on the indication, the patient's aesthetic expectations, occlusal loads, and the surface treatment and cementation protocols recommended by the manufacturer. Long-term clinical studies on current materials are needed to support the promising short-term results reported in the literature and to guide evidence-based material selection.

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