

The Digital Domain



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Dentistry uses computerized radiographs, practice management software with a computerized databases and scan documents to create digital records. Other technologies which provide information to clinical practice include digital cameras, intraoral cameras, digital impression units, caries detection units and tooth colorimetric devices. Digital technology (photography, email, digital models and collaborative software) empowers dentists and technicians to achieve excellence. Decisions can be made quickly and concisely when digital technologies are used before, during and after treatment.

Computer-aided design (CAD) and computer-aided manufacturing (CAM) has grown in popularity over the last two decades (Fasbinder DJ, 2012). The technology is used both in the dental laboratory and in the surgery and can be applied to the fabrication of simple to complex prosthodontics, depending on which system is used.

CAD/CAM technology was developed to address 3 challenges:

- ◆ Ensure adequate restoration strength, especially posteriorly.
- ◆ Create natural and aesthetic restorations. Demographics combined with increased demands for aesthetic dentistry has resulted in a rise in the number of fixed restorations which have been provided.
- ◆ Facilitate production of restorations to be easier, quicker and more accurate.

There are 3 components to the CAD/CAM system: scanning, designing and milling.

This article will focus on dentist-laboratory digital communication channels which ultimately improve workflow and dentists' clinical involvement and responsibility so that quality restorative dentistry can be provided.

DIGITAL SYSTEMS

There are a number of ways in which dentists and laboratories can work with new technology:

- a. A dentist can take a digital impression and then on-send to the laboratory. There are several examples of digital impression units (stand-alone configurations) which include iTero® (Cadent), 3M™ True Definition Scanner (3M ESPE), CEREC AC® Connect (Sirona), E4D Sky™ (Plan Mecca E4D Technologies), IOS Fastscan® (IOS Technology) and Trios® (3Shape).
- b. The dentist can use their own computer-aided design and mill in-house. Chairside CAD/CAM systems have manufacturer specific software programs that permit production of single

tooth ceramic or composite inlays, onlays, veneers and crowns. However, there are finite capabilities to in-house units as there are material and dimensional span limitations. Complex and larger restorations particularly for zirconia and metal customized abutments, implant-supported crowns, bridges and overdentures require laboratory manufacturing.

There are two prevailing available chairside CAD/CAM systems which consist of a handheld scanner, a cart that houses a personal computer with a monitor and a milling machine. These are the CEREC Acquisition Centre and E4D Dentist system.

Both chairside CAD/CAM systems also offer the option to be used as purely digital impression systems. The CEREC Connect system for the CEREC AC unit and the E4D Sky Network for the E4D Dentist system are options to allow electronic transmission of the digital file to the laboratory to make restorations of greater magnitude and complexity.

THE ROLE OF THE DENTIST

Digital Impression Techniques

For both conventional and digital impression techniques, an accurate final representation of the intraoral situation is crucial (Fig. 1).

In the case of digital impressions, the final restoration is only as accurate as the recorded data file.

Several principles are common to all the scanners which significantly affect the outcome of the data.

Digital impressions are sensitive to moisture contamination as are traditional impression materials. Blood and saliva obscure the surface to the tooth or margin from the camera and prevent an accurate recording. One of two undesirable things occurs: either the camera records the moisture as an inaccurate surface contour or no data is recorded where the moisture has collected. Thus, an accurate restoration cannot be fabricated.

Inadequate soft tissue management and retraction may prevent visualization of the marginal areas which can translate into an inaccurate recording with the camera. Current digital systems do not scan through soft tissues. Digital scanners can only record data that is directly visible to the camera lens. A digital scan should capture the entire restorative margin as well as about 0.5 mm of the tooth/root surface apical to the margin.

Digital scans include capture of the interocclusal registration. If the dentist can carefully follow the scanning procedure and checks the on-screen images for margin clarity, preparation form

and occlusal clearance, then immediate preparation adjustments and isolated scans can be done to check any concerns. Certain machines have verbal and visual prompts. The accuracy of scanning the occlusion and occlusal surfaces helps to reduce the time needed for minor occlusal adjustments at the issue appointment.

