ROLE OF COMPUTER AIDED DESIGN AND COMPUTER AIDED MANUFACTURING TECHNOLOGY IN PROSTHETIC IMPLANT RESTORATIONS

Hesham Ibrahim Othman

ABSTRACT

In this review article, the current status of CAD/CAM systems developed around the world is evaluated, with particular focus on the field of ceramic implant abutment. The use of dental CAD/CAM systems is promising not only in the field of prosthetic dentistry, but also in other fields of dentistry. CAD/CAM technology will contribute to the patient’s Health and comfort specially in the aging society.

Keywords: CAD/CAM; Implant; Restoration

The art and science of dentistry has provided significant advancements in dentist’s abilities to treat patients with both simple and complex dental problems. Over the past hundred years, biological improvements and new techniques had been developed to replace missing teeth. Additionally, the past twenty-five years, revolution had been seen in the form of introduction of digital radiology solutions, three-dimensional cone beam tomography, digital impressions, digital models, and computer-aided design and computer-aided manufacturing (CAD/CAM) restorations that are now making their way into the mainstream dental practice. Therefore, the purpose of this review article is to provide an update on the role of computer-aided design computer-aided manufacturing technology currently available for management of prosthodontic patient.

History

Development of dental implant treatment: Osseointegration between bone and titanium surface was discovered when Professor P-I Brånemark and collaborators nearly half a century ago in Sweden tried to extract a pure titanium plate that had been inserted into a rabbit fibula in order to observe the formation of blood cells in the bone marrow. The well-documented fact was that foreign-body reactions, commonly observed as inflammation. This fact did not exist around the titanium plate, and this phenomenon was afterwards named “osseointegration”.

Osseointegration was first applied into a edentulous mandible in 1965. Since then, successful long-term results of implant-supported prostheses have been presented and considered as a routine method in the rehabilitation of partially and completely edentulous jaws.

Range of implant-supported restorations: Implant based restorations can be either fixed or removable, depending on the patient’s desires and its ability to perform adequate hygiene. Also the presence of adequate support achieved by the implants alone without additional support of the soft tissue play an important role in selection of the treatment plane. Misch proposed five prosthetic options for implant dentistry. The first three options are fixed prostheses. These three options may replace partial (one tooth or several) or total dentitions and may be cemented or screw retained. These options depend on the amount of hard and soft tissue structures replaced and the aspects of the prosthesis in the esthetic zone. The other two options of final implant restorations are removable prostheses; they depend on the amount of implant support, not the appearance of the prosthesis.

Development of CAD/CAM in Dentistry

Computer-Aided Design/Computer-Aided Manufacturing systems (CAD/CAM) were applied to dentistry in the 1980s to 90s. The development of CAD/CAM is based around three elements namely; data acquisition, data processing and manufacturing. The data acquisition could be obtained either through taking impression and pouring a model or directly through intra-oral scanners. A 3D can be used to design the restoration such as inlays, onlays, crowns, bridges and supra-structures of implant. A further development in CAD/CAM technologies used in dentistry is the transition from closed to open access systems. Whereas in the past the digitizing, designing and manufacturing came as a closed system, more and more the technology is being opened up and more component parts of CAD/CAM system can be purchased separately. This creates much greater flexibility in that data can be acquired. Van Noort classified CAD/CAM systems according to methods of manufacturing (Table 1).

Table 1: Van Noort classification of CAD/CAM systems

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<th>CAD/CAM Manufacturing</th>
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<td>I. Subtractive Manufacturing</td>
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<td>a. Selective Electron Beam Melting (SEBM)</td>
<td>c. Selective Electron Beam Melting (SEBM)</td>
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1. Subtractive Manufacturing: This technology is based on processes in which milling power-driven machine tools, such as drill presses, saws, lathes, and milling machines are used to mechanically cut the material to achieve the desired geometry under a control of computer program. Thus one start out with a block of material and machine cuts away the bits that
are not wanted. However, this method in fact is very wasteful as more material is removed compared to what is used in the final product.

