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CAD/CAM technology in dentistry

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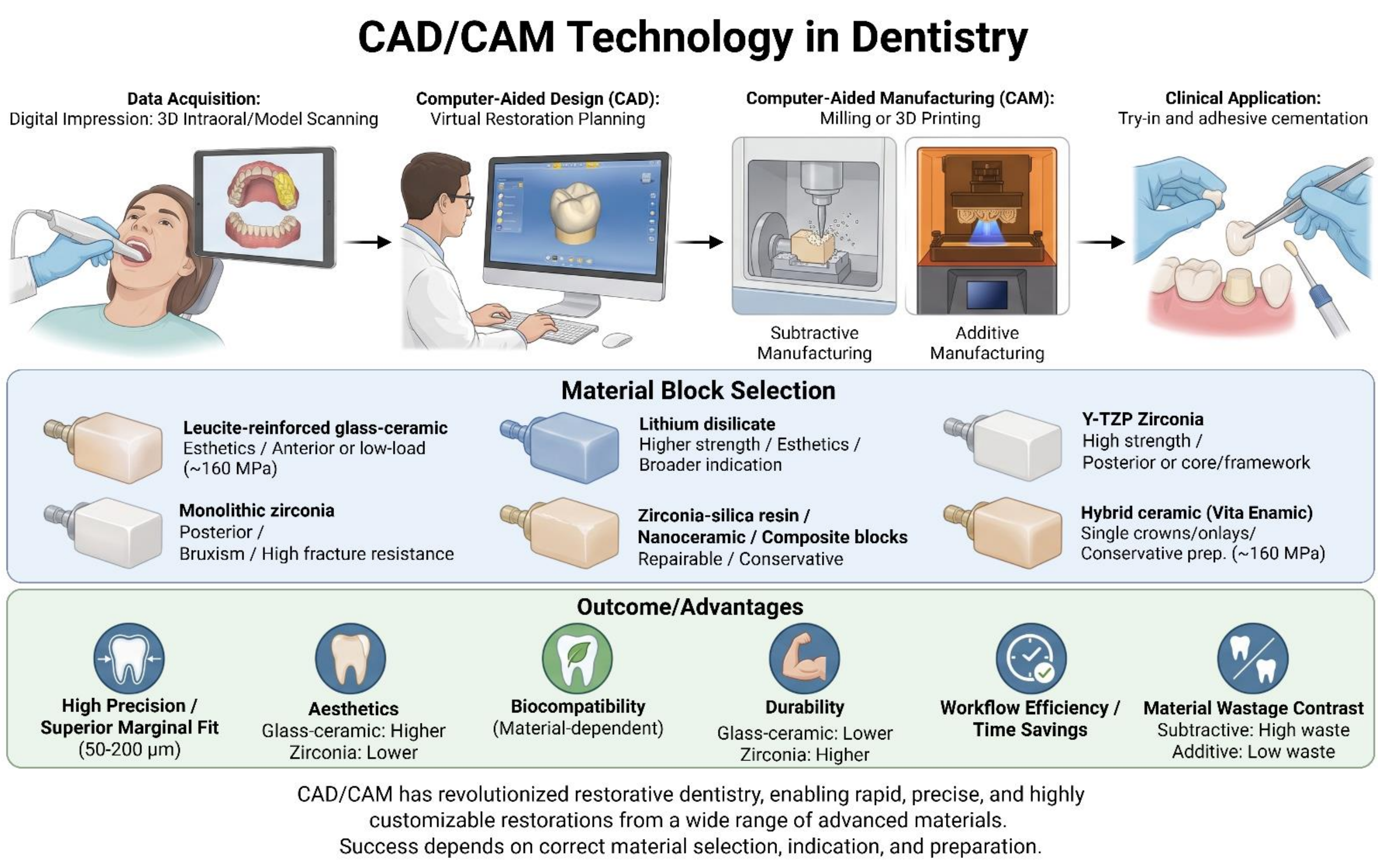
Abstract

