Contents

Fundamentals of CAD/CAM Dentistry

The American College of Prosthodontists

Acknowledgments

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Preface

This book is meant to be used as a supplemental learning tool along with the ACP's Digital Dentistry Curriculum. The book is structured into fifteen sections, compiled into two main chapters. The sections include learning objectives, supporting material, summaries and reading lists.

The American College of Prosthodontists is working to ensure that prosthodontists are prepared to lead the emergence of digital dentistry in clinical practice. To access and view additional resources available, please visit the Digital Dentistry Resources page of the ACP website.

We hope these learning tools will be instrumental in your Digital Dentistry education.

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Part One

1.1

THE HISTORY OF CAD/CAM IN DENTISTRY

LEARNING OBJECTIVES

Upon completion of this section, the reader should be able to:

1. Understand the basic components of dental CAD/CAM technology.
2. Discuss the evolution of dental CAD/CAM technology.
3. Identify areas of dentistry to which CAD/CAM technology can be applied.

1.1

Introduction

Dental computer-aided design (CAD) and computer-assisted manufacturing (CAM) technology is essentially a combination of three processes: data or image acquisition; image or information analysis and manipulation, or computer-aided design; and fabrication, or computer-assisted manufacturing. Data is acquired through a variety of techniques that capture relevant images, such as digital scanning or digital photography. Software is then used to render, analyze, and manipulate the images. Milling units or three dimensional (3D) printers are then used to fabricate the CAD-created restorations or treatment components.

First developed in the 1940s for industrial and engineering applications designed to make machining complex parts in large numbers easier and faster, CAD/CAM systems were initially used in the automotive and aerospace industries. CAD/CAM wasn't introduced to dentistry until the 1970s, when François Duret first conceived of how these technologies could be applied to the profession. His original rationale was that by using computer-controlled machine tools, a dental restoration could be fabricated with less effort, less variability, and at reduced production costs. While this model worked well for other industries, a fundamental challenge for using CAD/CAM in dentistry was that each part—or dental restoration—is uniquely different because it must fit a tooth preparation for an individual patient.

The application of technology to the creation and fabrication of dental restorations was later refined in the 1980s by Dr. Werner Mörmann with the development of the CEREC System (Sirona) for same day chairside restorations. He succeeded and was able to produce a ceramic inlay restoration using computer-assisted technology, the acronym for which stands for Chairside Economical Restoration of Esthetic Ceramics.

Despite many initial difficulties in this first effort (i.e., creating detailed occlusal morphology and achieving acceptable marginal fit), the first CEREC restorations were composite inlays that were heat processed and cemented with resin cement. Early studies of these restorations revealed degradation at the composite inlay margin, which was improved upon with the introduction of ceramic as a material for inlay fabrication.

With this pioneering system, an intraoral camera was used to measure or scan the intracoronal tooth preparation, the inlay was then designed, and the restoration carved from a solid block of ceramic material by a milling machine small enough to be located in the dental office. This system was the first operational system that could produce same day ceramic restorations and quickly became the leader in CAD/CAM dentistry.

Dr. Matts Andersson subsequently developed a CAD/CAM system for producing titanium copings (NobelProcera® CAD/CAM System, Nobel Biocare). In the early 1980s, base metal alloys were gaining popularity in dentistry due to a drastic increase in the price of gold. There were reports of patient allergic responses to the nickel in some of these alloys, along with risk of exposure to beryllium toxicity by the dental technician. In response to these negative side effects, the use of titanium was suggested. However, traditional lost wax techniques for casting titanium were considered problematic, so Dr. Andersson proposed fabricating titanium copings by spark erosion and composite veneers using CAD/CAM technologies. This evolved into a successful commercial manufacturing system whereby dies were scanned, restorations designed, and all-ceramic materials used for milling in centralized production facilities. This concept of networked production systems spread and was utilized by a number of companies.

Although dental CAD/CAM applications have expanded to multiple teeth restorations, implant abutments and surgical guides, and full-arch dentures, early CAD/CAM systems were limited to single tooth restorations, such as inlays, onlays, crowns, and veneers. Additionally, the hardware and software of early systems only enabled a two dimensional (2D) view of the scanned images, since the associated computer's capacity was unable to store the data required for 3D images.

1.1

Since then, a variety of manufacturers have introduced CAD/CAM "systems" and/or components for both dental practices and dental laboratories. CAD/CAM hardware, as previously described, includes a digital scanner, a computer, and production equipment (e.g., milling unit or 3D printer).

Although image manipulation and restoration design are completed using CAD software, the manufacturing itself requires CAM software to enable a fully automated process. Depending on the software, CAM capabilities today could include production of multiple restorations based on specific parameters (e.g., material, restoration type). Although early CAM software only allowed variations in material, currently available options enable greater productivity, process control, and cost-efficiency.

The CAD/CAM "systems" available for dentistry range from complete systems that scan, design, and mill, to those that only perform certain functions, such as digital scanning only, exclusively designing restorations, or only milling restorations. As a result, today it is possible for fabrication and production of restorations to take place in three environments: chairside in the practice; dental laboratories; and milling centers.

Among the complete "systems" introduced has been the E4D Dentist System (formerly E4D Technologies), which is now known as Planscan (Planmeca) in 2008 for same day CAD/CAM dentistry in the dental practice *(Figure 1.1-1)*. Its differentiating innovation was its unique and open architecture that enabled integration of select workflow components (e.g., digital scanners, CAD software, milling unit), rather than the entire system, according to user preferences.

Fig. 1.1-1 *The Planmeca PlanMill® 40*

Other chairside CAD/CAM systems (i.e., in dental practice) available today include CEREC® AC from Sirona, LAVA™ COS from 3M ESPE, iTero® from Cadent, and Trios from 3Shape. However, of these, only the CEREC AC has CAM capabilities incorporated. The LAVA COS, iTero, and Trios are considered dedicated, stand-alone digital impression systems. For laboratories, the CEREC inLab® MCXL milling unit is available.

Digital Impression/Scanning Devices

Digital impression systems refer to the hardware (i.e., computer-based cameras or scanners) that captures digital images of the teeth and soft tissues, or analog models and impressions, and the software required to manipulate the images and manage patient information. The first intraoral scanner required the use of a powder (i.e., titanium dioxide) to ensure acquisition of accurate digital images. Today, a variety of "powderless" digital scanners are available. Digital impression intraoral scanning devices were originally a part of complete in-office CAD/CAM systems (e.g., CEREC; E4D

Dentist/Planscan) produce a digital impression of prepared teeth but, again, are now available as stand-along devices.

The benefits of digital impression taking include eliminating the need for alginate or elastomeric impression materials and their accompanying impression trays and increased patient comfort. Rather than following cumbersome analog procedures, a scanning wand is used to digitally capture the impressions.

Intraoral scanning systems optically (digitally) scan objects using one of two techniques: amplified light (i.e., laser beams) or visible light (i.e., light beams). The software associated with the scanners processes the images either on a computer in the dental practice, or transfers them via the Internet to a laboratory or milling center.

Regardless of how they are captured, digital impression images can be viewed instantly on a computer screen and transformed into a virtual model. The ability to instantly evaluate the image (i.e., digital impression) quality allows the dentist to identify potential problems (e.g., incorrect preparation design or unclear margins) and correct them, then retake the image. Transferred to laboratories electronically, these digital impressions can then be used to create traditional (i.e., cast stone) or virtual (i.e., digital) models, or as part of the CAD/CAM restoration fabrication process (i.e., milling or 3D printing). Alternatively, the files can be used for digitally designing milled restorations chairside (i.e., in office CAD/CAM). If the dental practice does not use digital impression technology, an analog impression and/or model can be taken and sent to a CAD-capable laboratory for scanning.

Dental CAD/CAM Software

After scanning images, digital impression files are typically saved in .stl format. However, different digital impression system manufacturers may use a proprietary version of this file type that precludes its use with systems available from other manufacturers (i.e., closed system). This restricts dentists and laboratories to only using the computer design system/software and production unit (i.e., mill or 3D printer) specifically intended for that specific digital impression system. Fortunately, this is changing and, in recent years, digital dental technology companies have set aside the proprietary nature of their systems to accommodate an “open architecture” that provides dentists and laboratories with greater flexibility in terms of the hardware and software they choose. As a result, more dentists can work and collaborate with a wider variety of laboratories and specialists, since they are no longer confined to working with the systems their colleagues use.

