14 Restoring Dental Implants

Computer-aided design/computer-aided manufacturing (CAD-CAM) technology was originally developed and commercialized for industrial manufacturing but is of growing importance within dentistry. In fact, it has virtually revolutionized the fabrication of crowns and bridgework and has become the preferred method of making crowns and fixed partial dentures. In contrast to conventional dentistry, with an in-house CAD/CAM system, the dentist typically can fabricate and lute a prosthesis the same day.

Continuing developments in computer-based dental technologies have provided the dental profession with new opportunities for improved clinical workflow and, as indicated above, facilitated manufacturing of dental restorations. Over the last decade or so, CAD/CAM of dental restorations became an established fabrication process, especially for all-ceramic restorations. With the more recent introduction of intraoral scanning systems, digital techniques are now capable of replacing conventional treatment workflow. Numerous clinical trials have demonstrated that single-tooth restorations fabricated in a completely digitized workflow have a clinical fit that is equal to, or better than, conventionally fabricated restorations. Further, when compared with conventional impressions, digital impressions can be more time-efficient and improve the treatment comfort for patients, and clinicians.

In addition to ongoing improvements in digital technologies, new restorative materials that are optimized for CAD/CAM processing have led to further advances and optimization of digital workflows. Biomaterials research in recent years has focused on the development of materials that offer a combination of adequate translucency, improved mechanical strength, and optimized timesaving machining.

The ADA Practical Guide to Dental Implants, First Edition. Luigi O. Massa and J. Anthony von Fraunhofer.

CAD/CAM Dentistry

Although most dentists may be familiar to some degree with CAD/CAM dentistry, a brief discussion might be useful here. This is because the predominant trend in dental implantology is to take maximum advantage of digital technology in almost every aspect of the process other than the physical surgical implant placement.

There are numerous systems for digital restoration processing and although specific details vary with each system, all rely upon comparable basics underlying their operation and all CAD/CAM systems contain three components:

- Digital scanner or imaging system
- Software to process the scanned image into data that allows fabrication of the prosthesis
- Hardware that fabricates the prosthesis from the data.

The overall process starts from a three-dimensional (3D) image used by computer software to design the restoration. Imaging systems can now record images of the adjacent and opposing dentition as well as bite registration data. After the information is uploaded into the computer, a data file is assembled which, together with the computer's internal library of tooth shapes, is used to design the restoration.

After the implant and the healing cap are placed and the operative area has healed to the point that there is adequate osseointegration of the implant body, an image or scan is taken of the implant (or implants) and the adjacent/abutment teeth utilizing an intra-oral scanner (Fig. 14.1). Some clinicians, however, will scan the operative area at the time of implant placement to allow for restorative planning.

This image or digital impression is digitized by the recording software in the scanner and the data fed into a computer. Proprietary software then creates a virtual restoration, i.e., a prosthesis that replaces the missing dentition (Fig. 14.2). In technological terms, this process is termed *reverse engineering* and constitutes the CAD part of the overall operation. The software transmits this virtual data to a milling machine where the prosthesis is machined out of a solid (monolithic) block of ceramic or composite resin (Fig. 14.3). The latter process is the CAM part of the operation. Stains and glazes can be fired onto the surfaces of the milled ceramic crown or bridge to correct the otherwise monochromatic appearance of the restoration, Figure 14.4. The restoration is then adjusted in the patient's mouth and cemented or screwed in place.

Figure 14.1 Intra-oral scanner.