2. Additive Manufacturing: It is the process of joining materials to make object from 3D model data, usually layer upon layer. This process works by taking a 3D computer file and creating a series of cross-sectional slices. Each slice is then printed one on top of the other to create the 3D objects. One of the most advantages features of this process is that there is no waste. Traditionally additive manufacturing processes started to be used in the 1980s to manufacture prototypes, models and casting patterns. Thus it has its origins in rapid prototyping (RP), Today additive manufacturing describes technologies that can be used anywhere throughout the product life cycle from pre-production (i.e. rapid prototyping) to full scale production (also known as rapid manufacturing). 11-22

CAD/CAM Dental Systems in Prosthetic Dentistry

Duret in 1971, introduced CAD/CAM in restorative dentistry and, in 1983, the first dental CAD/CAM restoration was manufactured. 14 One of the main lines of implementation was the use of prefabricated ceramic mono-blocks. 15 This system has been used mostly for manufacturing of prosthetic fixed restorations, such as inlays, onlays, veneers and crowns. Nowadays there is a greater interest in the CAD/CAM systems for implant-supported prosthesis, as they have been used for the manufacture of implant abutments 11 and diagnostic templates in implant dentistry. 16

1. Digital vs. Conventional Implant Impression: Birnbaum and Aaronson studied the accuracy of the digital impression in tooth-supported fixed prosthesis, they reported that, digital impressions appear to be appealing when it comes to efficiency and patient satisfaction; also, they reported that, manipulation of the intra-oral scanner seems to be more user-friendly than the manipulation of impression materials from the conventional impression. 17 Lee et al. found that the digital impressions are a more efficient technique when compared with conventional impressions for a single implant restoration. 18 A potential benefit of digital impressions on implant components would be the possibility of intervention before the osseointegration has been achieved. In this context, a digital impression could capture the intraoral situation at early stages of osseointegration without the stressing of implant abutment component.

Glassman showed that the digital impression was more efficient than the conventional impression based not only on the amount of time consumed for each impression technique but also on participants’ perception. 19 Even though there was greater number of rescans performed in the digital impression, the rescan time of the digital impression was significantly less than the retakes of the conventional impression. Rescans or incorporation of additional scans were mainly due to the difficulty in scanning the interproximal contacts of neighboring teeth next to the implant site and the areas of refection from the laser source. Other investigators took space measurements in conventional (plaster) models and in digital models (OrthoCad system, Cadent, USA) and concluded that the accuracy of software for space analysis in digital models is just as clinically acceptable and reproducible as in conventional plaster models. On the other hand, Perrson et al. reported that, accurate dental casts can be made with either conventional impression or digital impression techniques. 22 A decrease in the accuracy might occur with both conventional and digital scanning methods if the procedure is not properly managed.

2. Currently available CAD/CAM systems

CAD/CAM Custom Implant Abutment Systems

i. Procera system (Nobel Biocare): this system provides custom abutments in titanium, alumina, and zirconia. A master cast is then scanned and the custom abutment is designed by a 3D CAD program. 23,24 Alternatively, a machined base cylinder is screwed to the implant analog and the abutment is waxed up. Pattern is then removed from the master cast and scanned by Procera scanner. 12,26 The design is sent to the production facility for the abutment fabrication. 24,25

ii. Atlantis abutment (Astra Tech): abutment is milled in titanium alloy or zirconia. Gold anodized coatings can be added to mask the silver color of the titanium abutment, giving natural shades through all-ceramic restoration. 27 In this system an implant-level impression is made and then both the diagnostic model and the master cast are scanned. In this way a computer accurately captures the implant location, orientation, angle, and depth. The abutment is then designed on a software system known as VAD and precision machined by a computer-controlled milling machine from a solid block of titanium alloy. 28

iii. Encode Restorative System (ARCHITECH PSR, Biomet 3i): CAD/CAM system limited to a specific implant (Biomet 3i). In this system the clinician needs to make an intraoral impression of a special healing abutment. This abutment has notches on its occlusal surface that serve as codes. When these embedded codes are scanned they give information about the implant platform diameter, the position of the hex, and the collar height of the healing abutment. The CAD/CAM abutment is designed on the computer and is milled from a solid block of titanium alloy. 29,30

iv. CARES (Computer Aided Restoration Service; Straumann): this system offers exclusively customized implant prosthetics for the Straumann dental implant system. It provides two types of abutments: zirconium oxide and titanium RNSynOcta custom abutments. After fabrication of an implant-level impression, a duplicate model of the master cast, known as a scan model, is made from a scanable plaster. A scan body, which is used to record the implant position during the scanning procedure, is attached to the implant analog on the master cast before the duplication or to the scan model after the duplication. The scan model is digitized using laser scanners from Sirona. The custom abutment is designed on-screen using 3D software. Generated data are electronically transmitted to the Straumann production center, where the custom abutment is man-
ufactured. Intraorally, the ceramic custom abutment needs to be fixed to the SynOcta 1.5 abutment, whereas the RNSynOcta 1.5 is not required if the titanium custom abutment is used, as the titanium custom abutment is screwed directly into the implant.29