In general, however, CAD software automatically recommends a standard restoration type or design. This recommended restoration design can then be refined by the operator (e.g., dentist, dental assistant, laboratory technician). Refinements typically involve margin placement, emergence profile, material thickness, and cusp morphology. Some software enables users to overlay a virtual wax-up of proposed restorations onto the virtual preparation to fine-tune restoration dimensions.

Additionally, today’s CAD software provides a variety of tools for additional modification, including adjusting the occlusion, height of contour, and interproximal contacts. In recent years, an assortment of CAD libraries has been developed to enable greater ease of restoration design.

Use of CAD techniques and today’s dental CAD software helps to enhance productivity, improve restoration design quality, and facilitate collaborative communication between dental treatment team members. A variety of dental CAD/CAM software is available, with capabilities and applications ranging from restoration design to orthodontic analysis, and from implant surgical planning to disease monitoring. But, overall, CAD software enables the user to design a restoration or prosthesis from start to finish by replicating the same processes (e.g., margin placement, block out of undercuts, anatomical modifications) typically performed by a dental technician.

CAM Fabrication

While industrial computer numerical control (CNC) machines use variety of tools (i.e., drills, saws, lathes) to the intended parts and components, dental milling machines use burs. Because the manner in which these milling units will be used varies (i.e., a few restorations produced per day or week; hundred to thousands per week or month), cost, size, and production mechanisms and capacity vary significantly among available systems.

Essentially, dental milling units use a subtractive process that removes material from a block produce restorations of the shape and size determined by the dentist using CAD software. The efficiency of the milling units depends upon a number of factors, including the number of axes and burs it contains. Original chairside or desktop milling units typically operated with three or four axes and were designed for light production volume and uncomplicated restorations. Today, however, chairside and desktop milling units are available with five axes, which enables control of the grinding tool in three linear planes and two rotary axes *(Figure 1.1-2)*.

Figure 1.1-2 *The Roland DWX-50 5-Axis Dental Milling Machine*

Production laboratory and milling center CAM units use five axes and are typically larger, faster, and inclusive of robotic automation for handling the material and restorations *(Figure 1.1-3)*. They also function with a higher level of precision.

Figure 1.1-3 *The HAAS VF-2TR – Axis Vertical CNC Machining Center*

However, additive manufacturing processes (i.e., 3D printing) are being used increasingly in dentistry for producing orthodontic aligners, surgical guides, removable and implant-supported dentures, and fixed restorations. Whereas milling units remove material using burs, 3D printing adds material through an additive process.

Dental CAM Material Diversification

Original dental CAD/CAM materials included feldspar-based, fine particle ceramics that were compressed into a blocks (e.g., Vitablocs Mark I, VITA). However, in the late 1980s, fine-grained, high glass content feldspar-based ceramic (Vitablocs II, VITA) was introduced, followed in 1997 by a ceramic alternative composed of resin-based silica (e.g., Paradigm MZ100, 3M ESPE). Since then, a variety of metal-free options have been introduced to meet the need for esthetic and durable materials capable of being processed through CAM methods. These included reinforced resin ceramic (e.g., LAVA Ultimate CAD/CAM, 3M ESPE), lithium disilicate (e.g., IPS e.max CAD, Ivoclar Vivadent), ceramics (e.g., LAVA, 3M ESPE; Cercon, DENTSPLY), and high-strength ceramics (e.g., alumina, zirconia).

In recent years, manufacturers have introduced material blocks that exhibit shade variations among cervical, body, and incisal aspects in order to more easily process CAD/CAM restorations that demonstrate superior, naturallooking esthetics. These materials currently include IPS e.max CAD Multi (Ivoclar Vivadent), as well as Vitablox Triluxe Forte and Vitablocs RealLife (VITA).

1.1

Today, dental CAD/CAM systems enable users—whether dentists or laboratory technicians—to design and produce a final restoration within minutes, not hours or days.

Additionally, the role of other technologies (e.g., cone beam computed tomography) in the dental workflow is expanding, particularly when combined with digital intraoral impressions and facial scanning technology. On-going enhancements to CBCT hardware and software are making the technology more applicable for routine dentistry, as well as for such specialties as endodontics, implantology, and orthodontics.

In fact, with CAD/CAM processes, orthodontic treatments are now being performed differently, with almost every treatment phase capable of being virtually programmed before tooth movement begins.

1.1

Summary

Overall, dental CAD/CAM affords dentists and their properly trained team members—as well as dental laboratories—greater control over the restorative process, and patients benefit from enhanced comfort and convenience (e.g., no uncomfortable or unpleasant impression materials in their mouth, reduced gag reflexes, enhance restoration quality and durable).

New workflow models are facilitating enhanced collaboration, and restorations that once took weeks now require mere hours. These workflow models allow delivery of same day anterior and posterior full-coverage restorations and partial coverage restorations; thorough treatment planning of veneers; enhanced patient involvement and planning of anterior restorations; and more precise and predictable implant treatments.

However, fixed restorations are just the beginning. Whether produced via CAD/CAM milling processes or in combination with 3D printing, removable prosthodontics are also being transformed by technology and new digital workflows.

With digital workflows for removable prosthodontics, dentists and laboratories can better facilitate treatment planning, try-in, and delivery of final dentures in fewer and more convenient appointments, providing dentures with better fit and greater comfort, enhanced durability, and more life-like esthetics.

Clearly, there is a lot to learn, and dental education is embracing digital processes to enhance preclinical education and student evaluations. In particular, computerized preparation evaluation is transforming how students learn and practice tooth preparations, providing opportunities to refine their skills and develop confidence that they are working toward the ideal.

1.1

Supplemental Reading

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1.2

DIGITAL SCANNING AND ITS APPLICATIONS

LEARNING OBJECTIVES

Upon completion of this section, the reader should be able to:

1. Understand the components of digital dental scanning systems, whether stand-alone, part of complete CAD/CAM systems, or benchtop scanners.

2. Discuss the differentiating characteristics among various types of digital dental scanners.

3. Explain the applications for digital dental scanners and their accompanying software alone, as well as in combination with CAD/CAM systems.

1.2

Introduction

In dentistry, taking an impression is the process of acquiring and transferring anatomical information for the purpose of creating indirect restorations (e.g., inlays, onlays, crowns, veneers, implant abutments, and fixed or removable prostheses). This technique-sensitive procedure is essential for providing well-fitting, functional, and esthetic restorations, as well as treatment planning surgeries and orthodontic movement.

Unfortunately, despite enhancements to the ease of use, detail reproduction, high elastic recovery, and dimensional stability of various analog elastomeric materials used for capturing impressions (e.g., polyvinyl siloxane, polyether, hybrids), obtaining an accurate reproduction of the oral anatomy using traditional techniques is wrought with the potential for errors both in the dental practice and at the laboratory. Among them are patient discomfort, delays and increased chair time, need for additional appointments, and unpredictable restorations that must be remade.

For example, trays required for delivering analog impression materials to the mouth may damage soft tissues, inadequately conform to the patient's oral anatomy, and contribute to patient discomfort (e.g., gag reflex, anxiety). The impression materials may become unpredictable when placed in the mouth (i.e., react with oral fluids), and often cannot be removed for several minutes to help ensure that they have set completely and captured a high level of intraoral hard and soft tissue detail. Additionally, other types of impressions are needed for fabricating properly fitting restorations besides those of the affected teeth, such as impressions of the opposing arch and the patient's bite in the area of concern (i.e., bite registration).

Assuming the impressions are acceptable and free of voids, tears, or bubbles that could affect the quality of the fabricated restorations, they must then be used either in the dental practice or laboratory for pouring stone models. This process, also, can present difficulties in terms of proper mixing and accurately identifying margins.

Fortunately, the introduction of digital intraoral scanning (IOS) and benchtop scanning to dentistry enables dentists and laboratories to eliminate many of the problematic techniques and characteristics associated with making traditional, analog impressions and models. Simultaneously, digital scanning, when combined with computer-aided design (CAD) and computer-assisted manufacturing (CAM) processes, also allows dentists and laboratory technicians to use innovative yet proven restorative materials to create restorations demonstrating greater accuracy of fit, anatomical form, esthetics, and strength. Accuracy is inherent in the digital impression and not affected by factors such as material distortion, improper model handling, improper model pouring techniques, inaccurate trimming and margination of dyes by an outsourced technician who did not create the preparation. In essence, digital dental scanners replace traditional analog impression materials and techniques with a technological and software driven approach for accurately and efficiently capturing and duplicating essential clinical information.