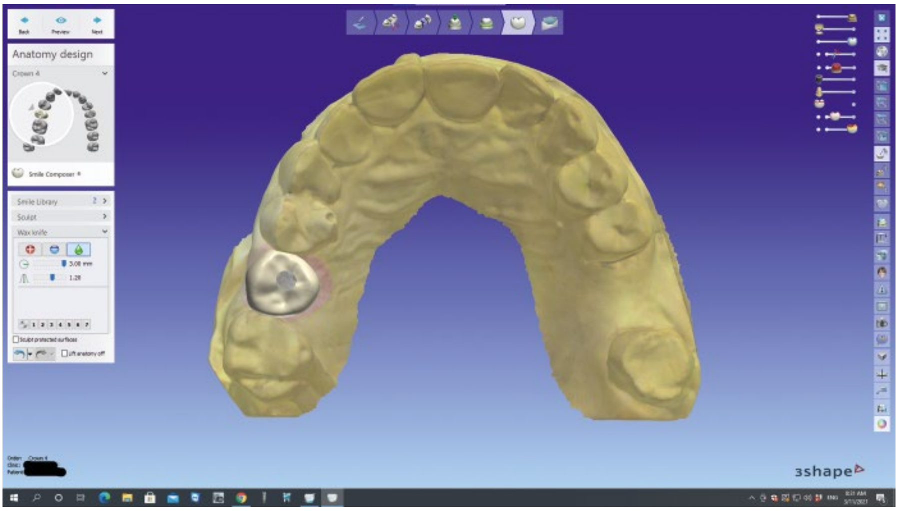

Figure 14.2 A digital image of a scanned cast.

Figure 14.3 A completed CAD/CAM fabricated restoration.

The CAD/CAM systems can either be used chair-side with the restoration fabricating hardware in an adjoining laboratory or the digital data is fed to a remote production center.

Typically, CAD/CAM dental restorations for implants are milled from solid (monolithic) blocks of ceramic or composite resin closely matching the basic shade of the restored tooth or adjacent teeth. Metal alloys may also be milled or digitally produced, often for the posterior teeth in patients with heavy bites and/or bruxers. The choice of restorative material is discussed below.

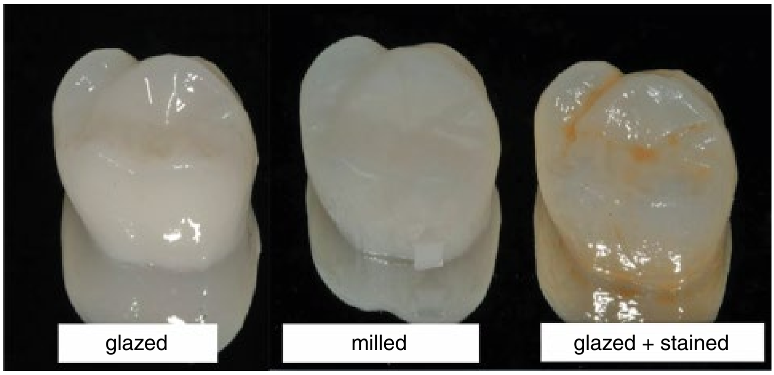

Figure 14.4 Finishing and characterization of a CAD-CAM ceramic restoration (*Source:* Courtesy of Sirona Dental Inc., Charlotte, NC).

It should be mentioned that additive manufacturing (once known as rapid prototyping) has now entered CAD/CAM dentistry. At first, additive manufacturing, also known as *3D printing*, was almost an experimental laboratory approach to fabricating dental restorations but now there is increasing interest in the scope of its applicability in dentistry. The underlying concept of additive manufacturing is in complete contrast to the *subtractive manufacturing* process of milling the object (prosthesis) from a solid block.

The term *3D printing* is commonly applied to all types of additive manufacturing, but this term should refer only to fabricating objects through the deposition of a material using printer technology such as a printer head or precision spray nozzle. In fact, "additive manufacturing" strictly refers to the construction of objects from 3D data, usually layer-by-layer until fabrication is complete. The three most common additive manufacturing methods are Selective Laser Sintering (SLS), Direct Metal Laser Sintering (DMLS) and Selective Laser Melting (SLM). SLS and DMLS are basically the same process in that the applied laser beam coalesces the particles in the deposited material through partial fusion but without achieving a full melt. When this sintering methodology is used for non-metallic materials, it is commonly referred to as SLS whereas DMLS is the term used for processing metallic particles. In contrast, with SLM technology, the metal particles are fully melted and then cooled to consolidate the constructed object. Although the two processes are somewhat similar, the major difference is that with SLM, the processed objects do not have the porosity found with DMLS because the complete melting/cooling cycle of the deposited particles ensures greater solidity and density of the fabricated object.