The remarkable advancement of dental materials, treatment techniques, and prosthesis manufacturing processes has elevated computer-aided design and manufacturing (CAD/CAM) systems to a new level of clinical capability. Since its introduction to dentistry in the 1980s—beginning with the chairside CEREC system and the Procera framework concept—CAD/CAM has reshaped contemporary practice by enabling aesthetic, durable, and reliably reproducible restorations while transforming the way laboratories design and fabricate both framework (substructure) and monolithic restorations. Because the production stages are tightly controlled and the material blocks are industrially processed, modern CAD/CAM materials also offer improved structural properties—reduced microporosity, greater homogeneity, and lower firing shrinkage—relative to conventionally processed ones, while reducing laboratory steps, working time, and the overall error rate. This narrative review examines the principal CAD/CAM restorative materials, the digital data-processing workflow, and restoration production methods, together with their influence on marginal fit. The main material classes are described—leucite- and lithium-disilicate-reinforced glass ceramics, yttria-stabilized tetragonal zirconia polycrystals (Y-TZP) and monolithic zirconia, resin-matrix and nanoceramic blocks, composite blocks, and hybrid ceramics such as Vita Enamic—with their compositions, mechanical properties, indications, and limitations, including flexural strengths ranging from approximately 160 MPa for glass ceramics to substantially higher values for zirconia. The data-processing stage, comprising direct intraoral and indirect model scanning followed by computer-aided design of a virtual model, is reviewed, along with the two production routes: subtractive milling from prefabricated blocks and additive fabrication by selective laser sintering and 3D printing, which minimizes material waste. Marginal adaptation is discussed as a key determinant of restorative success, with reported clinically tolerable misfit values of 50 to 200 µm and CAD/CAM milling shown to provide superior marginal conformance to conventional techniques. Overall, CAD/CAM workflows offer measurable gains in material quality, accuracy, and efficiency over conventional methods, although optimal outcomes depend on correct material selection, appropriate indication, and proper tooth preparation.

Keywords: CAD/CAM, dental ceramics, monolithic zirconia, intraoral scanner, marginal adaptation, digital workflow

Graphical abstract



1. Introduction

Both fixed and removable dentures are made to accommodate patients' demands in order to preserve tissue health and improve the patients' chewing function. The development of dental technology has led to the production of prostheses that are specifically tailored to each patient's needs. High-strength ceramic systems have been adopted as patients' aesthetic requirements have increased. These materials were previously thought to have a narrow range of uses, be challenging to create in a lab, and be incapable of withstanding intraoral stresses. A new era in dental material processing and variety has been brought about by CAD/CAM (1, 2).

Since designing and manufacturing dental equipment was easier than for industrial products, CAD/CAM technology was introduced in the dentistry industry in the 1980s. The overall cost, working time, simplicity of manipulation, and design of customized restorations were determined to be more feasible using CAD/CAM technology than with routine laboratory work (3, 4). Using a numerically controlled lathe, Dr. Duret was able to produce crowns based on their occlusal morphology in the 1970s after taking an intraoral optical impression of the abutment tooth and designing the restoration based on functional movements (4).

The first commercially available CAD/CAM system was developed by Dr. Moermann in Switzerland in the 1980s. An intraoral camera was used to take impressions at the patient's chairside, the restoration was planned using a ceramic block, machined, and delivered on the same day (CEREC® 1) (5).

Due to the high cost of gold, Dr. Andersson used CAD/CAM technology to design restorations using titanium (Procera AllTitan), zirconium oxide (Procera AllZircon), and aluminum oxide (Procera AllCeram) substructures (6).

With the use of CAD/CAM technology, data can be gathered in a computer environment, suitable designs can be made using the data, and ceramic blocks can be produced in a milling machine in compliance with the designs. This system comprises an optical camera, computer, and water-powered milling unit (7). The CAD/CAM technology eliminates the issues of microporosity, homogeneity, and shrinkage during high-temperature firing that are present in other systems because the blocks to be used in the restorations are obtained uniformly. Additionally, time and money are saved when laboratory procedures are reduced. Both physicians and patients greatly benefit from reducing the error rate (8). Inlay, onlay, partial crown, full crown, and bridge systems, laminate veneers, substructure of removable partial dentures, and the design and manufacture of stents for implant surgery are just a few of the many indications that are currently covered by CAD/CAM systems. Additionally, abutment, crown-bridge, and hybrid prosthesis frameworks for implant-supported prostheses are designed and manufactured using CAD/CAM technology. Currently, many CAD/CAM systems are used in dental offices (9, 10).

The variety of CAD/CAM ceramic restorative systems is always changing to satisfy the increasing need for restorations that are aesthetically pleasing, biocompatible, and long-lasting. For individual and complex tooth-supported restorations, the CAD/CAM machinability of narrow restoration margins and high material-specific margin stability offer a standardized manufacturing process that guarantees a dependable, predictable, and cost-effective workflow (11, 12).