As a result, digital impressions have made the impression-taking process more efficient and cost-effective. These digital impressions can then become part of the patient's file, used for designing and fabricating restorations either in the dental practice or dental laboratory, shared among members of the treatment team (e.g., restorative dentist, oral surgeon, periodontist, laboratory, etc.), and used for collaborate treatment planning in new and exciting ways. Additionally, almost any type of restoration can be designed and fabricated from a digital impression.

What remain significantly important to the success and predictability of both analog and digital impression processes, however, are preparation design and the gingival retraction techniques employed to ensure clear and unobstructed access to, and visualization of, the margins, finish lines, and gingival contours.

Additionally, understanding digital dental scanning technology—and its capabilities and roles in emerging dental process workflows—is also beneficial for maximizing accuracy, efficiency, and integration of this paradigm-changing tool.

1.2

Components of Digital Scanners for Dentistry

Differentiating the capabilities and applications of IOS and benchtop scanners in dentistry are the camera type and image capturing mechanism, type of light transmitted from the scanning device, architecture (i.e., open, closed), and whether they are stand-alone digital scanning systems or components of a complete dental CAD/CAM system. Additionally, the features and benefits of digital dental scanning systems vary and ultimately influence their ease-of-use and functionality. These attributes include IOS wand size, benchtop scanner size and camera operation, powder-coating requirements, scanning method, and color capture capabilities, among others.

Camera

Digital scanners for dental applications record information by capturing images via a scanning device and camera. The camera component of digital scanners records details of either the intraoral condition or analog objects (e.g., elastomeric impressions, stone models). Initial offerings essentially scanned a series of single images that were stitched together to form a virtual model; image quality and computer speed were factors limiting the size and details of the resulting digital models.

IOS scanner cameras are typically contained in a scanner wand, while benchtop scanner units usually house two cameras or sensors attached to a rotation mechanism; the objects being scanned are rotated (i.e., 3-axis or 5-axis) to allow the scanner to accurately and completely capture details from multiple perspectives.

Today's IOS cameras are more compact and approximately the size of a dental handpiece. Although these smaller cameras promote better intraoral access and easier scanning, they may not facilitate sufficient range of motion for full-arch scanning. However, if slightly larger camera bodies are ergonomically designed, for easier maneuverability, then intraoral scanning of the complete arch may be possible.

Original benchtop scanners used tactile probes for scanning analog objects (e.g., analog impressions, stone models), but today typically use light triangulation (e.g., laser or striped light), which projects light onto the object, with sensors capturing and converting the details into a 3D image. Some benchtop scanner cameras use high-resolution devices to record detailed information (e.g., surface texture) but, like some intraoral scanners, may require the use of a reflective powder coating. Scanning capabilities range from scanning dies to recording data for full-arch patients, to scanning analog casts and impressions to scanning articulated models; some benchtop scanners may be limited to only scanning casts created from scannable gypsum.

Light Source/Image Capture

Currently available digital scanning systems—whether intraoral or benchtop—emit different types of light (e.g., laser, structured (striped) light, visible light, or light emitting diode [LED] illumination) through their cameras to capture data via sensors that will ultimately be manipulated by computer software to create a three dimensional (3D) image. Original digital dental scanners required application of a light-reflective titanium dioxide powder on the object being scanned prior to taking digital impressions. Many updated scanners are now powderless, eliminating the additional step to further increase patient comfort and/or improve efficiency.

Light beam scanners acquire images of the teeth or analog models from different positions which are then combined and rendered into a 3D visual representation in one of three ways: still image capture (active triangulation); video capture (active wavefront sampling); or real-time imaging (ultrafast optical sectioning). Active triangulation dental scanners acquire images by emitting three linear light beams that intersect to identify a particular point in a 3D space. Active wavefront sampling scanners (e.g., Lava C.O.S., 3M ESPE) emit blue light through a single lens system that is detected by sensors at different angles, which then capture video images in order and assemble them into a 3D rendering; teeth or objects being scanned must be powdered coated. Ultrafast optical sectioning digital dental scanners (Omnicam, Sirona) resemble video scanners in their continuous acquisition of images of the teeth or models being scanned, but the 3D images they produce are based on real geometric data, not computerized interpretations.

An advantage of laser beam scanners, which capture images through either parallel confocal imaging or laser triangulation imaging, is their ability to acquire accurate images with precise detail without needing to use a reflective coating. Parallel confocal digital dental scanners emit parallel laser beams and optical scanning filtered light through the scanner head, which hit the object being scanned at a specific focal distance and then bounces them back through a small pinhole; only light reflected from the scanned object at the proper focal point returns through the pinhole. For highly reflective surfaces (e.g., enamel, polished or glazed porcelain, ceramic, metallic restorations), no powder coating is needed. The reflected beams are converted into digital images when they reach the sensor.

Laser triangulation intraoral scanners emit a single wavelength of red laser light as mirrors simultaneously oscillate to acquire still images of the object being scanned from multiple perspectives. This contributes to greater accuracy, but these scanners cannot record tooth color information. The images are then converted into a 3D rendering.

File Formats/Architecture

Digital impression files are typically saved in .stl format. However, because many manufacturers maintain their own proprietary .stl file format (i.e., closed architecture), universal application of .stl digital impression files may be difficult. This type of file format is very common for complete chairside CAD/CAM systems, since one manufacturer has produced the digital scanner, design software, and milling unit; therefore, that manufacturer's digital files cannot be shared across different chairside CAD/CAM systems.

As a result, many dentists and laboratories have been faced with using a single proprietary computer design software and/or milling unit system that is compatible with the digital impression system they use. Fortunately, an increasing number of manufacturers today are more willing to open their proprietary .stl files for use with different CAD/CAM systems (i.e., open architecture).

Open architecture files are not dependent on the equipment manufacturer, can be used with a variety of design software to create a restoration, and can then be further used by any number of CAM units to produce dental restorations, regardless of the milling unit's or 3D printer's manufacturer. This enables dentists and laboratories greater flexibility in sharing files across a variety of systems from different manufacturers and, therefore, with each other.

Complete Dental CAD/CAM Systems

Complete CAD/CAM systems include an IOS, design software, and milling unit for fabricating a restoration. Dental practices can use these systems to scan, design, and mill full-contour and partial-coverage restorations in-office. As previously described, IOS that are components of a complete dental CAD/CAM system eliminate the need for traditional analog impression materials and techniques, but rather than send digital files to a laboratory for restoration fabrication, the design and manufacturing steps are performed in the dental office. This enables practices to provide same day for many patients, making provisional restorations and follow-up cementation appointments unnecessary.

With complete in-office dental CAD/CAM systems (CERECA AC Bluecam, CEREC Omnicam, Sirona; Planscan, Planmeca)—as well as stand-alone IOS

—the scanner is used to take a digital scan of the patient's preoperative condition. These images can be viewed and evaluated with the patient chairside to enhance understanding of their condition and/or any treatments that are required. Additionally, computer software can be used to design and propose restorations to treat the identified intraoral problems, as well as demonstrate possible esthetic changes to the patient's smile.

When preparations are performed, the IOS is used to scan those, also, rather than take traditional analog impressions. A benefit of intraoral scans of preparations is the ability to view them immediately at significantly higher magnification in order to evaluate them and identify any possible problems that might negatively affect restoration fabrication (e.g., undercuts, sharp line angles). Areas requiring adjustment can be corrected, rescanned immediately, and re-evaluated.

Once the digital impressions are approved by the dentist, the computer software enables identification and marking of restoration margins on the virtual model, as well as designing of the restoration (e.g., crown, inlay, onlay, or veneer) using design tools (e.g., adjust interproximal contacts, height of contour, occlusion, morphological details). The restoration design file is then transferred electronically to the in-office milling unit for production, after which—depending upon the material used—it can be stained, glazed, and fired, then definitively cemented during the same appointment.

