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Simplifying Full-Arch Implantology With Digital Dentistry

Figure 1. A few 3-D printer options for dental environments: desktop (left, MoonRay [SprintRay] and Form 2 [Formlabs]) and laboratory-industrial (right, NextDent 5100 [3D Systems]).

INTRODUCTION

Clinicians are often faced with challenging decisions regarding working with patients who are completely edentulous or with a failing dentition and request treatment. Rehabilitation of the dentition with removable or fixed restorations with dental implants remains an exciting, yet challenging, dental procedure. While removable restorations such as tissue-supported or implant-supported overdentures are popular because they are simple to work with for both patient and clinician, many patients request a non-removable restoration option.

Fixed rehabilitation with dental implants typically requires a combination of precise surgical and prosthetic techniques that permit for seamless delivery of a prosthesis that accomplishes a complex interplay of aesthetic, functional, and maintenance goals. Fixed restorations are often technically demanding in regard to implant position, angulation, tooth position, emergence form, and the interplay between teeth and tissues.[1] Additionally, other factors related to patient-mediated outcomes, occlusal scheme, implant number, and implant position within the arch further complicate planning rehabilitation with fixed prostheses.[2]

While digital dentistry is predictable for working with single units and short span FPDs with dental implants, less is known about full-arch implantology. Reports and studies have determined that while digital techniques are extremely promising, many clinicians opt for traditional analog techniques for the most challenging cases to ensure the reliability and predictability of clinical procedures.[3] While traditional, analog techniques are readily used for clinical practice, digital technology is rapidly becoming an integral part of everyday clinical practice. This article aims to review digital technology and describe clinical approaches to using intraoral scanning and 3-D printing technologies to enhance clinical and laboratory procedures for full-arch rehabilitation with dental implants.

Understanding Digital Technology

The term *digital dentistry* has been used extensively over the past few years; however, the scope of digital dentistry remains elusive. Even though clinicians are exposed to many different digital technologies, the various approaches and workflows can still be confusing. The essence of digital dentistry remains a computerized digitization of some or all of the clinical and/or laboratory procedures. The 3 main technologies that encompass digital dentistry are optical scanning, additive manufacturing, and subtractive manufacturing.

Optical Scanning

Optical scanning uses a computerized acquisition machine that projects light onto an object to convert it into a virtual representation of the physical object. While there are 2 varieties of optical scanning, desktop and intraoral, the latter is primarily directed at clinicians and its use is of most relevance for clinicians. Intraoral scanning utilizes a light or laser projection directly within a patient's mouth, and images are prepared using a dental handpiece-style capture device.[4] The wand device is activated, the light/laser is projected onto the surface, and the projection is reflected back to the capture device, converting it into a 3-D image. The advantages of intraoral scanning include direct image acquisition, no requirement for physical impressions, and speed. Disadvantages include cost, learning curve, difficulty of maintaining scanner calibration, and computer software updates.

Subtractive and Additive Manufacturing Techniques

After acquiring the images via optical scanning, the clinician and/or laboratory technician can utilize the images for surgical

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and/or prosthetic procedures. In order to complete planning or treatment procedures, many desire to turn the virtual images into a physical object, which can be done using subtractive or additive manufacturing techniques. Subtractive manufacturing, known as milling, creates objects using a reductive manufacturing process. Milling uses a series of cutting tools to carve out the shape of a dental prosthesis from a larger object, often premanufactured discs, pucks, or blocks. Milling is an incredibly flexible tool in dental production; it can produce virtually any object, including resin polymers, zirconia ceramics, glass ceramics, metals, and waxes. Milling produces a very accurate and clean product almost immediately after tooling, whereas 3-D printing requires additional processing and curing steps to produce a prosthetic that can be used in clinical environments.

Additive manufacturing techniques, or 3-D printing, permit the user to create a physical object out of a liquid or plasticized resin material. Incorporation of 3-D printing into a clinical environment is a much simpler endeavor than in the past. Recent innovation and a reduction of printing material, equipment, and consumable costs have dramatically increased the penetration of 3-D printing into clinical practice. Multiple printer configurations and options exist for 3-D printing technology in clinical dentistry. However, in this author's experience, the 2 main categories of interest are desktop and laboratory-industrial categories.