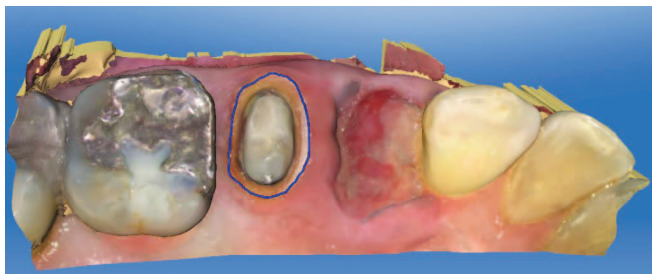


Fig. 1 Margin marking is a feature of digital system.

Clinic-Laboratory Communication

The combination of digital scanning and digital photography offer the opportunity to convey very accurate digital information between the clinician and the laboratory and vice versa. Digital photography is the fastest and most effective way to start using digital technology to increase communication (McLaren EA, Schoenbaum T, 2011).

Digital photography provides the laboratory with shade and contour information beyond the scope of shading notations and shade guides. The clinician and/or auxiliary can take a baseline comprehensive image survey to be uploaded to the technician. Most email systems allow emails up to 10MB at a time. Images can be uploaded via a secure File Transfer Protocol server (FTP) or through an online collaborative website. FTP is used to transfer files between computers on a network. This is crucial for aesthetic cases where preparation designs, angulation and morphology of the teeth and material selection criteria have a huge influence on the potential success or failure of the case.

Choosing the Correct Material

COMMONLY USED MATERIALS PRODUCED BY CAD/CAM

CERAMIC TYPE	CHEMICAL COMPOSITION	PRODUCT
Feldspathic ceramic	Glass Matrix NO filler particles	NOT APPLICABLE (Powder/liquid available for manual application)
Glass-based ceramics	2 Types: A. Filler particles added to glass BEFORE firing	Leucite-reinforced applications eg. machinable blocks IPS Empress® Esthetic
	B. Filler particles grown inside glass AFTER glass formation	Lithium Disilicate eg. IPS e.max®
Zirconium-reinforced ceramic	Lithium silicate reinforced with 10% zirconia	eg. SUPRINITY®
High-strength polycrystalline ceramics	Zirconia – can exist in several crystal phases dependent upon addition of: • magnesia • calcia • ceria or • yttria.	Types of zirconia: • Monolithic (FMZ) OR • Layered (PFZ) eg. IPS e.max® ZirPress = IPS e.max® pressed onto Zirconia framework eg. IPS e.max® ZirCAD = IPS e.max® layered onto CAD Zirconia Other products for dual-use: eg. Lava™ Classic Zirconia Frame eg. Procera® eg. KATANA™ Zirconia

Metal-ceramics	Alloys bonded with feldspathic ceramics eg. IPS Ivoclar InLine® eg. Initial™	High-noble/noble/base alloys
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Hybrid ceramics	Resin nano ceramic Ceramic/polymer	eg. Lava™ Ultimate Cad/Cam Restorative eg. ENAMIC®
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Understanding the compositional nature of the material will enable the clinician to see that with proper case selection and optimal preparation, if the following guidelines are followed for both indications and suggested preparation procedures, a successful outcome is likely.

Monolithic or Layered Restorations?

“The main aim of either monolithic or layered restorations is to reintegrate form, function, and aesthetics with minimal damage and maximum longevity to the remaining natural dentition” (Newton F. et al, 2014). The clinical decision to choose either monolithic or layered restorations will depend on several factors including strength, aesthetics and the position of the restoration. The layering porcelain veneered over the core of all restorations is the “Achilles heel” that gives under flexural loads between 90 and 140 MPa. Monolithic restorations are ideally indicated for stress-bearing areas as the flexural strength is higher (380-1000 MPa) and can be used as a single bulk material especially in the posterior zone or in the form of short-span anterior or posterior bridges.

There are many all-ceramic options. The outer aesthetic layer can be finessed with conventional powder and liquid porcelain or pressed over a ceramic coping which occurs more frequently due to the ease of fabrication and accuracy of the marginal fit. Layered all-ceramic restorations are suitable for veneers, inlays/onlays/overlays, full crowns and bridges. The main difference in layered all-ceramic restorations depends on which material used for the coping. The coping could be zirconia, alumina or lithium disilicate.

The challenge with monolithic restorations has been to optimise aesthetic outcomes. Newer blocks and ingots have improved colour and optical properties which reduce the need for the use of surface stains. The milling can be modified to obtain the required colour result while final staining is still possible for further customisation. This option is convenient posteriorly where aesthetic demands are not as great. Other CAM/CAM systems (e.g. Lava™ DVS) allow characterization to be applied internally so that the restoration will then appear more polychromatic and appear more natural. Some monolithic systems offer a high-translucency coping material that does not require a veneering layer due to improved optical characteristics (e.g. IPS e.max® HT). This restorative option is important in cases of anterior veneers where the occlusion can be demanding.

