The digital domain

Brenda Baker and **David Reaney** look at how to make the most of the opportunities provided by the brave new world of digital dentistry

Education aims and objectives

The aim of this article is to explain how the disparate elements of digital processes in dentistry work, fit together, and benefit the practioner and parient alike.

Expected outcomes

Correctly answering the questions on page 50, worth one hour of verifiable CPD, will demonstrate that the reader understands key terminology and functionality of the digital dental workflow.

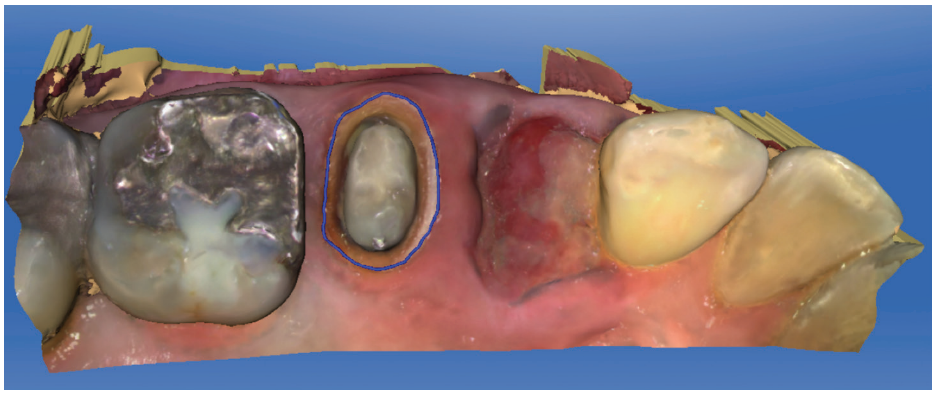

Figure 1: Margin marking is a feature of digital systems

The advent of digital technology has had an impact on almost every facet of dental practise.

Modern dentistry uses computerised radiographs, practice management software with computerised databases, and even allows practices to scan documents to create digital records. Other technologies that provide information to clinical practise include digital cameras, intraoral cameras, digital impression units, caries detection units and tooth colourimetric 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), more generally referred to as CAD/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 in used.

Dental CAD/CAM technology was developed to address three challenges:

- Ensuring adequate restoration strength, especially in the posterior
- The creation of natural and aesthetic restorations. Demographics combined with increased demand for aesthetic dentistry has resulted in a rise in the number of fixed restorations being provided
- Facilitating production of restorations to be easier, quicker and more accurate.

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

This article will focus on the dentist-laboratory digital communication channels that 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:

- The dentist can take a digital impression and send this to the laboratory. There are several examples of digital impression units (stand-alone configurations), which include the Cadent Itero, the True Definition scanner (3M Espe), the Cerec AC Connect (Sirona), E4D Sky (Planmeca), the Fastscan (Ios Technology) and the Trios (3shape).
- The dentist can use their own computer-aided design and mill in-house. Chairside CAD/CAM systems have manufacturer-specific software programs that permit the production of single tooth ceramic or composite inlays, onlays, veneers and crowns. However, these in-house units have finite capabilities in terms of their material and dimensional span limitations. Complex and larger restorations, particularly for customised zirconia and metal abutments, implant-supported crowns, bridges and overdentures require laboratory manufacturing.

There are two prevailing available chairside CAD/CAM systems that 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

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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	**Two types:** A. Filler particles added to glass before firing B. Filler particles grown inside glass after glass formation	Leucite-reinforced applications eg: machinable blocks IPS Empress Esthetic Lithium disilicate eg: IPS E.max
Zirconium-reinforced ceramic	Lithium silicate reinforced with 10% zirconia	eg: Suprinity
High-strength polycrystalline	Zirconia – can exist in several crystal phases dependent upon addition of: • Magnesia • Calcia • Ceria or • Yttria.	Types of zirconia: • Monolithic (FMZ) • 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
Hybrid ceramics	Resin nano ceramic	eg: Lava Ultimate CAD/CAM restorative
	Ceramic/polymer	eg: Enamic

Table 1: Choosing the correct material

the laboratory to make restorations of greater magnitude and complexity.

The role of the dentist

Digital impression techniques

An accurate final representation of the intraoral situation is crucial for both conventional and digital impression techniques (Figure 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 can obscure the surface of the tooth or margin from the camera and prevent an accurate recording.

When this happens, 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 visualisation 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 0.5mm of the tooth/root surface apical to the margin.