With patient-friendly technology that fabricates dental restorations from a range of materials, such as metal, wax, composite resins, and ceramics, using intraoral scanners and laboratory/chairside milling units, CAD/CAM is expanding and becoming an essential service in dentistry (6, 7). Comparing these materials with restorations made using conventional and additive manufacturing techniques may reveal differences in their quality. When selecting materials and production processes, it is critical to comprehend how these attributes vary (11).

Numerous CAD/CAM systems, including Cerec, Duret, Celay, Procera, Cercon, Cicero, and Lava systems, have been developed since 1984. Over the past 20 years, the use of dental CAD/CAM systems has increased, and they are currently widely used (12, 13).

2. Materials used in CAD/CAM systems

2.1 Glass-ceramics reinforced with leucite

Blocks of leucite-containing ceramics created using conventional techniques are now available for use in CAD/CAM systems. The leucite crystal phase, which has a particle size of 1 to 5 µm, constitutes 30% to 40% of the silicate glass matrix volume. The semi-translucency and wear effect are comparable to those of natural teeth, and the flexural strength is approximately 160 MPa. It is suitable for anterior and posterior single-tooth restorations, such as laminate veneers, crowns, and partial crowns (13, 14). There are two types of blocks available in the market: Paradigm™ C (3M ESPE, St. Paul, MN, USA) and IPS Empress CAD (Ivoclar Vivadent, Schaan, Liechtenstein). Polychromatic variants of IPS Empress CAD blocks are also available (IPS Empress CAD Multiblocks). The fluorescence transitions between the dentin and incisal regions of these blocks are extremely realistic. Because of their high luster, low-translucency blocks are favored for larger restorations (15).

2.2 Glass ceramic reinforced with lithium disilicate crystals

Lithium disilicate crystal-reinforced glass ceramic was created in 2005 specifically for CAD/CAM machining. Lithium disilicate crystals comprise 70% of the substance. Due to the material's fragility and difficulty in milling, these blocks undergo partial crystallization at 850 °C (9, 10). Veneers, crowns, inlays, onlays, three-unit bridges without molars, hybrid abutments, the superstructures of these abutments, and veneers with zirconium oxide substructures are among the indications. Distinctively blue IPS e.max CAD blocks (Ivoclar Vivadent, Schaan, Liechtenstein) are milled in the soft intermediate phase. Their aesthetic qualities of shade, translucency, and luster are attained when they are fully crystallized (15, 16).

The blocks of this group were separated into three categories based on the color characteristics of each group. Because of its chameleon effect and aesthetic qualities, HT blocks are highly translucent. LT blocks are not very translucent. Medium-translucency blocks are used when using the layering approach to mask discolored teeth. Full anatomical crowns are made with LT blocks, while inlay and onlay restorations are made with HT blocks (14-16).

2.3 Yttrium-tetragonal zirconia polycrystalline ceramics (Y-TZP)

Zirconia has been used in dentistry owing to CAD/CAM technology. There are two methods used to produce zirconia. Fully sintered blocks are formed by the system's milling unit, and restorations are created, or semi-sintered blocks are molded by milling and fully sintered at high temperatures. CERCON (DeguDent, Hanau, Germany), CEREC (Dentsply Sirona, Bensheim, Germany), LAVA™ (3M ESPE, Seefeld, Germany), and Procera (Nobel Biocare, Gothenburg, Sweden) are the most widely used CAD/CAM systems for milling semi-sintered zirconia blocks. People with parafunctional habits, such as bruxism, winged bridge prosthesis designs, deep bite cases, and insufficient occlusal space, are not advised to use Y-TZP blocks (1, 5, 6, 7).

Monolithic zirconia ceramic restorations, on the other hand, have recently entered the market, particularly for usage in the posterior group of teeth where masticatory forces are considerable. This material prevents porcelain chipping, which is commonly observed in zirconia-based restorations (7).

2.4 Monolithic zirconia ceramic blocks

Monolithic zirconia is partially stabilized with yttrium. Consequently, the material exhibits a high flexural strength. The non-porous structure, superior biocompatibility, and sophisticated optical qualities of monolithic zirconia provide it with an aesthetic appeal similar to the translucent, natural appearance of teeth. Therefore, veneering porcelain is not necessary (2, 3). Nevertheless, their optical qualities remain inferior to those of glass-ceramics, and the only way to attain a natural tooth color is to apply specific staining treatments. Because of their excellent fracture resistance, they can be used when the interocclusal distance is insufficient. They can also be used in posterior restorations since they can still provide adequate strength and resistance with an occlusal thickness of 0.5 mm. Patients with bruxism or other excessive occlusal stress are advised to use monolithic zirconia. Significant benefits come from monolithic zirconia restorations created solely using CAD/CAM technology (4-6).