More products are entering the market as manufacturers are increasingly developing competitive and thus innovative materials. Monolithic lithium disilicate (IPS e.max®) and monolithic zirconia have been the dominant materials and have performed well. The translucency of monolithic zirconia is being improved and surface colours can be applied. As more translucent zirconia is developed, technicians will be able to create anterior restorations that are monolithic with minimal to no addition of layered porcelain.

Monolithic zirconia is most suitable for posterior teeth for full-coverage molar crowns, when a gold restoration is undesirable aesthetically and there is inadequate space for a porcelain-fused-to-metal crown. If monolithic zirconia crowns are surface stained and if the occlusion needs adjustment, the restorations may need to be reglazed. It is difficult to drill through monolithic zirconia if the crown needs to be removed or endodontics performed. In clinical situations where cement is needed, conventional cements can be used such as phosphate or glass ionomer as the strength of the restoration is not enhanced by the bonding procedure.

Anteriorly, for monolithic restorations a high-translucency material such as lithium disilicate is required for aesthetics (Fig. 2). A new version on the market from VITA is called Suprinity®, a zirconium-reinforced glass ceramic. Like IPS e.max®, Suprinity® requires machine crystallization. Translucency is not an issue with the newer materials which can be made opaque or translucent.

As advances in metal-free restorations such as zirconia evolve and improve, limited data indicate zirconia-based bridges may be viable alternatives to traditional metal-ceramic bridges. The prognosis of zirconia bridges may be improved by proper tooth reduction that allows for anatomical framework design and case selection (Lops D. et al, 2012). Short-term clinical data suggest that zirconia-based fixed dental prostheses may serve as an alternative to metal-ceramic fixed dental prostheses in the anterior and posterior dentition (Raigrodski AJ. et al, 2012, Fig. 3).



Fig. 2 Aesthetic results are achievable with monolithic restorations.



Fig. 3 This monolithic zirconia crown fulfilled aesthetic and functional requirements.

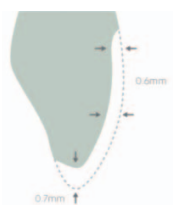
MATERIAL	INDICATIONS
GLASS-BASED CERAMICS	
Leucite-based e.g. IPS Empress® Esthetic	Veneers
Lithium Disilicate e.g. IPS e.max®	Veneers Inlays Onlays Anterior bridges
ZIRCONIUM-REINFORCED CERAMIC	
Lithium silicate VITA SUPRINITY®	Veneers Inlays Onlays Anterior and posterior crowns Anterior and posterior crowns on implant abutments Partial crowns
HIGH-STRENGTH POLYCRYSTALLINE CERAMICS	
Zirconia	Root canal posts Frameworks for posterior teeth Implant-supported crowns Multi-unit bridges Custom-made bars to support removable prostheses Implant abutments Overdenture implant abutments
Porcelain-fused-to-zirconia	Posterior multi-unit bridges Single posterior crowns Single anterior crowns Implant-supported crowns and bridges Customized gingival flange areas in aesthetically critical areas
HYBRID CERAMICS	
Resin nano ceramic e.g. Lava™ Ultimate Cad/Cam Restorative	Use with Titanium Base for implants Implant-supported crowns Crowns Inlays/Onlays Veneers
Ceramic polymer e.g. VITA ENAMIC®	Minimally invasive reconstructions Posterior restorations Reconstructions in cases of limited space available Reconstructions of minor defects (eg cervical veneers etc.) Veneers and non-preparation veneers Premolar and molar crowns Onlays/inlays

Dental CAD/CAM Milling applications also suit the following materials: Titanium, PMMA/Wax milling and Cobalt Chromium.

Preparation Requirements

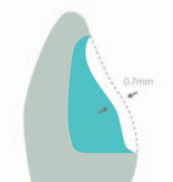
Most CAD/CAM systems are very sensitive to preparation discrepancies and offer little latitude by the technician for alteration. With most systems, clear finish lines, lack of parallel axial walls, rounded internal line angles and lack of undercuts are needed to produce CAD/CAM restorations.