Digital scans should also include capture of the interocclusal registration. If the dentist can carefully follow the scanning procedure and check 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 to help with this. The accuracy of scanning the occlusion and occlusal surfaces helps to reduce the time needed for minor occlusal adjustments at the issue appointment.

Clinic-laboratory communication

The combination of digital scanning and digital photography offers 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 and Schoenbaum, 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. Alternatively, images can be uploaded via a secure 'file transfer protocol' server (FTP) or through an online collaborative website. FTP can also be used to transfer files between computers on a network.

This process 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

Understanding the compositional nature of the material will enable the clinician to see that with proper case selection and optimal preparation, and by following the correct guidelines for both indications and suggested preparation procedures, a successful outcome is likely (Table 1).

Monolithic or layered restorations?

According to Newton and colleagues (2014), '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'.

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 (380-1,000 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 is a more frequently used option due to both 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 is used for the coping. The coping could be constructed from 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 (such as Lava DVS, for example) allow characterisation 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 (such as 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 aesthetically undesirable and there is inadequate space for a porcelain-fused-to-metal crown. If monolithic zirconia crowns are surface stained and the occlusion needs adjustment, the restorations may need to be re-glazed. 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.

Monolithic restorations in the anterior require a high-translucency material such as lithium disilicate, in order to meet aesthetic demands (Figure 2).

One new version of this on the market

Figure 2: Aesthetic results are achievable with monolithic restorations.

Figure 3: This monolithic zirconia crown was suitable for a bruxer

GLASS –BASED CERAMICS	**Leucite-based** **eg: IPS Empress Esthetic**	Veneers
	Lithium disilicate **eg: 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-supported crowns Overdenture implant abutments
	Porcelain-fused-to-zirconia	Posterior multi-unit bridges Single posterior crowns Single anterior crowns Implant-supported crowns and bridges Customised gingival flange areas in aesthetically critical areas
HYBRID CERAMICS	**Resin nano ceramic** **eg: Lava Ultimate CAD/CAM restorative**	Use with titanium base for implants Implant-supported crowns Crowns Inlays/onlays Veneers
	Ceramic polymer **eg: Vita Enamic**	Minimally invasive reconstructions Posterior restorations Reconstructions in cases of limited space available Reconstructions of minor defects (eg: cervical veneers and so on) Veneers and non-preparation veneers Premolar and molar crowns Onlays/inlays

Table 2: Material indications

comes from Vita, called Suprinity, a zirconium-reinforced glass ceramic. Like IPS E.max, Suprinity requires machine crystallisation.

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 indicates 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 et al, 2012).

Short-term clinical data suggests that zirconia-based fixed dental prostheses may serve as an alternative to metal-ceramic fixed dental prostheses in the anterior and posterior dentition (Raigrodski et al, 2012) (Figure 3).

Table 2 shows the indications for a number of materials.

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.

The box out 'Ideal preparation for all-ceramic restorations' (overleaf), as well as Tables 2 and 3, highlight some of the key points to consider when preparing a range of restorations.

Implications for dental practice

CAM-only and copy milling systems allow some flexibility to compensate for discrepancies that 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 standardised 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 computerised systems record the

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

digital impression to a data file in the software program provided by the manufacturer. The initial versions 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 the 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 stand-alone digital impression 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 lead manufacturers of computerised 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 formats. This is defined in the international DICOM (Digital Images and Communications in Medicine) standard (Pianykh, 2012). The International Organisation for Standardisation (IS0) has made this the referenced standard for image format and communications.

This assists and promotes 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 and so on).

The DICOM standards committee has 27 active working groups, including WG22 (Dentistry). A project was initiated by WG 22 in 2011 that will extend the DICOM standard to the prosthetics value chain (integrating images in dental manufacturing technology) and can be summarised as the establishment of standards between:

		Reduction	Finish line depth & configuration
Anterior crowns	**All-ceramic/hybrid ceramic** IPS E.max or IPS Empress Esthetic	2.0mm incisally 1.0mm buccal/lingual	0.8-1.0 mm shoulder
	Porcelain-fused-to-zirconia	2.0mm incisally 0.6-1.0mm lingual aspect (Porcelain guidance requires greater clearance)	>0.4mm chamfer lingually >1.0mm labial
	Metal-ceramic (porcelain-fused-to-metal)	2.0mm incisally 0.5-1.0mm lingual aspect (Porcelain guidance requires greater clearance)	1.5mm labial shoulder or heavy chamfer 0.5mm lingual chamfer 1.5mm circumferentially for 360-degree ceramic margin
Posterior crowns	**Full contour crowns** (metal/zirconia/hybrid)	1.0mm non-functional cusps 1.5mm functional cusps	0.3-0.5mm shoulder or heavy chamfer
	All-ceramic (veneered or monolithic) IPS E.max or IPS Empress Esthetic **Porcelain-fused-to-zirconia**	2.0mm non-functional cusps 2.5mm functional cusps	1.0mm shoulder or heavy chamfer
	Metal-ceramic (porcelain-fused-to-metal)	If metal occlusal, as with FCC 2.0mm non-functional cusps 2.5mm functional cusps	1.5mm labial shoulder or chamfer 0.5mm lingual chamfer (metal collar) 1.5mm circumferentially for 360-degree ceramic margin

Table 3: Suggested preparation features for crowns

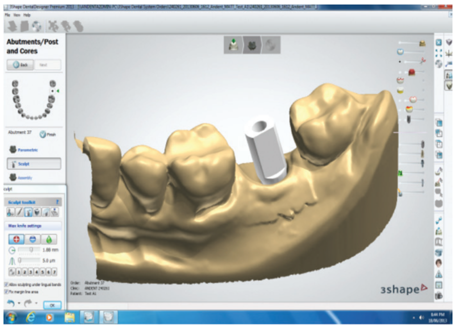


Figure 5: Digital technology is used to fabricate abutment

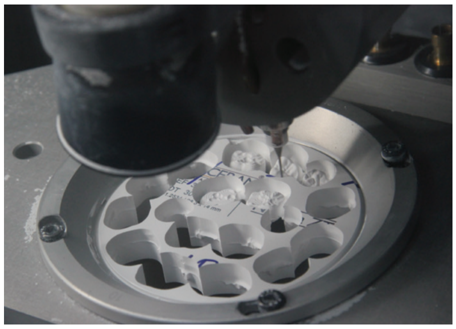


Figure 6: Multiaxis machining is a manufacturing process where computer numerically controlled tools are used to manufacture parts out of metal or other materials

• Dental scanners and dental design software

• Dental design software and manufacturing devices.

Another initiative to standardise design software occurred in 2011, when 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 DWOS, the software platform of Dental Wings, as the basic operating solution in their CAD/CAM systems.

A technician could design a customised 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 three-dimensional 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 (Figure 4).

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 five icons in the menu bar of DWOS that show the basic workflow and which can be summarised 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 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 five modules, which can be used independently or as an integrated suite. These modules are:

• 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

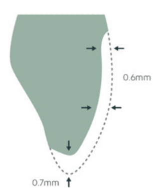
• The implant custom abutment: strategic designing of this module means that one-step planning of custom abutments can be done that considers the clinical situation. The topography of the patient's implant site is automatically computed to fit the designed implant abutment. DWOS features an integrated 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 that uses a scan body for implant hex position and height is shown in Figure 5

• Partial frameworks: this module allows automated functions such as undercut measurement and block-out and unrestricted design tools that transfer technical information to a digital environment

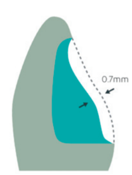
• Virtual model builder: the aim of this function is to generate a virtual model that can be produced with the preferred manufacturing solution

• Manufacturing modules: there are two manufacturing modules, called DWOS-

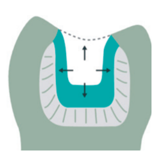
Veneer
• ≥0.6mm labial and cervical reduction (do depth cuts)
• ≥0.7mm incisal reduction
• Incisal preparation margins must avoid areas of static or dynamic contact
• Bevel the incisal one third back to the lingual incisal edge
• Lingual preparation is not needed on all veneers. It can be used on the 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 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
• 6^0 sidewall taper
• Proximal box should be diverging walls
• [Inlay bridge] – contraindicated.



Ideal preparation for all-ceramic restorations

Table 4: 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 pre-cementation 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 2. With minimal or reduced retention	RMGI (useful because of fluoride release) Resin cement with prior application of separate self-etching bonding agent

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 paths and curves for milling. DWOS-RPM provides automatic generation – for example, 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.

Computer-aided manufacturing 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 use 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 three-dimensional 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 (Figure 6).

With these, dry or wet milling is achievable. This type of machine is unparalleled for milling complex implant situations.

Conclusion

Digital technology has totally altered the capability 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 face of dentistry and, in many cases, clinical outcomes.

Care to comment? @AesDenToday

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