v. Etkon: It is another system that supports the prosthetic portfolio of the Straumann dental implant, among others. Using the laser light-band principle to scan, it can fabricate abutments made of zirconia or titanium. After an implant-level impression is made, a master cast is produced. A plastic cylinder is placed into the implant analog and the abutment is waxed up. The generated pattern is then removed and scanned. The resulting design is sent electronically to a manufacturing facility to produce the final custom abutment.29

CAD/CAM Custom Implant Framework Systems
i. Procera: implant partial prostheses are available in zirconia or titanium. CAD/CAM custom Procera partial prostheses are screw-retained implant-supported restorations that can be used with a wide range of implant systems. The zirconia implant prosthesis is available at the implant level, while the titanium implant prosthesis is available at the implant and abutment levels (www.nobelbiocare.com). Using acrylic resin, a framework pattern is fabricated directly on temporary implant cylinders.31 The acrylic resin framework pattern is then laser scanned, and the framework is milled in a CNC-milling machine with 5 degrees of freedom.32–35

ii. CAM StructSURE: precision milled bars (Biomet 3i) are available in Hader and Dolder designs for over-denture bars and primary bars and in fixed hybrid designs. With this system, the technician does not need to wax or resin design the framework; instead, the design is made on-screen with a sophisticated software program.36

iii. BioCad: milled bars (BioCad Medical). BioCad software permits the design of bars for most implant systems. They are made from surgical grade titanium alloy milled on industrial machines. BioCad implant bars are available in Hader, Dolder, fixed, and round styles.36

iv. Etkon system can produce frameworks up to 16 units from a variety of materials, such as zirconia and titanium.29

CAD/CAM Implant Abutments
Dental implants are considered an essential treatment modality. Published data have demonstrated high success rates for implants placed in partially edentulous arches for the replacement of both single teeth37–39 and multiple teeth.40–42 UCLA abutment was widely used.43 This abutment was designed to engage the implant directly and it is usually cast in gold alloys.44 Adell et al, reported that dental implants and abutments are usually fabricated out of commercially pure titanium, primarily because of its well-documented biocompatibility and mechanical properties.45 However, despite numerous modifications to the fabrication and design of metal abutments, there is still the disadvantage of metallic components showing through when such abutments are used.46–48 The resultant dull grayish background may give the soft tissue an unnatural bluish appearance.49–51

Some investigators reported that a specific problem for titanium trans-mucosal implant-abutment systems, particularly in butt–joint or external–internal hex designs, is that the micro-gap between the implant and the abutment may increase because of bending moments and consecutive fatigue and wear at the interface.52–54 This is followed by plaque retention at the interface, resulting in clinical sequelae such as bone loss, peri-implantitis, and possible loss of osseointegration. Jansen et al. used 13 different two-piece implant systems to investigate the correlation between component fit and micro-bial leakage of the implant-abutment interface.55 The authors concluded that the implant-abutment systems with fine mating surfaces may not prevent microbial leakage. Piattelli et al. compared cement-retained and screw retained implant-abutment connections by scanning electron microscope (SEM) analysis and concluded that cement-retained abutment implants offer better outcome in terms of fluid and bacterial permeability.54 Further, Dellow et al. reported that manufacturing variations can result in as much as 0.1 mm of space at the implant-abutment interface.55

Development of ceramic abutments: The first ceramic abutment was introduced in 1993 in small and large diameters (not commercially available).56 The abutment was a prototype of alumina ceramic with resistance to shearing forces that reached values up to those of the metal-ceramic crowns.57 Compared to metal abutments, these new abutments offered optically favorable characteristics, low corrosion potential, high biocompatibility, and low thermal conductivity.58 On the other hand, restorations made out of such ceramic cores were weaker when compared to metal-ceramic restorations.59 Such controversies led to further investigations into new designs and materials for ceramic abutments. Custom-made ceramic abutments were fabricated using alumina blocks.29 The abutments showed improved values for resistance to fracture but they were still weaker.56,60 Another step toward perfecting the overall aesthetic outcome was taken with the development of the customizable CerAdapt abutment (Nobel Biocare).61 The abutment was made of pure, highly sintered aluminum oxide and demonstrated significantly improved resistance compared to previous abutments. It was indicated for the fabrication of implant-supported single crowns and short-span fixed partial dentures in both anterior and premolar regions. Clinical studies have demonstrated high success rates of the CerAdapt abutment, showing advantage of computer-aided design/computer-aided manufacturing technologies, before the development of zirconia abutment, which was later introduced to the range of ceramic abutments.63