The desktop 3-D printer, such as a Form 2 (Formlabs) or MoonRay D (SprintRay) (Figure 1, left), is a small form factor printer intended for a limited scale. It is often intended for those in low-volume clinical environments who wish to perform select procedures, such as surgical guides. Many factors are related to this indication; however, it often results from the slower printing speed and limited material options for clinical use. The laboratory-industrial 3-D printer, such as the NextDent 5100 (3D Systems) (Figure 1, right), is a larger form factor printer that is intended for higher-volume clinical or laboratory environments. Printers that fit within this category are often very fast, have robust material options for clinical dentistry, and have a resolution/accuracy that can produce dental prosthetics. Dental 3-D printing is a diverse, however somewhat limited, manufacturing technology compared to others as the materials are typically resin polymers. Three-dimensional printing is no longer an emerging technology and, in its current form, serves an important role in technical as well as clinical procedures.

Table 1. Conventional vs Digital Implant Techniques

Conventional Implant Techniques	Digital Implant Techniques
Advantages: • Long history and familiar use • Precise and predictable • Any laboratory able to perform	**Advantages:** • Less steps required, often 2 to 3 visits • Precise and predictable • Digital database and storage of restorations
Disadvantages: • Multiple steps required, often 4 to 6 visits • Relies upon stone models • More laborious technique	**Disadvantages:** • Laboratory standardization and the calibration of techniques are challenging • More expensive initially

Figure 2. A patient presented with a failing dentition and requested a full-mouth rehabilitation with dental implants.

Figure 3. Selective teeth were extracted, and the 3-D printed surgical guide was adapted to the mandibular dentition/tissue.

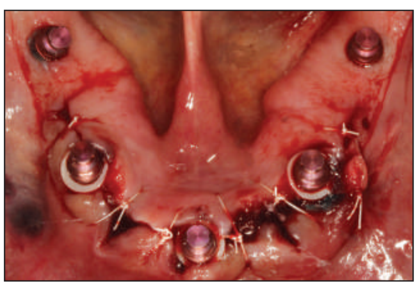

Figure 4. Dental implants (Tapered Internal Plus [BioHorizons]) and abutments (LOCATOR F-Tx [Zest Dental Solutions]) were placed. Housings (LOCATOR F-Tx Denture Attachment Housings [Zest Dental Solutions]) were tilted/reoriented until parallel to each other.

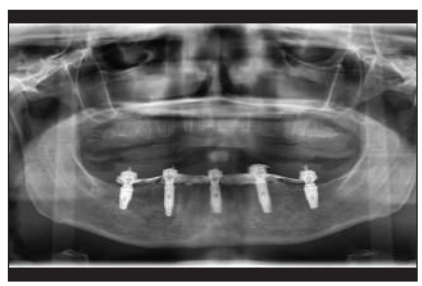

Figure 5. A panoramic radiograph (Green CT [Vatech America]) was taken immediately after completion of surgical and prosthetic procedures.

Figure 6. After complete dental implant healing, the patient returned for the definitive prosthetic procedures. The interim restoration was inspected for proper aesthetics, phonetics, and tooth position.

Figure 7. The interim prosthesis was removed, and housings (LOCATOR F-Tx Denture Attachment Housings) were placed onto each abutment. An intraoral scan (TRIOS [3Shape]) was made of the edentulous ridge to ensure that proper anatomical features and overextended soft tissues were captured within the scan. A second case scan was made of the patient's prosthesis and opposing in occlusion.

Simplified Workflows

Simplicity is a constant challenge for clinicians and technicians in a dental practice. We are often inundated with new technologies, new techniques, and newer materials, so it is often difficult to keep up with the latest and greatest trends occurring in dentistry. Dental procedures can be difficult to perform, especially when considering the limited room inside the oral cavity, patient cooperation, ergonomics and positioning of the operator, and detailed procedures required. As newer technologies and techniques are employed, the complexity of performing the procedures to maintain the same standards increases (Table 1).

Full-arch fixed rehabilitation remains one of the more complex procedures performed in dentistry. Due to the high amounts of precision required for dental implants, dental implants must be restored with as much passive fit as possible.[5] To achieve as much passivity of a fixed dental prosthesis, multiple procedural steps are often required.

The Traditional Workflow

When evaluating the clinical and laboratory procedures for traditional fixed full-arch reconstruction, techniques often require several clinical procedural steps to complete each patient treatment. In the scenario where a patient received an interim prosthesis by the restorative clinician, the same-day existing teeth were extracted, and implants were placed by the surgical clinician, the patient often requires 4 to 6 additional steps after the interim prosthesis is in place. With the conventional workflow, the patient is seen by the restorative clinician approximately 2 to 6 months after surgical procedures, with the clearance to do so being given by the surgical clinician. During this first visit, the interim prosthesis is removed, primary impressions are made with closed-tray impression copings, and the prosthesis is replaced. The primary impressions are poured into gypsum stone, and a luting jig is fabricated using the open-tray impression copings provided by the dental