IDEAL PREPARATION FOR ALL-CERAMIC RESTORATIONS



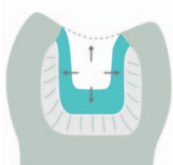
Veneer

- ≥0.6mm labial and cervical reduction (do depth cuts)
- ≥0.7mm incisal reduction
- incisal preparation margins must avoid areas of static or dynamic contact
- bevel the incisal one third back to the lingual incisal edge
- lingual preparation is not needed on all veneers. It can be used on the lingual aspect of the cuspid to re-establish canine rise.



Maryland Bridge

- 0.5-0.7mm lingual reduction for metal
- 0.8-1.2mm for zirconia or nano ceramic (a non-CAD/CAM zirconium silicate which is reinforced with mesh) and higher clearance required
- Preparation should be in enamel instead of dentine
- Use of retentive element is recommended – either a groove, a ridge or a pinhole
- Retentive element must have a minimum radius of 0.5mm
- Circular/island preparation of wings is not possible



Inlay/Onlay

- ≥1.5mm preparation depth
- ≥1.5mm isthmus width
- 6° sidewall taper
- Proximal box should be diverging walls
- [inlay bridge] – contraindicated

SUGGESTED PREPARATION FEATURES FOR CROWNS

	Reduction	Finish Line Depth & Configuration
ANTERIOR CROWNS	All-Ceramic/Hybrid Ceramic IPS e.max® or IPS Empress Esthetic®	2.0 mm incisally 1.0 mm buccal/lingual
	Porcelain-fused-to-zirconia	0.8-1.0 mm shoulder >0.4 mm chamfer lingually >1.0 mm labial
	Metal-ceramic (Porcelain-fused-to-metal)	2.0 mm incisally 0.5-1.0 mm lingual aspect (Porcelain guidance requires greater clearance) 1.5 mm labial shoulder or heavy chamfer 0.5 mm lingual chamfer 1.5 mm circumferentially for 360-degree ceramic margin
POSTERIOR CROWNS	Full contour crowns (metal/zirconia/hybrid)	1.0 mm non-functional cusps 1.5 mm functional cusps 0.3-0.5 mm shoulder or heavy chamfer
	All-ceramic (veneered or monolithic) IPS e.max® or IPS Empress Esthetic®	2.0 mm non-functional cusps 2.5 mm functional cusps 1.0 mm shoulder or heavy chamfer
	Porcelain-fused-to-zirconia	
	Metal-ceramic (Porcelain-fused-to-metal)	If metal occlusal, as with FCC 2.0 mm non-functional cusps 2.5 mm functional cusps 1.5 mm labial shoulder or chamfer 0.5mm lingual chamfer (metal collar) 1.5 mm circumferentially for 360-degree ceramic margin

CHOOSING THE CORRECT CEMENT

CLINICAL SITUATION	TYPE OF CEMENT
Tooth-coloured inlays, onlays, leucite and lithium disilicate-based, hybrid ceramic crowns	Self-etching resin cement or resin cement with prior application of separate self-etching bonding agent
Ceramic veneers and leucite- and lithium disilicate-based crowns, hybrid ceramic crowns demanding optimal aesthetics	Resin cement used after total etch of enamel and a subsequently applied self-etch of dentine.
Crowns and bridges that have repeatedly come loose during service	Resin cement with a precementation application of self-etching bonding agent, applied after both the fitting surface of the restoration and the tooth preparation have been roughened to increase retention
All-metal, PFM, hybrid ceramic crowns, alumina and zirconium-based crowns and bridges	
1. With good or adequate retention	RMGI (useful because of fluoride release)
2. With minimal or reduced retention	Resin cement with prior application of separate self-etching bonding agent

Implications for Dental Practice:

CAM-only and copy milling systems allow some flexibility to compensate for discrepancies which may compromise coping framework fabrication – eg. by telescoping an abutment during waxing, a compromised path of insertion can be addressed for a bridge design.

The creation of CAD/CAM models at a manufacturer's facility allows for standardized quality control procedures which in turn ensure reliability and accuracy.

THE ROLE OF THE LABORATORY

Software designs and Open and Closed Architecture

All of the computerized systems record the digital impression to a data file in the software program provided by the manufacturer. The initial version of these proprietary data files were designed according to the concept of "closed architecture" which meant that digital files could only be read and used by equipment from the same manufacturer using the manufacturer's software program. This still applies for digital files used by CEREC AC and E4D systems for full-contour restorations. Digital files cannot be moved between the two manufacturer's systems for processing chairside restorations.