Stand-Alone Intraoral Scanners

Stand-alone or dedicated IOS are available today (e.g., iTero Digital Impression System, Align Technology; True Definition Scanner, 3M ESPE; IOS FastScan, IOS Technologies; Trios, 3Shape) that enable dentists to work with their preferred laboratory and/or specialist colleagues, not just those using the same proprietary equipment *(Figure 1.2-1a-c)*. This helps to facilitate communication, treatment planning, and a higher level of patient care. Stand-alone digital scanners are used for the same functions as those available with complete CAD/CAM systems (i.e., scan preoperative condition, scan preparations, evaluation, treatment planning, virtual model creation), but the extent to which restorations are designed in the dental practice may vary.

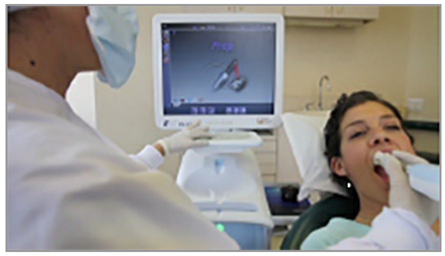


Figure 1.2-1a *Intra-oral scanning*

Figure 1.2-1b *Model scanning*

Figure 1.2-1c *Impression scanning*

The digital impression file can be sent directly to a dental laboratory for creation of a digital model and subsequent fabrication of definitive restorations, or for creation of a 3D printed surgical guide for implant placement.

Additionally, it is also possible to use an IOS to digitally scan implant abutments or scan bodies for fabrication of implant-supported restorations. Alternatively, digital impressions resulting from IOS can also be used for creating digital models that form the basis for programmed orthodontic treatment using 3D printed clear aligners.

Like IOS that are components of complete in-office CAD/CAM systems, stand-alone scanners relieve dental practices of the time-consuming processes involved with analog restorative techniques, including tray selection, dispensing and setting materials, disinfection, and shipping impressions to a dental laboratory. Laboratories also experience efficiencies by eliminating the need to pour models, cut and trim dies, or articulate models. Although the laboratory still fabricates the definitive restorations, they are created based on digital data and virtual models, not stone or gypsum models produced from analog, elastomeric impressions.

1.2

Developing virtual models and digital diagnostic wax-ups from digital scans enables dentists and laboratories to perform a variety of restorative tasks in ways that facilitate greater patient comfort and understanding of the their condition and proposed treatment plans. (Figure 1.2-2–1.2-10). Additionally, scanned images and virtual models represent significantly enhanced visual aids for diagnosing disease during consultation and collaboration, and new applications for digital impressions to enhance patient care are continually being introduced.

Figure 1.2-2 *Although the intraoral scanner was significant in identifying esthetic issues with tooth #7, what was most significant was the ability to utilize the immediately available images—along with significant magnification—to explain complicating factors to the patient for greater understanding of treatment requirements.*

Figure 1.2-3 *For example, this lingual view was useful in clearly demonstrating and explaining to the patient the need to address the extensive crack on the lingual aspect. The patient immediately accepted a treatment plan to restore tooth #7 with a full-coverage crown restoration.*

Figure 1.2-4 *The lingual view of the digital impression scan shows details of the patient's preoperative tooth morphology, soft tissue architecture, and extensive lingual crack on tooth #7.*

Figure 1.2-5 *The facial view of the digital impression scan shows the patient's upper arch in exacting detail for diagnosis, analysis, and treatment planning.*

Figure 1.2-6 *Tooth #7 was prepared for a full-coverage crown restoration, the preparation scanned, and the tooth provisionalized.*

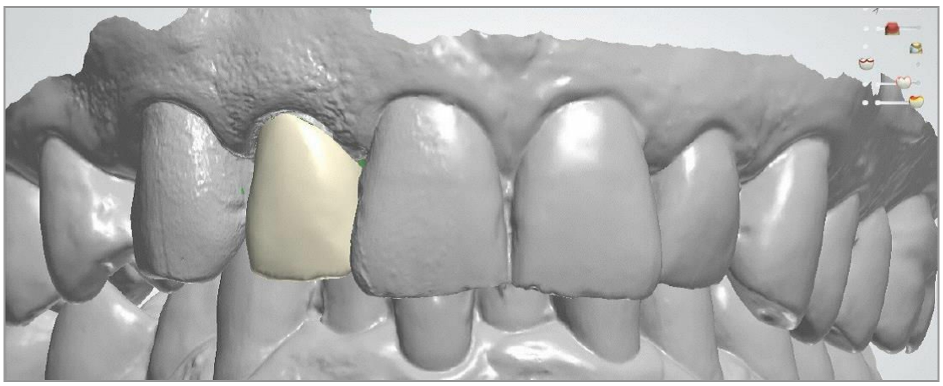


Figure 1.2-7 *The patient was pleased with the provisional restoration, which was later scanned and, using the design software, morphed to conform to the preparations to create a virtual mockup of the definitive CAM restorations.*

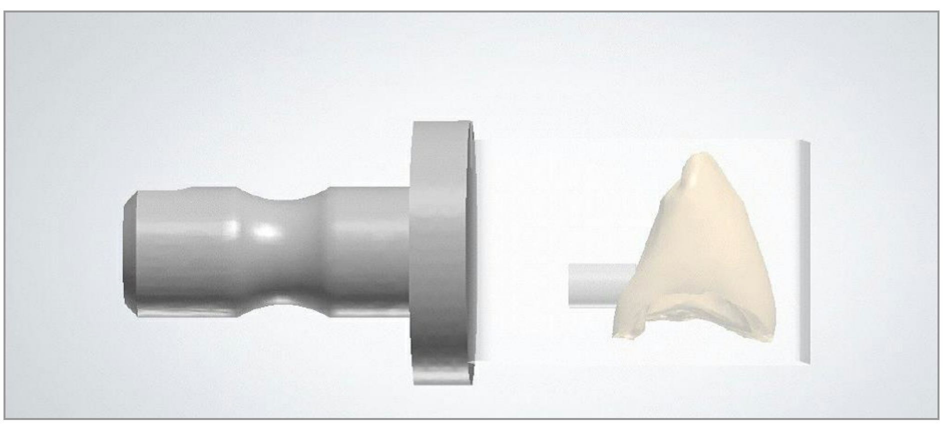


Figure 1.2-8 *View of the proposed restoration prior to milling.*

Figure 1.2-9 *After milling and prior to firing, staining, and glazing, the restoration was tried in to confirm fit.*

Figure 1.2-10 *View of the definitive in-office CAD/CAM restoration following cementation.*

Shade Matching

Whereas digital shade taking can be accomplished using a variety of photospectrometers, current CAD/CAM developments are enabling shade taking and matching with a single system (e.g., Trios, 3Shape). Early shade taking technology used digitally acquired scans to map the colors of teeth (e.g., ShadeEye NCC, Shofu Dental Corporation; ShadeVision, X-Rite Inc.). Moving forward, rather than relying on human interpretation of shade, which is wrought with errors resulting from the influence of daylight, artificial light, clothing color, and individual optical perceptions, CAD/CAM shade taking will eliminate color discrepancies and save time. With CAD/CAM shade taking, the scanner automatically detects the shades of adjacent teeth as it captures images of the affected teeth and/or preparations. Then, the identified shades can be indicated in the digital impression files and/or restoration design files.