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implant manufacturer. The patient returns (visit 2), the luting jig is placed into the mouth and attached using auto-polymerizing acrylic resin, and a transfer/open-tray impression is made over the cylinders. The impression is poured with gypsum in the dental laboratory, creating a master cast with metal analogs in place. On the master cast, the laboratory fabricates acrylic resin record bases with baseplate wax rims. The patient returns (visit 3), and jaw relations, including bite records and tooth selections, are made with assistance from the record bases. Additionally, during the visit, the clinician may do a verification of the master cast with an additional jig transfer. The record bases are used as a guideline for the laboratory for diagnostic tooth assessment or wax-up procedures. Denture teeth are applied to the record base and are supported by the record base and baseplate wax. The patient returns (visit 4) for a try-in, and the prosthesis with denture teeth is tried in to evaluate aesthetics, phonetics, centric relation, and vertical dimension. If the prosthetic tooth relationship is confirmed, the try-in assessment is completed. If the patient requests a change, additional visits are necessary to make modifications. Upon approval by the patient, the wax-up is sent to the laboratory where a bar suprastructure is fabricated around the denture teeth. Using conventional metal-casting techniques often results in bars that require an additional try-in to confirm the fit of a bar in a patient's mouth. If the clinician feels comfortable with the master model accuracy, he or she can request that the laboratory put denture teeth on the fixed bar in the same position where it was on the removable denture base. The patient returns (visit 5) for the final try-in; the denture teeth/suprastructure is placed; and final verification of centric relation, vertical dimension, and aesthetics is performed. The teeth/suprastructure is returned to the laboratory for the final processing procedures. The patient returns (visit 6) for the final delivery of the prosthesis, where the prosthesis is placed and adjusted and definitive procedures are completed.

The Digital Workflow

In contrast to the above workflow, the digital workflow is potentially a much simpler and more streamlined approach. In the same scenario listed above, the patient returns for the initial visit after restorative and surgical clearance, and the opposing arch, interim prosthesis, and bite registration are optically scanned prior to the removal of any prostheses by using an intraoral scanner. The prosthesis is then removed, scan bodies or housings are placed on each abutment, and the arch is scanned using an intraoral scanner. Next, the prosthesis is replaced, and digital files are processed and sent to the dental laboratory. The laboratory joins together the multiple scans and imports them into design software, and the prosthesis is designed using the superimposed scanned outline of the patient's interim prosthesis as a guide. The digitally designed prosthesis is 3-D printed, post-processed, finished, and polished. The patient returns for a clinical try-in procedure (visit 2), and the prosthesis is tried in the mouth and evaluated for clinical fit, centric relation, vertical dimension, and aesthetics. If everything is approved by the patient, the prosthesis is delivered for clinical evaluation by the patient. Many clinicians, including this author, like the option of being able to have the patient "try out the teeth for a few weeks" prior to fabrication of the final prosthesis. Since the prosthesis was designed digitally, there is no need to return the trial prosthesis to the laboratory for further procedures, as the laboratory has the digital file that can be utilized for further laboratory procedures. The digital design file is utilized to fabricate a bar suprastructure that fits within the confines of the digital file, and the bar and teeth are fabricated using subtractive milling manufacturing methods. The patient returns (visit 3) for delivery; the prosthesis is placed, any adjustments are made, and definitive procedures are performed.

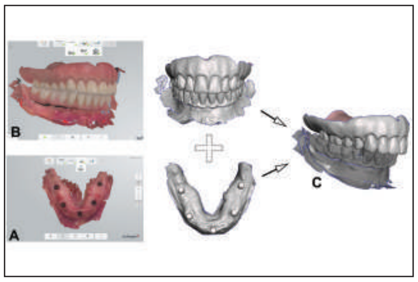

Figure 8. The 2 sets of case scans, the edentulous ridge with housings **(a)** and the maxillary/mandibular prostheses in occlusion **(b)** were fused together using dental-specific laboratory software (exocad [exocad America]) **(c)**.

Figure 9. A 3-D printed prototype prosthesis was fabricated from dental resins (NextDent C&B MFH and NextDent Denture 3D+ [3D Systems]) and joined together in the dental laboratory.

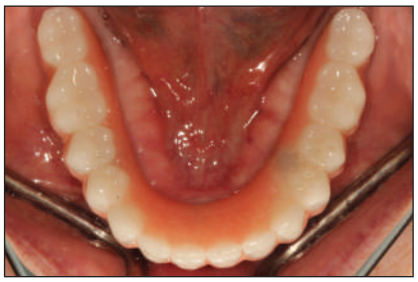

Figure 10. The prototype prosthesis was tried in, and the evaluation of aesthetics, phonetics, vertical dimension, and centric were completed. The prototype was approved, and the definitive prosthetic procedures were completed in the laboratory.