As digital impression stand-alone systems evolved, laboratories were faced with the problem of having to acquire systems from each manufacturer in order to manage all the data files they received from dentists. This led manufacturers of computerized systems to move to "open architecture" with their digital files. Multiple corporate partnerships have developed to allow the use of a specific manufacturer's digital files across a number of different software programs and CAD/CAM equipment.

Thus, it is now possible to connect scanners from multiple suppliers to various brands of design software and export to multiple manufacturing solutions.

Software Standards

One basic set of standards exists for image file format. This is defined in the International DICOM (Digital Images and Communications in Medicine) Standard (Piankyh OS, 2012). The International Organisation for Standardisation (ISO) has made this the referenced standard for image format and communications.

This assisted and promoted the open exchange of medical images and associated information between different devices. All

images including visible light and various radiographic procedures are included (CT, CBCT, MRI etc). The DICOM Standards Committee has 27 active working groups which includes WG 22 (Dentistry). A project was initiated by WG 22 in 2011 which will extend the DICOM Standard to the prosthetics value chain (integrating images in dental manufacturing technology) and can be summarized as the establishment of standards between:

- ◆ dental scanners and dental design software
- ◆ dental design software and manufacturing devices

Another initiative to standardize design software occurred in 2011. Three companies – Dental Wings, 3M ESPE and Straumann – united to create an open global standard software platform to use across a range of applications in dentistry. The software is independent of scanning and manufacturing solutions. 3M ESPE and Straumann have embraced the software platform of Dental Wings, DWOS, as the basic operating solution in their CAD/CAM systems. A technician could design a customized CAD abutment and coping and multi-unit prosthesis to be made in a milling centre with one software solution. The whole design of the multi-unit prosthesis is designed by the technician in any virtual environment. DWOS has well-established interfaces to the leading intraoral and laboratory scanners, milling devices and 3D printers belonging to different suppliers. This means that DWOS has open interfaces at both ends so it can import scan files from different scanners and scanning technologies and export generic Surface Tessellation Language or STereoLithography (STL) files that can be used for production using any machine with open interfaces. An STL file describes only the surface geometry of a three dimensional object without any representation of colour or texture (Fig. 4).

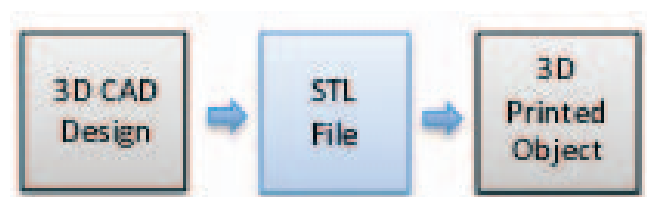


Fig. 4 An STL file serves as the bridge between 3D CAD designs and 3D printer hardware.

Software Scope

DWOS aims to provide an interface to connect open architecture devices along with a well-defined and secure connection with leading scanning and manufacturing processes, thereby guaranteeing the final quality of the end product.

There are 5 icons in the menu bar of DWOS that show the basic workflow and can be summarized as:

- ◆ **Prosthetic design:** This contains information about the dentist and the patient.
- ◆ **Scan import application:** The scanner can either be present near the design station or the scan data can be imported as a file from a scanner located anywhere.
- ◆ **CAD engine:** This provides the automatic proposals based on requirements in the order and scan information.
- ◆ **CAD application:** This allows changing or optimising the automatic proposal.
- ◆ **Production management:** DWOS software contains 5 modules which can be used independently or as an integrated suite:
 - *The DWOS Crown and Bridge module* is the cornerstone of prosthesis design and permits designs from coping to full contour, from a simple unit to a full arch design. The framework designs are actively adjusted to the shape of the full restoration to allow the most desirable porcelain support. The operator has several editing tools- axis modification, virtual wax knife and contacts between adjacent and

opposing teeth. Rotations can occur buccolingually and mesiodistally. Simultaneous designs of upper and lower arches, wax-ups and virtual articulator capabilities are possible in the latest version of the software. Flexibility exists to change the design at any time without losing valuable information.