Contemporary ceramic abutments: Today, the majority of implant manufacturers offer ceramic abutments. The abutments are available in pre-fabricated or customizable forms and can be prepared in the dental laboratory either by the technician or by utilizing computer-aided design/computer-aided manufacturing techniques. The materials of preference are
densely sintered high-purity alumina (Al2O3) ceramic and yttria (Y2O3)-stabilized tetragonal zirconia polycrystal ceramics. These high-strength ceramics have improved mechanical properties.64,69 Piconi and Maccarico reported that alumina ceramic has a flexural strength of 400 MPa, a fracture toughness value between 5 and 6 MPa/m0.5, and a modulus of elasticity of 350 GPa, while yttria stabilized zirconia ceramic has twice the flexural strength of alumina ceramic (900–1400 MPa), a fracture toughness of up to 10 MPa/m0.5, and a modulus of elasticity value of 210 GPa.64,67

Compared to alumina ceramic, the enhanced strength of zirconia (ZrO2) can be explained by micro-structural differences, such as higher density, smaller particle size, and polymorphic mechanism against flaw propagation.64,68 The main reason for the superior resistance of zirconia lies in the stabilizing effect of yttria, which allows the processing of zirconia in the metastable tetragonal crystalline structure at room temperature (18°C–23°C). The tetragonal phase at room temperature allows for transformation to the monoclinic phase under stress and represents an efficient mechanism against flaw propagation. The transformation results in a compressive stress as the result of volume expansion and slows down further crack propagation, resulting in improvement of the mechanical properties (i.e. transformation toughening).64,69

Andersson and Oden,70 introduced to the market alumina abutments composed of 99.5% pure alumina ceramic. These abutments provide certain aesthetic advantages when compared to more whitish zirconia abutments.71 In addition, the alumina ceramic is easier to prepare; this saves time during definitive preparation, which is usually performed intraorally. While other investigators59–61 presented some problems of alumina abutments include their radio-opalescence at the time of radiographic examination and their weak resistance to fracture. In this context, it is commonly agreed that ceramic abutments should show proper resistance against the masticatory forces raised during chewing or swallowing. Several studies reported a mean loading force of approximately 206 N and maximum biting forces of up to 290 N in the aesthetic zone.72,73

For a successful restoration, the abutment should present resistance to fracture values greater than such forces and, to guarantee long-term success, maintain this resistance for at least 5 years of clinical function. A study performed in vitro72 compared titanium, reinforced zirconia and pure alumina abutments for their outcome after chewing simulation and static loading in a chewing simulator to simulate 5 years of clinical service, the median fracture loads were 294 N, 239 N, and 324 N for the zirconia, alumina, and titanium abutment groups, respectively. The authors concluded that titanium and reinforced zirconia abutments perform in a similar way to metal abutments, and can therefore be recommended as an aesthetic alternative for the restoration of single implants in the anterior region, while ceramic abutments made of alumina showed less favorable properties. However, clinical study by Henriksson and Jent (24) using alumina abutments demonstrated excellent aesthetic outcomes and favorable survival rates when accepted treatment concepts were followed and documented components were used.

With the advancement use of a CAD/CAM technique and development of customized zirconia abutment, it becomes widely used and abutment could be individually prepared according to the anatomic needs allowing an individual placement of the margin of the crown.73,74 Several studies reported that zirconia abutments supporting single-tooth implant crowns showed a survival rate of 100% over 3–4 years.75,76

On the other hand, it has been reported that saliva and blood can degrade the bond strength of a zirconia-based restoration,77 as can surface flaws in zirconia that are induced during grinding. Grinding using a coarse high-speed diamond rotary cutting instrument removes tens of microns of material in each pass. The associated high stresses and temperatures can induce surface cracks that can lower the strength and reliability of the material.78

The introduction of the Procera system, based on CAD/CAM technology, allowed the production of abutments made of commercially pure titanium, eliminating concerns about the use of dissimilar metals and about interfaces between machined and cast components.10,12,79,80 The Procera system also allowed the production of sintered alumina and zirconia abutments, which have provided new opportunities for single-tooth esthetic restorations.