Figure 11. The definitive, milled prosthesis (BarZero [Cagenix]) was placed onto the edentulous ridge, and the confirmation of prosthetic acceptability was completed. F-Tx housings were placed onto each abutment, and composite resin material (CHAIRSIDE Attachment Processing Material [Zest Dental Solutions]) was applied onto each housing and into the recesses of the prosthesis and placed onto the edentulous ridge. After complete polymerization, the prosthesis was removed and polished. Definitive retention inserts (Retention Balls [Zest Dental Solutions]) were placed.

Figure 12. The definitive prosthesis was fully adapted to the abutments and finalized.

CASE REPORT

A patient presented with a request to rehabilitate her dentition with assistance from full-arch prosthetics and dental implants (Figure 2). A cone-beam computed tomography (CBCT) scan (Green CT [Vatech America]) and an intraoral scan (True Definition Scanner [3M Oral Care]) were made. The CBCT files were imported into implant planning software (Blue Sky Plan [Blue Sky Bio]). The implants (Tapered Internal Plus [BioHorizons]) were planned within the software. The surgical guide was 3-D printed using a desktop-level 3-D printer (Form 2), and conventional heat-processed prosthetics were fabricated on models printed from the same 3-D printer.

Patient's First Clinical Treatment Appointment

Preoperative antibiotics (Amoxil, Moxatag) and chlorhexidine oral rinse (Peridex [3M]) were administered. Local anesthetic was applied (2% Lidocaine [Zahn]), maxillary and select mandibular teeth were extracted, and the surgical guide was placed onto the mandibular dentition to confirm full adaptation of the guide (Figure 3). Minimally invasive procedures with sequential osteotomy preparation were done using an implant-specific surgical guide system (Guided Surgery Kit [BioHorizons]) through the surgical guide until full preparation was completed. Implants (Tapered Internal Plus) were placed, and LOCATOR F-Tx abutments (Zest Dental Solutions) were placed onto each implant. A panoramic radiograph (Green CT) was made to confirm complete adaptation of the abutments to the implants. Snap-cap healing abutments (LOCATOR F-Tx) were placed onto each implant, and tissues were sutured closed (Cytoplast [Osteogenics]).

Recesses within an interim denture were prepared with a specialized bur kit for LOCATOR-style abutments (Denture Prep and Polish Kit [Zest Dental Solutions]). Flexible resin for blocking out undercuts (Block Out Resin [Zest Dental Solutions]) was applied around the abutments, and housings (LOCATOR F-Tx Denture Attachment Housings [Zest Dental Solutions]) were placed onto each abutment (Figure 4). After confirming adequate preparation of the denture, composite resin (CHAIRSIDE Attachment Processing Material [Zest Dental Solutions]) was applied to the recesses within the denture and placed onto the edentulous ridge, and the patient was instructed to close. After complete polymerization, the prosthesis was removed and polishing procedures were completed. Definitive retention inserts were placed, and the prosthesis was placed onto the implants—firmly securing into place. A final radiograph was made to confirm complete adaptation of the prosthesis onto each abutment (Figure 5).

Approximately 3 months after implant placement and interim prosthesis placement, the patient returned for definitive prosthesis procedures. The prosthesis was inspected for prosthetic acceptability, and the confirmation of proper tooth position factors was completed (Figure 6). The interim prosthesis was removed using a special lever tool (Bar and Loop [Zest Dental Solutions]), and housings (LOCATOR F-Tx Denture Attachment Housings) were placed onto each abutment. Each housing can be tilted, pivoted, and moved until all are parallel to each other, ensuring a single path of insertion. An intraoral scan (TRIOS [3Shape]) was made of the edentulous ridge and housings (Figure 7) while paying special attention to ensuring the oral tissues remained overextended to enhance the amount of soft tissue captured in the optical scan of the edentulous ridge (Figure 8a). New retention inserts (Retention Balls [Zest Dental Solutions]) were placed into the housings within the prosthesis, and the prosthesis was replaced was placed onto the mandibular arch and secured to each implant. A second, separate digital case file from the edentulous arch case mentioned earlier was then created within the intraoral scanner (TRIOS), and a scan of the maxillary arch was done. A scan of the mandibular arch was added to the same case within the intraoral scanner, with emphasis on ensuring the entire prosthesis and adequate retracted soft tissues were captured (Figure 8b). The patient was then instructed to close, and a scan of the patient in occlusion was completed, providing the intraoral scanner with adequate landmarks to ensure that digital articulation of the maxillary and mandibular scans was provided. Two sets of intraoral case files were created: (1) an overextended mandibular edentulous ridge with F-Tx housings alone, and (2) a maxillary arch/prosthesis, a mandibular arch/prosthesis with overextended soft tissues on the scan, and a bite scan to ensure that full dental articulation occurs. The intraoral scans were processed, and the patient was dismissed.