- *The Implant Custom Abutment:* Strategic designing of this module meant that a one-step planning of custom abutments could be done which considered the clinical situation. The topography of the patient's implant site is automatically computed to fit the designed implant abutment. DWOS features an integrated implant library so the accurate interface geometry is achieved. The framework design is actively adjusted to the shape of the prosthesis. One session dedicated to design means that a custom abutment, framework and the full contour design can be obtained. A workable scanned model from a physical impression which is utilizing a scan body for implant hex position and height is shown in Fig. 5.

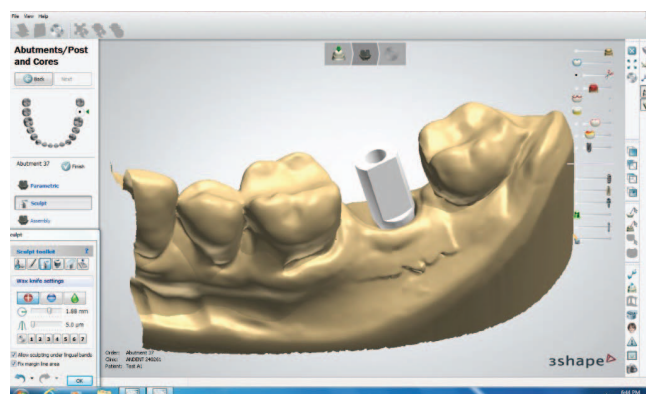


Fig. 5 Digital technology is used to fabricate an abutment.

- *Partial Frameworks:* This module allows automated functions such as undercut measurement and block-out and unrestricted design tools which transfer technical information to a digital environment – eg. clasp design and retention grid, pins for artificial teeth and attachments.
- *Virtual model builder:* The aim of this function is to generate a virtual model which can be produced with a preferred manufacturing solution.
- *Manufacturing Modules:* There are two manufacturing modules called DWOS-CAM and DWOS-RPM which form the interface between the design and production environments. DWOS-CAM handles digital processes such as compensation for shrinkage, calculation of tool paths and curves for milling. DWOS-RPM provides automatic generation eg. support for rapid prototyping.

Dental networks have evolved as a result of the need to allow dental professionals to connect. The DHS (Dental Hub System) is one such network which is connected to DWOS software. Many milling centres employ it for the collection of dental design files from clients. The dynamics of this system means that all scanners used in laboratories in combination with DWOS are connected to DHS and the order requirements, file transportation and order tracking are catered to with this system. The DHS facilitates a global synergistic platform for technical support people and service centres to access real-time accountability and traceability. All DWOS users are DHS enabled and have connectivity to an ever-growing open dental forum.

CAM HARDWARE

When laboratories receive a digital impression, they can create a printed/milled model from the data, either to fabricate a restoration traditionally or to check a digitally produced restoration. Alternatively, the laboratory can do all of the design work directly on the computer based on the images received.

Some digital machines use CAD/CAM resin (polyurethane) models which are not subject to voids, shrinkage or expansion of materials or defects. The models are strong and durable with excellent marginal adaptation and resistant to abrasion and chipping. Other systems utilize stereolithography (SLA) which provides a solid model and a working model.

The production of the desired restoration obtained from CAD can be done at either the dental laboratory or at an off-site milling centre. The actual fabrication can be achieved with either a subtractive or an additive technique.

The subtractive technique which is most commonly used involves cutting the coping or framework from a solid block. The milling time and type of milling instruments used depends on the block type (green-stage, pre-sintered or fully sintered). The milling size of the coping or framework depends on material shrinkage during sintering. Sintering is needed to achieve strength for green stage and pre-sintered blocks.

The additive technique involves building a coping or framework by adding material to a die.

Selective laser sintering or melting is another way to produce metal frameworks. Laser sintering collects CAD data to create a 3-D freeform object. Thin layers of a heat-fusing powder are fused with a scanning laser beam to create a single coping or framework.

The most sophisticated machines are 5- to 9-axis simultaneous milling machines with multi-tool changers, tool sensors and breaker detectors (Fig. 6).



Fig. 6 Multiaxis machining is a manufacturing process where computer numerically controlled tools that move in 4 or more ways are used to manufacture parts out of metal or other materials.

Dry or wet milling is achievable. This type of machine is unparalleled for milling complex implant situations.

CONCLUSION

Digital technology has totally altered the capabilities of the dental team to communicate without the constraints of time or geography, thus producing easily accessible and transmittable records. Lab-side CAD-CAM technologies – increasingly involved in the production of prosthodontics (including implants) and removables are set to permanently change the visage of dentistry and, in many cases, clinical outcomes. ♦

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