**CAD/CAM Technology: Bars and Frameworks**

CAD/CAM technology had significantly improved the restorative aspects of implant dentistry as well. Implant restorations can be supported or retained by individual attachments, splinted with a bar for an over-denture, or splinted by a framework that supports a fixed restoration such.81 Prior to CAD/CAM, bars and frameworks had to be cast from gold alloy, however, several investigators81,82 reported that traditional castings for frameworks fabrication have a major limitation inherent in the process, which is distortion of the casting with increasing size of the pattern in comparing to CAD/CAM process. Osseointegrated implants have lack of periodontal ligament, thus tolerance of fit is greatly reduced when comparing tooth-supported cast restorations to implant-supported restorations. Single and two implant restorations can be cast within this tolerance, because the distortion is limited based on size. Full arch restorations, however, are difficult to cast successfully. Over the years, a multitude of casting corrective procedures have been employed, including sectioning and soldering, laser welding, and electric discharge machining.

Eisenmann et al stated that as long as it remains unclear what bone biologic reaction to chronic loading will be and whether and how much bone resorption will occur, clinicians should strive to achieve a precise, passive fit of implant frameworks to minimize additional stress at the implant–bone interface.83 CAD/CAM fabrication of bars and frameworks has resulted in elimination of distortion, better fit, fewer fabrication steps, and faster turn-around.81,83,84 Furthermore, with CAD/CAM technology the unfavorable implant angulations can be corrected and proper emergence profile can be achieved.22 The workflow for creating a CAD/CAM bar starts with an accurate
impression and model including the implant analogs. The model containing the implant analogs is scanned, and then the CAD portion begins. Currently, bars and frameworks can be milled from titanium or zirconium. Titanium is abundant on Earth and offers a significant cost savings relative to gold.82

Nobel Biocare of Gothenburg, Sweden, introduced framework milled from a solid piece of titanium resulting in a strong and lightweight restoration, free from defects and distortions.83 The fit of the framework on the master cast has been shown to be more precise than frameworks fabricated with the conventional casting technique.84-86 Romero et al.87 reported that the milled structure once completed will not require any modifications (i.e. cutting, laser welding) to achieve a passive intraoral fit.

Kurtzman concluded that, CAD/CAM implant prosthetics provide stronger frameworks than the traditional cast free from porosity and provide better durability clinically.88 Park stated that CAD/CAM in implant dentistry has broadened their application areas into treatment planning, implant placement and restorations.89 Ortorp and Jemt compared the clinical and radiographic result of implant-supported fixed prostheses with conventional lost wax technique and computer numeric control (CNC) milled titanium framework, and found better fracture resistance and fitness on titanium framework in a 5-year clinical follow-up.90 Several authors consider one-piece CAD/ CAM milled technology to be the treatment of choice because it results in frameworks that are stable, potentially more homogeneous and passively fit.85-90,91 Non-passively fitting frameworks may result in many complications such as screw loosening or component fracture.85,90-92

According to Klineberg and Murray frameworks with gap widths up to 30 μm across 90% of the abutment cylinder area can be considered to have a satisfactory passive fit.93 Bräne- mark et al. suggested that a gap width between abutment and superstructure of <10 μm be considered to be a passive fit.94 Ortorp et al. reported the results of a laboratory study in which the accuracy of implant frameworks fitting a laboratory master model were compared.95 Frameworks were either fabricated with a computer numeric controlled (CNC) process, or the frameworks were made using the conventional lost wax technique. The computer-designed and -milled frameworks demonstrated significantly better fits between the frameworks and the implant analogs than the cast frameworks: 13-15 μm for the CNC frames and 43-180 μm for the cast frameworks.