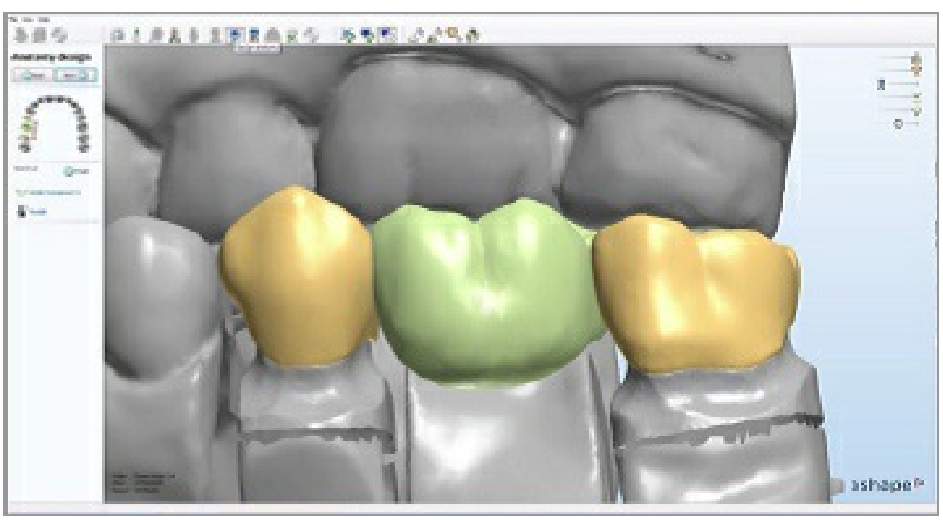
Diagnosis/Monitoring

Intraoral digital scans facilitate enhanced diagnosis of oral lesions, pathology, and dental disease. When combined with cone beam computed tomography (CBCT), these digital files help dentists to develop more objective and comprehensive assessments of a patient’s condition. Fortunately, a number of CBCT systems are available today (e.g., iCAT, Imaging Sciences International; Galileos, Sirona; Gendex, Gendex Dental Systems; ProMax, Planmeca). Integrating CBCT with intraoral scanning will also help to redefine dental procedures, particularly for implant dentistry, orthodontic/orthognathic therapies, and other oral-maxillofacial treatments.

Certainly digital caries detection tools (e.g., Logicon, Carestream) can be incorporated into the diagnostic process as a means to verify the presence of questionable lesions. Considering that the manner in which dental operatories are illuminated could influence the accuracy of visual radiograph assessment, utilization of such digital technology could enhance caries diagnostic abilities.

1.2

Similarly, other enhancements to IOS are enabling imaging of other aspects of the jaw and entire quadrants, including adjacent and opposing teeth. The relationship of the upper and lower teeth to each other can also be scanned intraorally, either via intraoral bite registrations or scanning from the buccal aspect, and the data used for designing occlusal surfaces and/or assessing uneven wear patterns indicative of occlusal issues *(Figure 1.2-11 through Figure 1.2-14)*. When this data is combined with other biometric findings (e.g., jaw motion trackers) that suggest stomatognathic disease or dysfunction (i.e., temporomandibular joint disorder), a more specific and appropriate treatment plan can be developed.



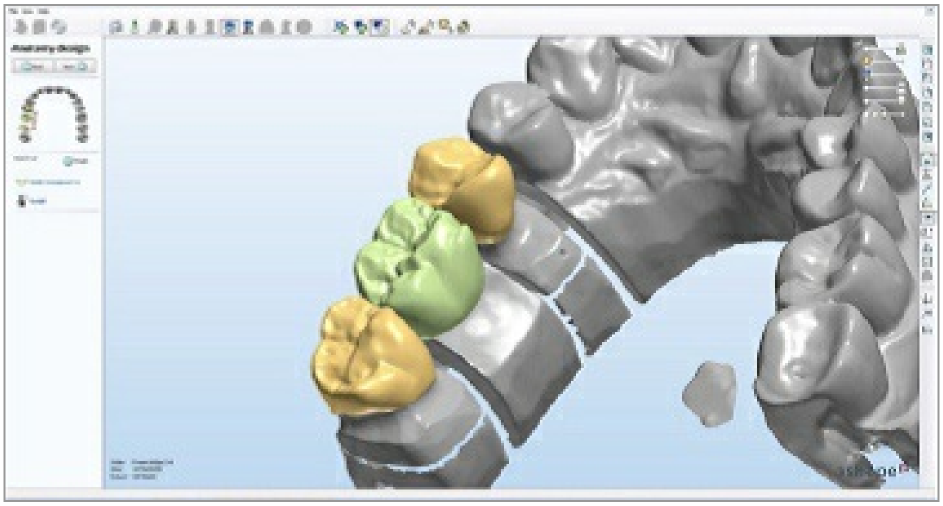
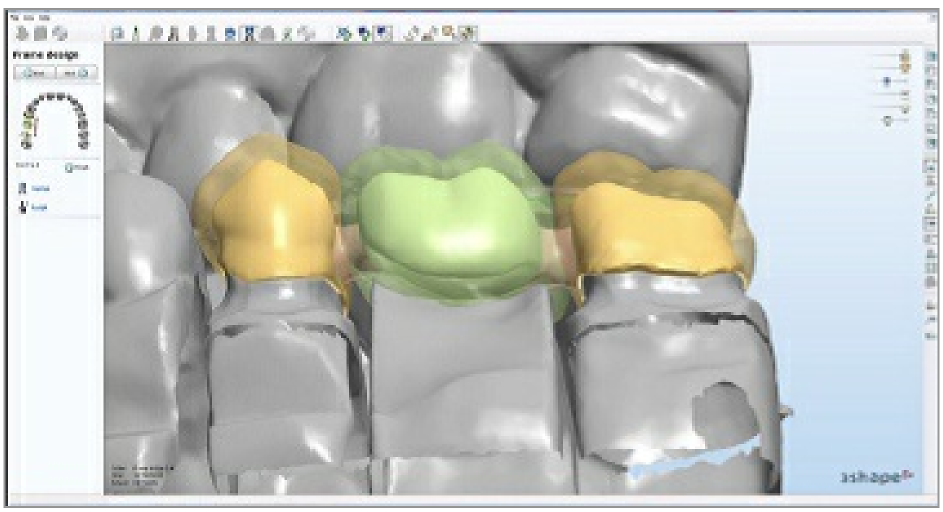


__Figure 1.2-11a-b__ Based on intraoral scans from the buccal aspect, the intercuspation of proposed maxillary restorations with the natural mandibular teeth could be analyzed, along with the occlusal scheme of the proposed restorations.



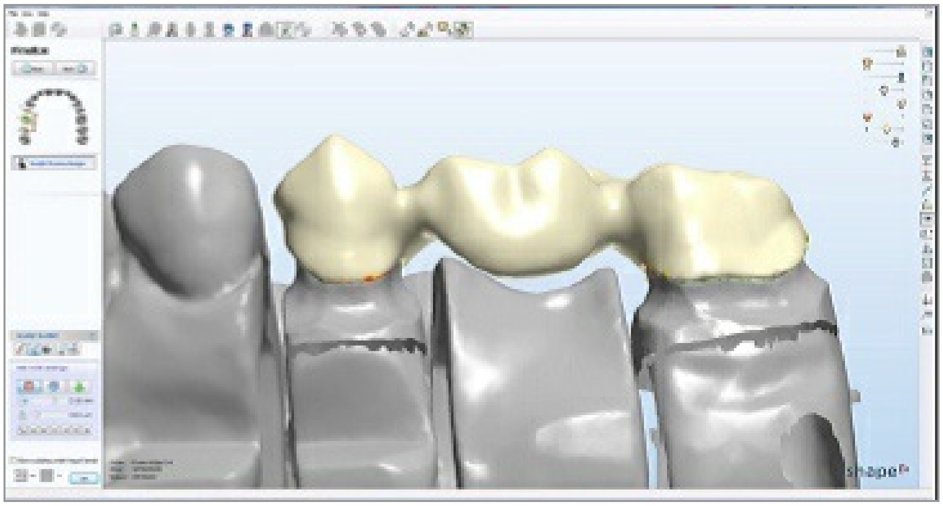


Figure 1.2-12a-b *Based on the occlusal analysis, it was determined that the anticipated 3-unit fixed partial denture should be fabricated with core material (b) overlayed with a veneering ceramic (a). File splitting capabilities enabled the software to visualize the core and veneer together.*

Figure 1.2-13a *Occlusal view of the restoration.*

Figure 1.2-13b *Buccal intercuspation view of the completed restoration.*

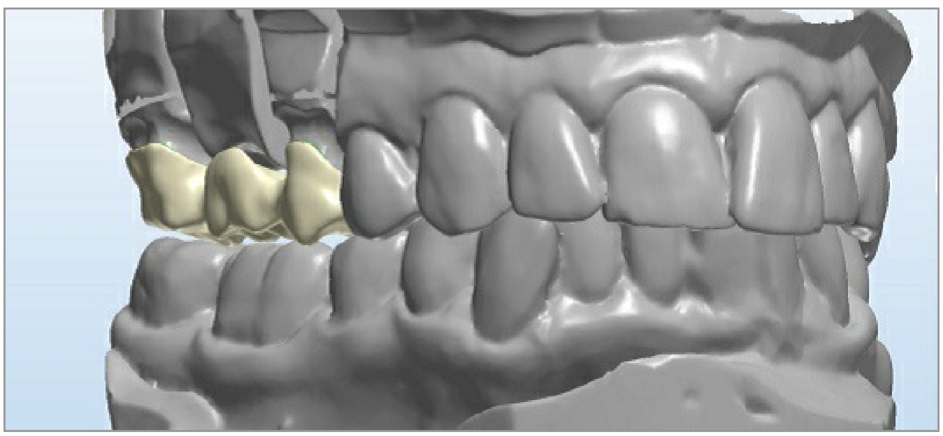


Figure 1.2-14 *Buccal view of the virtual mockup of the proposed restoration.*

1.2

Summary

Because they represent ideal tools for more accurately and efficiently capturing relevant intraoral patient information, as well as based on their ability to facilitate treatment planning and restorative processes, the use of digital impressions is rapidly growing.