BruxZir solid zirconia (Glidewell Laboratories, Newport Beach, CA, USA), Zirkonzahn (Zirkonzahn GmbH, Gais, Italy), and Lava all-Zirconia (3M ESPE, Seefeld, Germany) are the blocks available on the market for the creation of monolithic zirconia restorations (6, 7).

2.5 Zirconia-silica ceramic added to resin matrix

Zirconium silicate, silica powder, UDMA, and TEGDMA constitute the organic composition. Shofu Block HC (Shofu Inc., Kyoto, Japan) is inherently translucent and fracture-resistant, and is fabricated using CAD/CAM. This ceramic is used to create long-lasting and aesthetically pleasing restorations. Inlay, onlay, and implant-borne restorations can all use them (5, 6).

Paradigm MZ100 blocks are a zirconia-silica ceramic with enhanced mechanical properties because they complete their polymerization during the manufacturing phase. They contain extremely fine particles of zirconia-silica ceramic. Less tooth preparation is required to complete the restoration, and they are simple to fit. Patients who suffer from bruxism may use them (5).

2.6 Nanoceramic blocks

UDMA-containing resin and ceramic particles comprise 80% of nanoceramics. Lava Ultimate (3M ESPE, St. Paul, MN, USA) and Cerasmart blocks (GC Corp., Tokyo, Japan) are two examples. The potential leakage of monomers such as bisphenol-A raises concerns about the biocompatibility of resin-containing items. If the prosthesis develops a crack, these materials can be directly fixed. Short bridges or single tooth restorations, ideally in the posterior region, can be completed with nanoceramic material. Compared to traditional ceramics, the matrix polymer is more likely to wear against opposing teeth because it deteriorates more quickly (6, 8, 10).

2.7 Composite blocks

Zirconium-silica filler constitutes 85% of these blocks by weight. The representative polymer composite block is Paradigm MZ100 (3M ESPE, St. Paul, MN, USA). It comes in six colors and is radiopaque. In the mouth, it is simple to polish and conform. It is repairable (4, 5).

2.8 Hybrid ceramics

Hybrid ceramics were developed to overcome the limitations of the two material classes they combine. The better aesthetic appearance, durability, biocompatibility, and color stability of porcelain restorations are just a few of their many advantages. Additionally, there are drawbacks such as increased dental tissue loss, tooth abrasion, and opposing tooth fragility. Fine cracks and fractures can occur during production, particularly when thin edges, such as margin areas, need to be sculpted. Furthermore, over time, fractures in the dentin tissue may result from the difference in bending strength between porcelain and dentin tissue in restorations, including overlays, inlays, and endocrowns. Furthermore, intraoral repair has a poor chance of success if porcelain restorations break in the oral environment, particularly if the fractures are extensive (1, 2). Polymerization shrinkage, low mechanical characteristics, and poor wear resistance are some of the drawbacks of composites. Materials that hybridize porcelain and composite in different chemical structures have been introduced for clinical use to take advantage of the aesthetic qualities of porcelain material as well as the benefits of composite resins. These ceramics, which are categorized in the literature as resin-containing ceramics, have advanced qualities such as outstanding edge conformability, easy workability, and fracture resistance (2). Resins can be used in tooth-supported restorations (crowns, onlays, inlays, and veneers) and single-member implant-supported restorations. Glass-ceramic and nanoceramic blocks are more durable than hybrid blocks. They are therefore not advised for use in bridge or implant-supported crown restorations that need to be very durable, when parafunctional habits are present, or when the proper distance for restoration cannot be provided (2-4).

The first ceramic CAD/CAM hybrid material was Vita Enamic (Vita Zahnfabrik, Bad Säckingen, Germany). The structural characteristics of Vita Enamic include greater flexibility, improved machinability, decreased hardness, and decreased brittleness. Similar to enamel and dentin, it has a flexural strength of approximately 160 MPa and an elastic modulus of about 38 GPa. It has a higher fracture strength than complete ceramics. The network structure's integrated polymers prevent cracks from forming. CAD/CAM technology simplifies the preparation process. Only single tooth restorations can employ Vita Enamic (4-6).