**CAD/CAM Restorations for Dental Implants**

Patel reported that, adhesive bonding of conventional all-ceramic materials to implant abutments remains unpredictable and reduces the reliability of success.96 The initial attempts to fabricate implant restorations chairside was developed with the CEREC system included the use of feldspathic and leucite-reinforced ceramic CAD/CAM blocks. Reports of increasing the occlusal thickness of the restoration beyond the 1.5 millimeters recommended for conventional tooth prepa-

rations does not offset the fracture risk of adhesive glass ceramic CAD/CAM blocks used on implant abutments.97,98 The results of the study by Wolf et al. suggest that increasing the thickness of the crown to an unusual 5.5 mm in combination with shortening the abutment does not result in greater crown strength.97 The introduction of a lithium disilicate glass ceramic with 360 megapascals of biaxial flexural strength (IPS e.max CAD, Ivoclar Vivadent, Amherst, N.Y.) provides dentists with the option to use either cementation or an adhesive bonding protocol. This material has the potential to be used for definitive implant-abutment restorations. The higher flexural strength of the material reduces the risk of fracture under normal masticatory load compared with that of conventional glass ceramic CAD blocks.99,100 The results of the study by Wolf et al. suggest that the interaction between abutment material and mode of cementation plays an important role in the viability of conventional glass ceramic CAD/CAM materials.97 They noted that the use of adhesive resin cement increased the overall fracture load of conventional CAD/CAM ceramic restorations compared with that of non-adhesive cements. The recent availability of a high-strength ceramic material developed more favorable outcome for implant-supported restorations.101 Retention of full coverage dental restorations to natural abutments involves numerous variables including convergence angle, axial wall height and diameter, surface area, margin geometry, and any additional retentive features incorporated by the clinician.102 Also important is the surface finish of both the preparation and the restoration, the physical properties of the cement, placement technique, seating force, and environmental conditions during delivery.103,104 While many of these features are held in common with implant dentistry, significant differences exist between smooth, machined abutments, and natural teeth.105 The surface irregularities of natural teeth do not exist on manufactured smooth abutments.

Kaufman et al., in a study on the retention of gold castings, described the “uncemented grip” of a full-coverage restoration.103 Others have referred to it as the “frictional fit” of the cast crown restoration.104 Regardless of the name, this phenomenon can be attributed to “unavoidable discrepancies” in the manufacturing process, including internal surface nodules and roughness of the restorations.105 In a study of fixed partial denture retainers, Lorey and Myers found no relationship between pre-cementation and post-cementation retention values,106 this conclusion was also found in other investigation.107 Lorey and Myers theorized that tight castings reduce the thickness of cement below optimal levels, ultimately reducing retention. This suggested that a well-fitting casting should seat easily and provide a uniform cement space.108 Grajower et al., added that tight castings could result in damage or “digging” into natural abutments, resulting in increased crown elevation.108 CAD/CAM systems do have flaws, and manufacturing discrepancies do exist on the internal surface of the restoration; however, they are minimal compared to hand-fabricated restorations, and should not be expected to have a significant effect on retention. Retention is more dependent on the properties of the
abutment (natural or titanium) and the cement. Mansour et al, have already noted that cements should be expected to react differently with implant abutments than with natural abutments. This study was unique in that it was one of the first to consider CAD/CAM crowns on machined abutments. Each abutment and crown combination was only tested once—Carnaggio et al. reported that restorations cemented self-adhesive resin cement to implant abutment showed the highest overall retention values that and resin-modified glass ionomer cements showed retentive forces closer to the “temporary cements” than to the permanent adhesive resin cements.

Accurate Fit of Abutment

Accurate fit of dental prostheses is thought to be critical to the long-term success of the supporting structures whether those structures be teeth, mucosa, or implants. It had been stated that a passive fit of a reconstruction is important for a physiologic tissue response and long-term osseointegration of implants. Although more recent findings suggest that stress in the bone adjacent to implants induces bone formation. But because of the ankylosis character of the implants, stress induced by a misfit of the suprastructures persists. Therefore, a passive fit of the suprastructures is desirable to prevent uncontrolled stress not only in the adjacent bone but also in the reconstruction itself. Namely, it has been claimed that supra-structures with a poor fit may lead to prosthetic complications such as loosening or fracture of screws, as well as fracture of frameworks or veneering ceramic and even fractures of abutments or implants.

Binon highlighted on the importance of absence of rotation at the implant-abutment interface, he suggested that the fit between the external hexagon of the implant and the internal hexagon of abutment should permit less than 5 degree of rotational movement to sustain a stable screw joint. A study done by Vigolo et al. was undertaken to assess the rotational freedom between the hexagonal extension of an implant and the abutment hexagonal counterpart for Procera abutments made with different types of material (titanium, zirconia, and alumina). They reported that greater rotational freedom was demonstrated for all 3 types of Procera abutments compared to pre-machined UCLA abutments. In any case, the rotational freedom of all 3 types of Procera abutments was consistently demonstrated to be no greater than 3 degrees. This should allow for a stable screw joint and may reduce the risk of screw loosening.