To keep pace with demands for greater functionality and interoperability, manufacturers are introducing more innovative digital dental scanners on an on-going basis.

The benefits of incorporating digital dental scanning are many. Digital scans can be retained electronically in practices and laboratories, eliminating the physical space requirements for storing conventional models, as well as the risks of chips, breaks, and distortion. Patients experience greater comfort, convenience, and understanding of their condition and treatment objectives when digital impressions are used compared to analog techniques, and practices themselves benefit from the efficiencies associated with no longer needing to use conventional impression materials.

When used as part of a complete in-office dental CAD/CAM system, dentists can provide state-of-the-art restorations within hours, with restoration design and fabrication being performed chairside with computer software and milling technology.

1.2

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1.3

OPTIMIZING PREPARATIONS & GINGIVAL RETRACTION FOR SCANNING

LEARNING OBJECTIVES

Upon completion of this section, the reader should be able to:

1. Understand the importance of proper preparation design and gingival retraction techniques when taking digital impressions.

2. Discuss the preparation design requirements for different types of CAD/CAM restorations.

3. Understand the methods for achieving appropriate gingival retraction for digital impression-taking.

1.3

Introduction

The use of intraoral scanners (IOS) for obtaining digital impressions has made the impression-taking process more efficient and cost-effective. Not only does digital impression scanning make the majority of analog impression materials and techniques obsolete, but almost any type of restoration can be designed and fabricated from a digital impression.

What remain significantly important to the success and predictability of both analog and digital impression processes, however, are preparation design and the gingival retraction techniques employed to ensure clear and unobstructed access to, and visualization of, the margins, finish lines, and gingival contours.

In fact, the biggest factor in predicting success with dental computer aided design/computer assisted manufacturing (CAD/CAM) is the dentist's ability to properly prepare and retract the teeth. Among the reasons that preparation and retraction remain important to the success of CAD/CAM restorations are the capabilities of the IOS scanner and software itself, combined with the type of milling unit and burs used to manufacture specific types of restorations (e.g., anterior, posterior, intaglio surfaces) *(Figure 1.3-1)*.

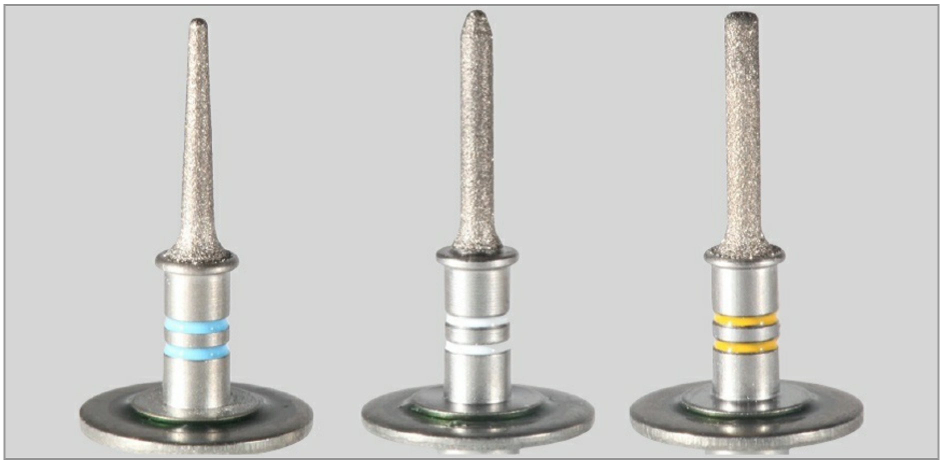

Figure 1.3-1 *The three milling burs shown here are used for manufacturing different restorations. The one on the left is used for anterior restorations; the middle for posterior restorations; and the one on the right for the internal intaglio surface of posterior crowns.*

Essentially, if the scanner cannot "see" it, then the digital impression will lack the specific preparation landmarks necessary for producing a properly-fitting restoration. Additionally, due to the shape of the milling tools used to create CAD/CAM restorations, preparations must be shaped and angled according to the ultimate geometry of the milling tools *(Figure 1.3-2 and Figure 1.3-3)*.

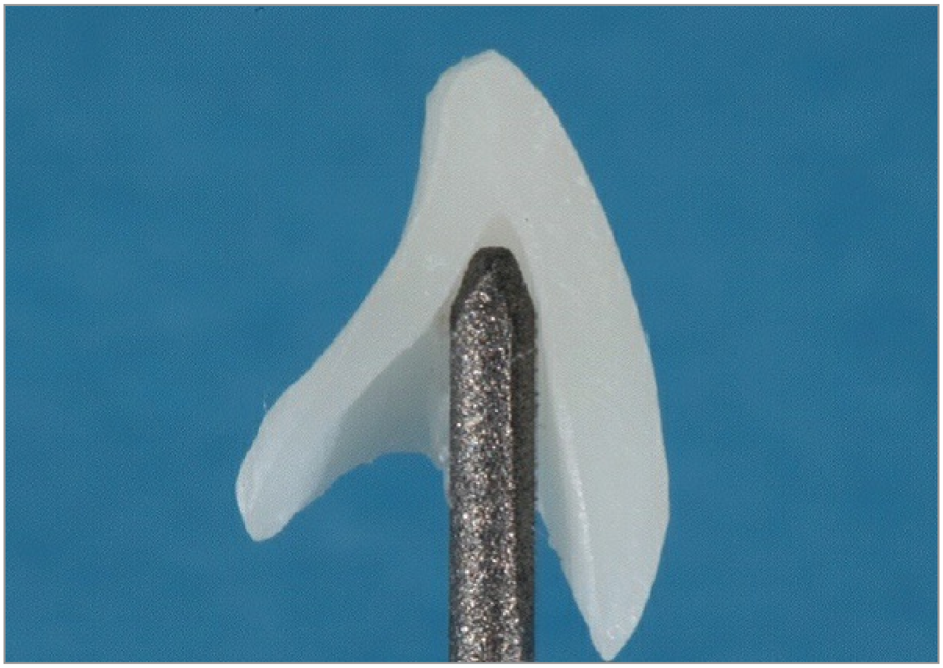

Figure 1.3-2 *The geometry of the milling unit burs limits the types of*

internal angles of restorations that can be produced. Because the milling unit burs are rounded, they cannot accommodate sharp angles. In this example of a lower incisor pressed crown, the milling bur would likely mill the restoration shy of the preparation requirements, creating a short crown with improper margins.