Advantages and Drawbacks of CAD/CAM Technology

Many commercial CAD/CAM systems are available, including the CEREC (CERamic REConstruction), Planmeca, E4D, 3Shape Dental and Cera systems. Examples of chair-side and laboratory CAD-CAM systems are shown in Figs. 14.5 and 14.6. In addition to the increasing variety of CAD/CAM systems available, continuing technological advances include increasingly versatile software, direct

Figure 14.5 A CAD CAM chairside system (*Source:* Courtesy of E4D).

Figure 14.6 A CAD-CAM laboratory system (*Source*: Courtesy of Planmeca).

digital recording of the dentition and CAM units with greater speed and accuracy in milling operations.

Modern dental CAD/CAM technologies based on integrated implantology software enable the dentist to plan the implant treatment and implement the trephining precisely using a surgical guide (Fig. 14.7). Combining CAD/CAM software with 3D-imaging data encourages greater safety and helps prevent problems arising from any intraoperative mistakes.

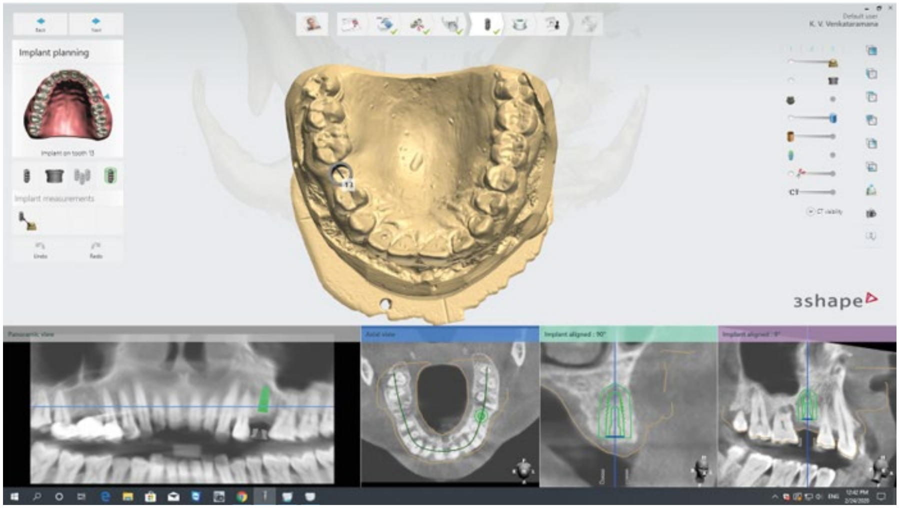

Figure 14.7 Computer-generated planning of implant placement.

Ideally, the CAD/CAM restoration should fit perfectly but CAD/CAM restorations may often require some adjustment to ensure an exact fit with the correct occlusion, particularly with regard to abutment teeth and implant abutments as well as opposing dentition. Fit accuracy can vary with the CAD/CAD system utilized and from user to user, with some systems attaining higher standards of accuracy than others and greater accuracy with more experienced operators.

In general, milling all ceramic restorations from a monolithic block and layering with “enamel” ceramics enables better blending with the surrounding dentition for an esthetic outcome and, ideally, the restored implant will have an anatomically and functionally perfect restoration. CAD/CAM has improved the consistency of dental prostheses and standardized the production process. It has increased laboratory and practice productivity while providing the dentist with an opportunity to work with new materials with a high level of accuracy. Further, digital dentistry enables the dentist to send electronic impressions to the lab so that restorations are milled from a block of ceramic, and these restorations will have fewer flaws and are produced in minutes rather than hours (Fig. 14.8). However, CAD/CAM requires a large initial financial outlay and occlusal detail may often require manual amendment to achieve optimum results. Further, the dentist’s technique and operative approach may need to be adapted to the demands of CAD/CAM and milling technology. Typically, this includes correct tooth (abutment) preparations with a continuous preparation margin, typically in the form of a chamfer so that it is recognizable by the scanner. Further, shoulder-less preparations and parallel walls should be avoided as well as preparations having rounded incisor and occlusal edges to avoid stress concentrations.