However, the evaluation of an absolute passive fit of superstructures is not possible using conventional clinical and laboratory procedures, as clinical fit evaluation methods often do not detect inaccuracies that are below the level of visual acuity or the measurement capacity of the testing equipment. Brannmark et al suggested that a gap width between abutment and superstructures of <10 μm be considered to be a passive fit. Klineberg and Murray, frameworks with gap widths up to 30 μm across 90% of the abutment cylinder area can be considered to have a satisfactory passive fit. Blackman et al reported that approximately one third of the castings surveyed exhibited casting related defects, while milled restorations from blocks of homogeneous materials such as metal, resin, or ceramic should eliminate some of the problems inherent in dental castings. Jemt et al. demonstrated the precision of CAD/CAM-milled frameworks for implant treatment and concluded that the precision of fit of the first CAD/CAM-milled prosthesis was comparable to that of conventional cast frameworks. Thus, CAD/CAM technology has been described as a method that reduces error and thereby improves the fit of prostheses. Karl et al. found through strain gauge analysis of fit that, restorations fabricated using optical impressions demonstrated a level of fit that is at least as accurate as that of conventional fixed dental prostheses.

In randomized clinical trials, Jemt and Ortorp demonstrated acceptable clinical performance after 1 year with CAD/CAM-milled titanium frameworks supported by implants in edentulous arches. Similar clinical and radiographic performance was observed with CAD/CAM and conventional cast frameworks. In their researches they demonstrated improvement of the accuracy and precision of fit with CAM frames over conventional wax casting techniques. Other studies compared between the fitness of CAD/CAM supra-structures and other methods like the electrical discharge machining (EDM) technique, also known as spark erosion technique, and Cresco, Astra Technique. EDM technique is a method to improve the fit of conventionally cast metal frameworks. It applies electrical discharges or sparks to shape the metal workpiece by erosion. The surface of the cast framework is exposed to high-intensity electrical energy pulses transmitted by a working electrode, which itself is the negative of the shape aimed for. The metal or alloy is gradually melted until the work piece is shaped according to the shape of the working electrode. While in Cresco, Astra technique, the approach for achieving a precise fit of cast metal frameworks is by employing horizontal sectioning of the frameworks followed by laser welding. The coronal part of the framework is thus reassembled to prefabricated abutment like supports. Prior to the welding procedure, these abutments have to be cut in the proper level to achieve the correct occlusal height, which is obtained by a numerically controlled milling machine. In general, laser welding is challenging and carries the risk of crack formation, gas inclusions, or distortion when laser parameters are not well-adapted to the respective material. A study done by Fischer et al. reported that there were no significant differences between the three methods although CAD/CAM method revealed the lower means of marginal gap discrepancies.

Survival Rate:

Clinical studies demonstrated excellent survival rates for fixed implant reconstructions supported by titanium abutments, a systematic review done by Pjetursson et al., only a few complications were associated with metal abutments supporting fixed implant reconstructions. For this type of abutment, the most frequently occurring retrievable technical problem was loosening of the abutment screw. Andersson et al. reported that Metal abutments exhibit high
survival rates due to the excellent physical properties of metal, where metals are ductile, which enhances their tolerance toward small defects or cracks, while ceramics, in contrast, are delicate materials due to their brittleness. 

Improvements in the field of ceramics have encompassed the development of the high-strength ceramics alumina and zirconia, which exhibit increased fracture toughness. Some investigators, reported promising survival rates of implant abutments made out of both alumina and zirconia. Among all dental ceramics zirconia exhibits the highest fracture toughness. Other study on zirconia and titanium abutments showed that this ceramic can be used as an abutment material even in posterior regions of the jaws with success similar to metal. 

Ceramic abutments made of alumina showed less favorable properties. However, clinical studies using alumina abutments demonstrated excellent aesthetic outcomes and favorable survival rates when accepted treatment concepts were followed and documented components were used. Andersson et al. reported that alumina implant abutments when used for the fabrication of implant-supported, short-span, fixed partial dentures, had a cumulative survival rate of 98.1% after an observation period of 5 years, other studies revealed that alumina abutments used for the fabrication of implant-supported, single crowns had cumulative survival rates between 93% and 100% after observation periods between 1 and 3 years. Clinical studies on zirconia abutments confirmed that these abutments had a cumulative survival rate of 100% after observation periods between 4 and 6 years.