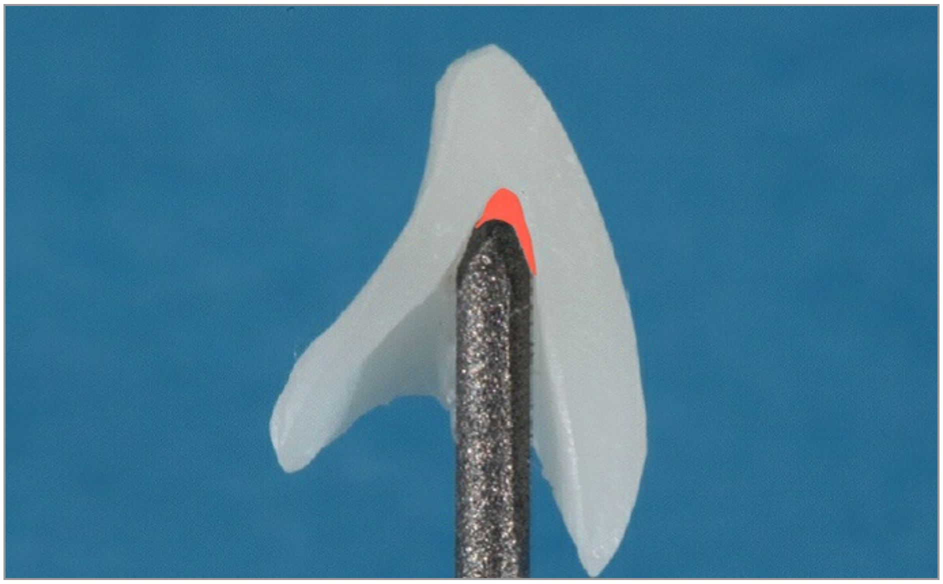

Figure 1.3-3 *Illustration of the manner in which the preparation in Figure 1.3-2 would need to be modified in order to ensure a proper fit after milling, based on the shape and geometry of the specific milling bur. In this example of a lower incisor pressed crown, the milling bur would likely open up the internal surface, resulting in a loose-fitting crown.*

Although IOS and digital impressions enable dentists to immediately view images and impressions of preparations at enhanced magnification, the quality of digital impressions is just as affected by the presence of blood, saliva, and improperly placed retraction and hemostatic materials as are analog impressions, particularly because IOS cannot differentiate between tooth structures, gingival tissue, and debris. Therefore, repeatedly scanning preparations that gradually become wet from saliva ultimately will produce distorted and inaccurate impression images *(Figure 1.3-4)*. Additionally, unlike analog impression materials, the IOS camera does not displace gingival tissues when capturing images and reading through the surrounding tissue, making it all the more important to ensure that gingival margins and subgingival finish lines are easily visible and sufficiently retracted.

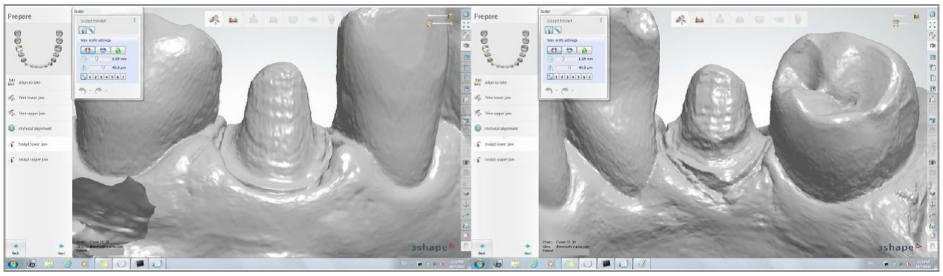

Figure 1.3-4 *After repeatedly scanning a preparation that gradually became wet with saliva, the IOS and CAD software produced a distorted impression image, since the software cannot differentiate between a dry tooth and wet tooth.*

Interestingly, while taking digital IOS impressions does not require dentists to deviate from their preferred preparation techniques, there are caveats associated with preparation design.

Specific parameters for digitally produced restorations ensure sufficient occlusal clearance, minimal restorative material thickness, and the ability of CAM systems to properly mill the anticipated restorations. In particular, preparations that will be digitally scanned for creating CAD/CAM restorations need to be designed based on how the dental CAD software will visualize and manipulate the images, as well as how the specific CAM system produces the restorations.

Fortunately, IOS and CAD software enable immediate visualization, review, and correction of preparations that deviate from the ideal, after which new digital impressions can be taken for use in designing the restoration. However, adhering to recommendations for designing preparations and achieving isolation/retraction for IOS impressions will help to ensure accuracy, efficiency, and predictability.

1.3

Despite their tremendous capabilities, IOS are limited in terms of the digital impression quality they produce, which are affected by the types of margins and preparation angles that they image.

For example, IOS and subsequent milling units perform better when margins are flat and the exit angle is 90˚. Therefore, reverse, trough, and feather-edge margins should be avoided. Other potential problems with IOS impressions can be encountered when sharp line angles and undercuts are present *(Figures 1.3-5 through 1.3-8)*. Additionally, depending upon the specific brand of IOS, CAD software, and milling unit used to fabricate the restorations, specific guidelines dictate the preparation design for posterior, inlay/onlay, anterior, and veneer restorations.

Figure 1.3-5 *This preparation for a molar full-coverage crown appears*

acceptable for a traditional analog-produced restoration. However, to angles are too sharp to be reproduced by CAD/CAM technology.

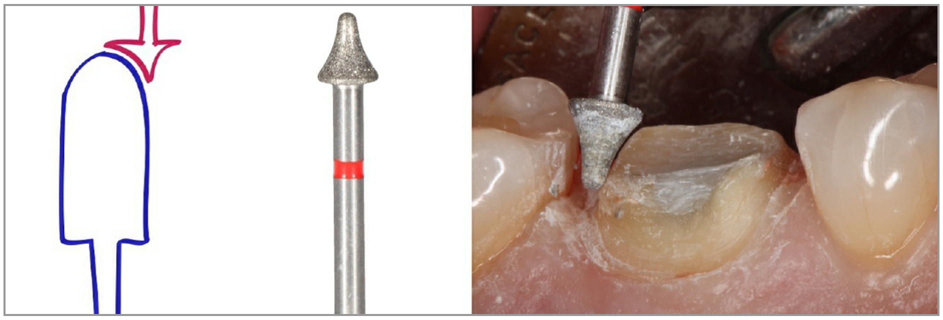

Figure 1.3-6 *The bur needed to create the ideal preparation is one that will produce a rounded edge.*

Figure 1.3-7 *A variety of burs specifically created for CAD/CAM tooth preparations are available.*

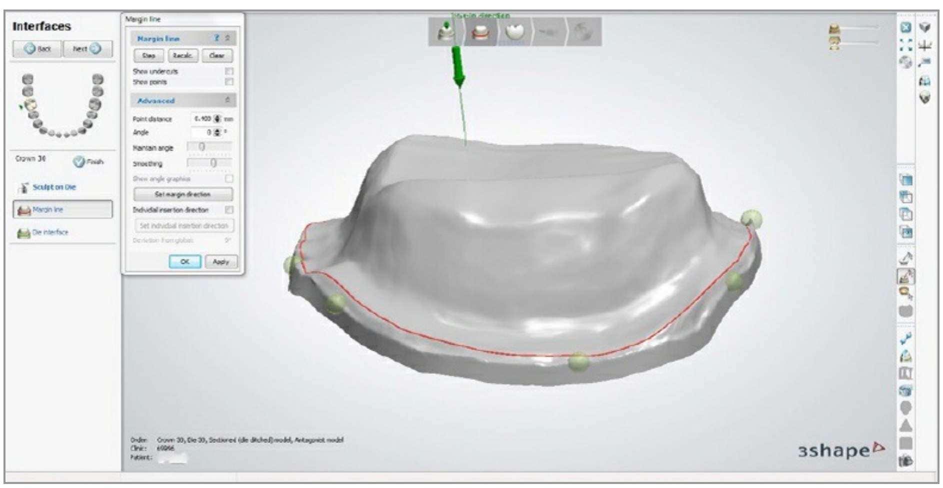

Figure 1.3-8 *The scanned preparation illustrates the rounded axial-occlusal portion of the preparation. This rounded design improves the fit and retention of the milled crown.*

Posterior Restorations

It is important to note that each IOS device and CAD/CAM system may have specific manufacturer recommendations for achieving ideal preparations. However, in general, when preparing a posterior restoration for IOS, the internal angles should be rounded, and the teeth should be reduced between 1.5 and 2 mm, and 1 mm at the margin. The entire margin should be visible from the occlusal aspect *(Figure 1.3-9)*. Heavy chamfer, shoulder, or butt joint margins, and a 6 to 10˚ taper, are recommended. Angled preparations and undercuts, which may contribute to insufficient material thickness and milling challenges, should be avoided.