It must be stressed that there is a learning curve with CAD/CAM technology so that “one-visit” dentistry may not always be possible at first, particularly if multiple post-fabrication adjustments are necessary. Modifying the computer-generated restoration design (the CAD phase of the operation) to achieve optimal margins

Figure 14.8 Completed CAD/CAM generated full-arch restoration.

and avoid brittle knife edges with ceramic restorations requires practice, experience, and skill.

There are many advantages to using digital restorations for implants, notably significantly faster delivery of the restoration compared to traditional laboratory-fabricated restorations and potentially fewer patient visits. Further, with monolithic ceramic restorations, minor adjustments are relatively easy to make without the need for reglazing or heat treatment and/or recasting of metal crowns and bridgeworks. It is also possible to refine margins, contacts, and so forth on the CAD pattern before the finished data file is transmitted to the CAM unit for processing.

However, depending upon the system used and the particular case, digital restorations may be approximations rather than exact matches to the patient's dentition and an accurate bite cannot always be guaranteed. As a result, esthetics may be compromised and there is often a risk of an unbalanced occlusion. These effects arise because the technology for CAD-CAM restorative procedures cannot always guarantee good marginal fit and, unfortunately, the margins of ceramic and resin restorations cannot be swaged like gold crowns. However, it must be stated that advances in dental CAD/CAM technology are occurring on an almost daily basis due to software updates and improvements, more comprehensive data banks and improved milling technology within CAM units.

Restorative Materials

Although implants may be restored with cast and metal-ceramic (porcelain-fused-to-metal or PFM) crowns and prostheses, most digital implant restorations are fabricated from high-strength ceramics today. In addition, high-strength composite materials based on restorative resins have been developed specifically for CAD-CAM applications.

Depending on the selected restorative material, however, CAD/CAM-generated restorations can have esthetic limitations, often depending on whether they were created at the dental practice or outsourced to a remote dental laboratory. Nevertheless, contingent on the requirements of the dentist and/or the skill of the technician, CAD/CAM restorations can be layered to give a deeper more natural look, improving esthetics and avoiding a monochromatic appearance.

There are also different radiological ramifications associated with each restorative material. If the CAD/CAM restorative material is zirconia, then the restoration will be radio-opaque, comparable to metal restorations. However, alumina, lithium disilicate and some composite resin materials are radio-lucent, a property that enables the dentist to track potential carious attack on the natural dentition.

Many ceramic digital restorations have high strength, natural translucency and fluorescence combined, usually, with good fit. Further, with some materials such as leucite-reinforced glass–ceramics, restorations can be polished and characterized, (Fig. 14.3). Ceramic restorations also have the major advantage of outstanding chemical resistance and may suffer less from certain problems such as plaque build-up and staining found with other materials. On the other hand, some materials do not possess high flexural strength or fracture toughness and they can cause wear of opposing dentition, as discussed below. It should be mentioned that because CAD/CAM restorations are machined from monolithic material, they are generally stronger than those that are incrementally constructed, e.g., porcelain restorations and multi-layered composites.

As mentioned above, implant crowns in the past were primarily made from PFMs but the modern trend is to use more esthetic all-ceramic crowns made from lithium disilicate or zirconia,[a] with lithium disilicate being preferred in esthetically critical cases. However, little is known about the long-term performance of this material as an implant crown with a screw access hole.