Four studies analyzed the cumulative 5-year survival rates for CAD/CAM fabricated restorations. Three studies reported on full arch FDPs with titanium frameworks veneered with resin acrylic teeth. One study reported on all ceramic supra-structure restorations. They reported survival rate of 72.2%, 100%, 98.5% and 100% respectively. However the high rate of lost restorations in the study by Komiyama et al. was principally as a result of failure of the implants rather than of the restorations themselves.

It should be noted that only anterior crowns were included in the CAD–CAM fabricated all-ceramic SCs, while in the review of Jung et al. (136) crown location had not been considered. However, crown location has been reported to have an influence on the failure rates of all-ceramic crowns, i.e. anterior crowns have a higher survival rate than posterior crowns. Out of the clinical studies reporting on implant-supported CAD/CAM fabricated restorations, one study was designed to explore differences in the outcome of CAD/CAM vs. conventionally fabrication technique. The lack of data makes a scientifically valid comparison between CAD/CAM fabricated and conventionally fabricated restorations for the broader range of applications impossible.

Complications of CAD/CAM implant’s Restorations

In addition to the survival and failure rates of the CAD/CAM restorations, equally interesting are the complications of the final CAD/CAM restorative outcome. In the literature, numerous systematic reviews have evaluated “biological,” “technical,” as well as “esthetic” complications of dental restorations/implants. To determine if there is a difference regarding the influence of CAD/CAM design on the tissues, the “biological” complications could be subdivided into peri-implant mucosal lesions, gingival inflammation, soft tissue dehiscence, formation fistulas, and marginal bone height. Similarly, the “technical” complications could be separated into groups such as abutment/screw loosening, fracture of the veneer material, fracture of the CAD/CAM framework/abutment, and loss of retention due to cementation. Although the esthetic outcome has become a main focus of interest in implant dentistry, none of the included studies evaluated the esthetic appearance of CAD/CAM-fabricated prostheses. This is a difficult task, since there is a lack of standardized aesthetic criteria. Hence, there is a need for widely accepted and reproducible esthetic scores, not only for the evaluation of CAD/CAM restorations, but also for the peri-implant soft tissues.

Yong and Moy evaluates early clinical results of CAD/CAM-guided surgical implant placement (Nobel Biocare) with a focus on surgical and/or prosthetic complications. The study included 13 patients with 14 arches and the follow up period was 26.6 months. They classified the complications into; 1) early complications (i) planning, (ii) surgical and prosthetic procedural, 2) late complications; (i) surgical, (ii) prosthetic failure. They found that no complications arise from planning, for early surgical complications; three implants faced bony interference which led to incomplete seating of the prosthetic restorations. Early prosthetic complications encountered included prosthesis looseness, speech problems, and bilateral cheek biting, while for late surgical complications encountered including nine implant failure, one of them was associated with persistent pain and one implant had a residual buccal soft tissue defect. The rest were late implant failures. The total number of implants used in this study was 78 implants; therefore the rate of failure was 9%. Finally for late prosthetic complications, there were nine recorded late prosthetic complications. Two of the prostheses had heavy occlusal wear and two had loosening of screws. Fracture of prosthesis was observed in

Pjetursson et al., in their systemic review estimated survival rate of conventionally fabricated implant-supported FDPs after 5 years was 95.2%. 

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three of the prostheses. There was one case of aesthetic dissatisfaction and one case of pressure sensitivity while chewing. Eight of the nine complications (88.9%) occurred in the prostheses made from carbon fiber frameworks with acrylic teeth.

**Conclusion**

In conclusion the diversity of contemporary materials and of methods available for the fabrication of implant supported, all-ceramic restorations makes it difficult to select the most appropriate treatment modality. New products are constantly being added to the wide range of existing products. Zirconia ceramics and abutments are being intensively investigated and are gaining in popularity. Future improvements in the ceramic will focus on its color and long-term stability. Attempts are being made to add coloring oxides to zirconia ceramic before the sintering process; this would change its whitish color and enhance the aesthetic outcome. A custom design, a perfect fit and a higher resistance are the main characteristics of CAD/CAM implant abutments. Future developments of CAD/CAM will make it possible to produce more resistant abutments and restorations with higher quality and lower fabrication time and costs.

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**References**


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