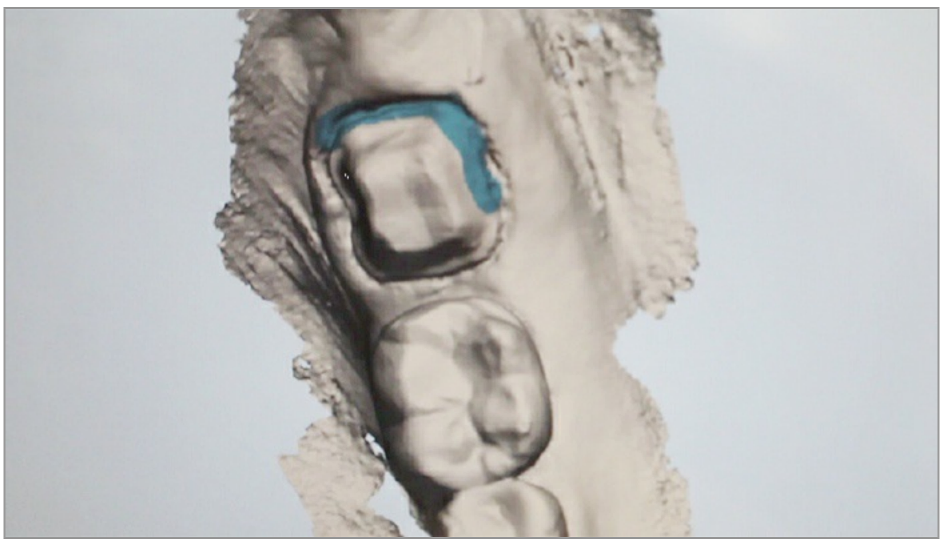

Figure 1.3-9 *Once the margin has been checked for clarity, the scan of the preparation can be "locked" to prevent over-scanning and the possibility of replacing accurate data with errors caused by saliva or the loss of retraction.*

Anterior Restorations

Anterior tooth preparations that will be digitally scanned should demonstrate facial and lingual reductions of between 1 and 1.5 mm, margin area reduction of 1 mm, and incisal edge reduction of between 1 and 2 mm. Chamfer or shoulder margins, and a 6 to 10˚ taper, are also recommended.

Onlay Restorations

Unlike anterior and posterior preparation requirements, onlay restoration preparations that will be digitally scanned do benefit from sharp edges at the margins to facilitate identification. However, sharp internal line angles, as well as parallel walls, may contribute to incomplete seating of the final onlay restoration. Therefore, rounded internal line angles, and a 6 to 10˚ taper of the internal axial walls, are preferred. More than 1.5 mm of occlusal reduction is recommended, and butt joint margins are preferred over feather edge margins. Interproximally, onlay restorations should demonstrate a 100 to 120˚ flare, since undercuts may contribute to open margins.

Inlay Restorations

Similarly, inlay restoration preparations that will be digitally scanned should demonstrate sharp edges to facilitate identification; occlusal reduction of between 1.5 and 2.0 mm; rounded internal line angles and internal axial walls with a 6 to 10˚ taper; and an interproximal flare of between 100 and 120.˚ Additionally, however, preparations for digitally scanned inlay restorations require an isthmus width of between 1.5 and 2.0 mm, and an isthmus depth of more than 1.5 mm.

Veneer Restorations

Ideally, veneer preparations that will be digitally scanned should demonstrate incisal reduction of between 1.0 mm and 1.5 mm, as needed, in addition to depth cuts of between 0.5 mm and 0.8 mm. However, it’s important to note that if the veneer restorations will mask underlying tooth structure—and/or be characterized with hand-layering techniques—additional reduction may be required.

The facial enamel surface should be prepared to a uniform thickness using a medium grit, round-ended diamond bur, and care should be taken to ensure that interproximal chamfer margins are properly prepared.

1.3

Tissue Management

When taking a digital impression, tissue management helps ensure the margins of the preparation are visible by moving the gingival tissues away from them and promoting hemostasis. There are several techniques to effectively manage and move gingival tissues during preparation and when taking either a digital or analog impression that can broadly be characterized as mechanical, chemical, and surgical. Among them are gingival retraction cords, chemical agents, hemostatic materials, electrosurgery, and laser troughing, in addition to several other methods.

Mechanical Retraction with Cords & Pastes

Mechanically displacing gingival tissue involves physically moving them from preparation margins to the depth of the sulcus using either a singular retraction material and technique, or a combination of options (e.g., retraction cord and hemostatic agent).

One mechanical retraction method is placing retraction cord (e.g., woven, braided, twisted; non-impregnated, chemically impregnated), which are available in a variety of diameters and thicknesses *(Figures 1.3-10 through 1.3-17).*

Figure 1.3-10 *Braided retraction cord is placed into the sulcus using a packing instrument.*

Figure 1.3-11 *The retraction cord is placed deep into the sulcus around the circumference of the gingival margin.*

Figure 1.3-12 *Note that the gingival margin is clearly visible from the occlusal aspect.*

Figure 1.3-13 *View of the digital impression in the CAD software. All aspects of the preparation and margins, including the retraction cord, are clearly visible.*

Figure 1.3-14 *The CAD software is used to evaluate the preparation and margins.*

Figure 1.3-15 *View of the CAD designed restoration.*

Figure 1.3-16 *The restoration is tried in to confirm an excellent, passive fit.*

Figure 1.3-17 *View of the completed posterior crown restoration.*

Braided cords are preferred by many dentists due to their tight and consistent weave, which facilitates placement into the gingival sulcus. Braided cords can be easily pushed into place using either serrated or smooth packing-placement instruments. Knitted cords, however, are increasingly being used because their weave remains intact after cutting and during placement, facilitating ease of use. When wet with astringents, knitted cords expand within the sulcus to enlarge it for enhanced access and visibility.

Gingival health and sulcus depth typically indicates which retraction cord technique is ideal (e.g., single cord, double cord). Single cord techniques are ideal in patients where the sulcus depth is shallow. However, the double cord technique (i.e., first placing a thin cord deep in the sulcus, followed by a wider diameter retraction cord) is recommended whenever possible.

Another technique for mechanically displacing gingival tissues involves the use of retraction pastes, which are putty-like in consistency and demonstrate hemostatic properties (due to components such as aluminum chloride). Retraction pastes are considered cordless retraction materials that atraumatically displace the gingiva, making them ideal complements to other retraction techniques (e.g., laser troughing, retraction cord). To establish gingival retraction, the paste is injected into the sulcus, where it produces constant pressure to move the soft tissue during digital impression scanning and/or analog impression procedures.

Chemical Retraction

A variety of chemicals (e.g., ferric sulfate, aluminum chloride, racemic epinephrine, aluminum potassium sulfate, aluminum sulfate, zinc phenolsulfonate/racemic epinephrine) can be used with gingival retraction cords to promote hemostasis and shrink the gingival tissues surrounding preparations. Available as solutions or gels, these astringent or hemostatic chemicals promote the contraction/retraction of gingival tissues, or coagulation by constricting blood flow, respectively. When gingival retraction cords are impregnated with these hemostatic/astringent chemicals, they demonstrate better tissue displacement in the sulcus.

Surgical Retraction Using Lasers

A surgical option for displacing the gingival tissues surrounding preparations is troughing it—rather than retracting it—using a soft tissue laser. Used increasingly to manage soft tissues, laser troughing promotes hemostasis through coagulation and sealing blood vessels, enhances visualization of the margin through ablation of the tissue, and typically results in little to no postoperative discomfort for the patient after the procedure. Soft tissue lasers have even been shown to reduce bacteria in the sulcus, promote tissue re-growth, and stimulate faster healing.

Contributing to the effectiveness of soft tissue lasers (e.g., Neodymium YAG (Nd:YAG) and diode lasers) for gingival troughing is their laser wavelength, which is specifically absorbable by water and hemoglobin (i.e., oxygenating protein in red blood cells). The soft tissue laser energy penetrates the gingival tissues, ablates it, and simultaneously seals blood vessels and nerve endings. These photo-thermal lend to the efficacy of soft tissue lasers for soft tissue management during digital impression taking procedures.

1.3

Summary

Concepts of tissue retraction/management will evolve, and new products will be developed to help dental professionals become more efficient in such an important clinical step when implementing CAD/CAM technology. Although using IOS to obtain digital impressions has streamlined the restorative workflow, preparation design and gingival retraction remain important considerations to ensure the accuracy and predictability of anticipated restorations. Therefore, caveats for successfully using digital IOS include following recommended preparation designs based on the indication, as well as ensuring proper gingival retraction/management using either mechanical, chemical, or surgical techniques.

1.3

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