3. Data processing in CAD/CAM system

Inlay, onlay, laminate veneer, partial crown, full crown, and bridge systems, as well as the skeletal structures of removable partial dentures, the design and manufacture of stents for implant surgery, and the fabrication of maxillofacial prostheses are just a few of the many indications for CAD/CAM systems. The workflow consists of gathering and documenting information, creating the repair design using computer-aided design (CAD), and fabricating the restoration (CAM) according to the standard guidelines (7-9).

There are two methods for performing three-dimensional scanning: directly in the mouth and indirectly on the model. Both approaches include meticulously documenting the preparation and transferring it to a computer, where the design is created. The preparation, proximal contacts, and occlusion records acquired using the scanner are merged in a computer environment and transferred to the intraoral system throughout the design process. Computer software is then used to transform the digital data into a virtual model comprising points. Once the restoration design is completed, the CAD program converts the virtual model into a set of instructions that operate the CAM unit (10, 11).

4. Production of restorations

There are two types of production in CAD/CAM technologies: additive and subtractive manufacturing. The 'subtractive approach' of CAD/CAM systems in the past only permitted the production of the restoration by milling it from prefabricated blocks using milling cutters, diamonds, or diamond discs. Approximately 90% of the material was wasted and removed using this procedure. Production by addition was later incorporated into the systems. Selective laser sintering is a technique for creating metal or ceramic restorations. With this technique, the restoration's computer design follows a similar procedure to the cutting process in modern CAD/CAM systems; however, the material in the metal powder or ceramic pool is sintered with constant additions throughout the process sequence to complete the restoration rather than being cut. Consequently, no material is wasted or left over. Certain CAD/CAM systems (Procera, Nobel Biocare, Gothenburg, Sweden) combine subtractive and additive techniques (5-9).

3D printing systems, sometimes referred to as solid free manufacturing, have been developed in the field of additive manufacturing. This technique is based on layering liquid or powder material to create the repair. As a result, no unnecessary material is wasted. 3D printing is a cutting-edge dental procedure that makes it possible to accurately create intricate and sophisticated structures (13, 14).

5. Marginal harmony/fit in CAD/CAM restorations

Four characteristics are essential for a successful dental restoration: mechanical durability, aesthetics, biocompatibility, and marginal adaptability. Marginal incompatibility can increase the risk of caries in abutment teeth, change the distribution of microbiota, and enhance plaque accumulation (16). Passive fit prevents the abutment-screw-implant assembly and the supporting bone from being overloaded and offers mechanical and biological balance in implant dentistry.

There is disagreement over the greatest clinically tolerable marginal misfit based on the available scientific data, with reported values varying from 50 to 200 µm. The fracture resistance of the crown and its porcelain is reduced as the marginal misfit values increase (17, 18). The distance between the restoration and the abutment decreases, and the internal and marginal fit of the restoration improves as the impression accuracy and clarity increase (19).

According to studies, CAD/CAM milling offers superior marginal conformance when compared to traditional techniques (16-19).

Although CAD/CAM technology has already revolutionized dentistry, it still requires advancements in data processing, scanning procedures, fabrication processes, and material handling to be a competitive substitute for conventional fabrication techniques. To improve internal and marginal compatibility, guarantee long-term success, and enhance patient comfort, CAD/CAM restorations should be the initial course of treatment.

6. Conclusions

To select the best system for CAD/CAM restorations, it is critical to have a thorough understanding of the systems and their benefits and limitations. Fixed prosthetic treatments that satisfy functional, cosmetic, and biological needs are being created and developed in CAD/CAM systems by choosing the best ceramic systems with the right indication and proper tooth preparation.

The variety and caliber of materials used in dentistry have significantly improved owing to CAD/CAM technologies. Dental labs have evolved from manufacturers to contemporary computerized manufacturing facilities because of CAD/CAM technology. The application of virtual waxing has made prostheses more dependable, pleasant, and quick. With CAD/CAM technology, computer-generated long-term temporary restorations can be replicated to the final prosthesis using a different material since the restorations can be altered to meet the patient's functional and cosmetic needs. Finally, CAD/CAM technology enables the highly accurate machining of novel materials, such as titanium and high-performance ceramics. However, it is also important to note some drawbacks of this manufacturing process. Some uses are restricted by software and manufacturing processes, and the high cost of these devices may be beyond the means of smaller laboratories. CAD/CAM technology, which has already revolutionized dentistry, is expected to replace more traditional methods of producing dental restorations.

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