Zirconia-based crowns and prostheses have been used as an alternative to PFM restorations because they are metal-free and have a white color. In fact, zirconia-based restorations are the favored treatment for extensively compromised teeth because of the material's biocompatibility and excellent mechanical properties. On the other hand, because of the material's opacity, zirconia copings often must be veneered with porcelain to improve esthetics but this, unfortunately, results in a bi-layer restoration. Cohesive fracture within the veneering porcelain is one of the most common clinical failures found in veneered zirconia restorations but this problem is averted by CAD/CAM manufacture of zirconia monolithic crowns. Not only can the prostheses be milled in anatomical contour with different levels of translucency, it is possible to improve the esthetics of monolithic restorations by using some staining techniques. As discussed below, monolithic zirconia crowns seem to cause more wear clinically to the opposing enamel than human enamel itself and even other restorative materials and this problem is exacerbated when post-installation occlusal adjustments are required. This is because occlusal adjustments with a diamond bur significantly increases surface roughness of the zirconia which, in turn, increases wear of both the agonist and antagonist surface. Further, inadequate polishing of the zirconia occlusal surface will result in densely distributed cracks throughout that surface which may compromise mechanical properties. This issue is theoretically a problem not just for zirconia but with all glass–ceramics.

CAD-CAM composite resins possess high flexural strength and fracture toughness and their wear characteristics are comparable to those of enamel, obviating damage to opposing dentition. They are easier to finish and polish than ceramics and can be easily characterized using light-cured composite stains. They also have the advantage that restorations can be repaired in the mouth. Further, because composite restorations have a resin matrix, it is relatively easy for the interior (fitting) surfaces to be treated to facilitate bonding. In contrast, ceramic restorations may require hydrofluoric acid etching and silane treatment prior to adhesive bonding. On the other hand, as with all resin-based restorations, they can be subject to staining and wear in use.

Cement retention compared to screw retention of implant restorations was discussed in Chapter 13, but it should be mentioned here that digital restorations are usually luted with dual-cure adhesives although if sufficiently translucent, light-cured adhesives can be used. Light-cured glass ionomer cements (GICs) and resin-modified glass ionomers (RMGIs) are not recommended for all ceramic restorations because hygroscopic expansion can cause fracture over time.

Studies indicate that, depending on the impression technique and the selected restorative material [1, 2], the marginal gap with digital restorations is typically 60–150 μm, i.e., comparable to those with conventional (cast) restorations [3, 4]. If the luting material can be leached out or worn away, particularly with wide or open margins. With restored implants, the frequency of undetected excess cement depends essentially on the type of cement used. Cements that tend to leave more undetected excess such as methacrylate cements have a higher prevalence of peri-implant inflammation and cause more severe peri-implant bone loss compared to a zinc oxide-eugenol cement. Interestingly, it has been found that there is a significantly greater amount of excess cement in the peri-implant tissue with larger diameter implants.

It is also possible that when a precious or semi-precious metal crown has been cemented to a titanium implant, galvanic corrosion can occur, leading to bone necrosis and implant failure. It should be stated, however, that galvanic corrosion at a mixed metal restoration-abutment junction can also occur with screw-retained prostheses.

Wear and Abrasion

Wear of restorations is a complex phenomenon that can be influenced by several factors including the material's microstructure, environmental effects and patient behavior and characteristics. In general, it is accepted that large differences in surface hardness can be a contributing factor to abrasion and wear. On the other hand, it has been found from studies on veneering porcelain that wear had no direct relation with its hardness, but was more a result of its composition and the particle size and distribution of crystals. In fact, there does appear to be a correlation between surface roughness and wear, with abrasivity being a major contributor to wear when the agonist (or antagonist) has a crystal size less than 5 μm. Research studies indicate wear of alumina surfaces caused by lithium disilicate and zirconia is reduced when the surfaces were polished rather than glazed.

Normally, wear leads to loss of the original anatomy and alteration of the vertical dimension of restorations which, in turn, can result in malocclusion. This may cause physiological and pathological disorders as well as esthetically compromise the restoration. Problems associated with wear-exacerbated malocclusions as well as parafunctional habits and bruxing can lead to loosening of implants, especially in the case of single units.

In the past, there have been various studies that looked at the wear of prosthetic, notably denture, teeth against different antagonists and, generally, unfilled cross-linked polymethyl methacrylate resins exhibited less wear than filled composite resins. This almost counter-intuitive finding suggests that the dentist's decision to prescribe artificial teeth and restorative materials for prostheses should be based on considerations of functionality and esthetics, together with the cost of the material.

A widely used material for CAD/CAM restorations is lithium disilicate, a glass–ceramic material similar to but with a far greater strength than porcelain. Lithium disilicate materials are commonly used to fabricate restorations because of their durability, translucency, and close resemblance to the color of natural teeth. Although lithium disilicate is brittle with low elasticity, it has greater fatigue resistance than feldspathic porcelain and, in clinical use, its mechanical properties are far more predictable when used with at least a 1.5 mm thickness for occlusal surfaces.

However, placing a screw access hole in lithium disilicate crowns results in a significant decrease in load-bearing strength and some suggest that the material should not be used for screw-retained restorations. On the other hand, other studies have found no significant difference in the clinical behavior of screw-retained, cemented, or hybridized screw-retained restorations. The consensus appears to be that whereas lithium disilicate is weakened by a central fossa hole, as indicated by early fractures along the central groove, they are still indicated in areas of minimal loading. Despite cement-retained implant crowns being less expensive, seating passively and are easier to work with, the use of screw-retained implant crowns eliminates possible cement-related complications and permits retrievability should screw loosening occur. Interestingly, the majority of clinician- and patient-assessed success parameters indicate that screw- and cement-retained restorations have comparable clinical performance on implants in the anterior maxilla.

Studies of the clinical performance of ceramic single crowns over 5- and 10-year periods support their application in all areas of the mouth. However, with layered ceramic posterior crowns, most fractures of the core occur early in the lifetime of the restoration and monolithic ceramic systems are probably advisable for posterior crowns. Interestingly, research indicates that tooth-supported crowns had a slightly lower or comparable success rate than implant-supported crowns [5, 6] whereas fixed dental lithium disilicate glass–ceramic framework prostheses (FPDs) were found to have 5- and 10-year survival and success rates that were similar to those of conventional metal-ceramic FPDs [7]. Further, it was noted that neither the cementation mode nor positioning of the restoration impacted restoration survival. The consensus is that lithium disilicate is a reliable material for fabricating restorations, especially for the single-unit restoration. Zirconia-based single crowns with a sintered veneering cap showed promising clinical results on both tooth and implant abutments although the dental implants were more prone to complications. Consequently, high-strength ceramic with a sintered veneering cap can be recommended for both tooth- and implant-supported single crowns in molar regions [8].

In situations where prosthetic crowns are required to have greater strength, the material of choice has been zirconia. Zirconia, however, has esthetic limitations and studies have shown that well-polished monolithic zirconia caused similar or more agonist enamel wear than natural enamel, but this wear was less than that with metal-ceramic restorations. Nevertheless, the high hardness and wear resistance of zirconia may adversely affect opposing natural dentition and other indirect restorative materials, especially when the restoration's surface is not perfectly smooth. As previously stated, monolithic zirconia crowns seem to cause more wear to the opposing enamel than human enamel itself.

In order to address these issues, a new group of machinable ceramics has recently been introduced for CAD/CAM techniques. These high-strength ceramics include zirconia-reinforced lithium silicates (ZLS) such as Celtra Duo and Suprinity with superior esthetics. The reinforcement is achieved through the addition of 8–10 wt.% of zirconium oxide (ZrO_2) to the glass–ceramic. These materials have comparable physical properties to lithium disilicate and strengths some 3X greater than traditional leucite-reinforced glass-ceramics. Further, the presence of ZrO_2 results in a more homogeneous structure to the ceramic. Whether there are differences in wear susceptibility between lithium disilicate and ZLS are unknown currently.

Conclusions

Today, most fixed restorations are fabricated utilizing CAD/CAM technology. The process digitizes a standard impression, a stone cast, or the implant itself. Thereafter, the restoration is designed using a specialized software. The design is then sent to a mill which machines the restoration out of the material of choice. The two most common materials utilized for implant restorations today are zirconia and lithium disilicate. Materials used in CAD/CAM technology for dental restorations have many pros and cons to consider and are rapidly evolving.

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Note

a Yttria-partially stabilized tetragonal zirconia polycrystal (Y-TZP) is frequently referred to as *zirconia*.