The scan images were sent electronically to a dental laboratory (MDS Prosthetics, Sonora, Calif) for processing. Using anatomical features within the soft-tissue landmarks on each scan, the scan of the mandibular edentulous ridge with housings in place was merged with the scan of the patient's mandibular ridge with the prosthesis in place (Figure 8c). The anatomical landmarks permit the clinician to properly and reliably articulate the mandibular edentulous ridge with the mandibular ridge with the prosthesis. This approach permits the clinician to leverage the use of the interim prosthesis to set the tone of the vertical dimension, CR and MIC positions, tooth position, and approximate occlusal configuration. The 2 sets of case files were then exported into dental-specific software (Dental System [3Shape]) for dental prosthesis planning. Next, a prosthesis was digitally planned by using the dental anatomical features of the interim prosthesis. The digital file was exported into 3-D printer software; teeth (NextDent C&B MFH [3D Systems]), and tissues (NextDent Denture Base [3D Systems]) were printed as 2 separate prints on a laboratory-industrial 3-D printer (NextDent 5100 [3D Systems]). The materials were then processed by the dental laboratory team, gluing the teeth and tissues into a single prosthesis (Figure 9).

Patient's Second Visit: 3-D Printed Prototype

The patient returned for her second visit, and the 3-D printed prototype was tried onto the edentulous ridge and evaluated for prosthetic factors (Figure 10). Evaluation of the vertical dimension, centric positions, phonetics, aesthetics, and comfort ensured that the prosthetic design was acceptable to the patient. If any changes were needed, alterations of the prototype prosthesis could be completed using conventional dental techniques prior to returning the prosthesis back to the dental laboratory. The patient approved the prototype prosthesis, and the interim prosthesis was replaced. Upon approval by the patient, the dental laboratory (Cagenix, Memphis, Tenn) was informed that the prosthetic design was satisfactory to the patient and that the lab team could proceed with the definitive prosthesis fabrication procedures using the protoype digital design file produced earlier. If a patient requests to further evaluate the prototype prosthesis outside of the dental office, the prosthesis can be firmly secured to the LOCATOR F-Tx housings, and the patient can take the prototype prosthesis home for a prescribed period of time until he or she is comfortable with the prosthetic design. If the prosthesis had been modified at all, the prototype would have been sent to the laboratory for modification of the digital design file prior to performing definitive laboratory procedures. The definitive restoration was fabricated out of a high-strength milled polymer (BarZero [Cagenix]).

Patient's Third Visit: Delivery of the Definitive Prosthesis

The patient returned for the definitive prosthesis placement. The interim prosthesis was removed, and block out rings (Block-Out Spacers [Zest Dental Solutions]) and LOCATOR F-Tx housings were placed onto each abutment. The definitive prosthesis is provided with recesses within the intaglio of the prosthesis that are sized for the LOCATOR F-Tx housings. The prosthesis was placed onto each housing, ensuring the proper path of insertion of the prosthesis onto the edentulous ridge. The patient was instructed to close into centric, and the confirmation of vertical dimension, aesthetics, and phonetics was verified. Composite resin (CHAIRSIDE Attachment Processing Material) was placed onto each housing and into the recesses in the definitive prosthesis, and then the prosthesis was seated onto the edentulous ridge, and the patient was instructed to close. After complete polymerization of the resin, the prosthesis was removed, polishing procedures were completed, and definitive retention inserts (Retention Balls) were placed (Figure 11). The prosthesis was inserted, ensuring complete adaptation of the prosthesis to each abutment, beginning with the posterior abutments and seating the anterior abutments (Figure 12). The final prosthetic adjustment procedures were completed, and the patient was given wear and care instructions for the prosthesis, including for hygiene and maintenance.

The unique characteristics of contemporary abutment systems, such as the LOCATOR F-Tx abutment and housings, permit the clinician to greatly enhance the patient experience surrounding surgical and definitive restorative procedures. Since housings are placed during optical scanning procedures, it permits the laboratory team to size the intaglio of the prosthesis to adequately accommodate the housing on the edentulous ridge. When the prosthesis is placed on top of the edentulous ridge, the clinician processes the housings within the prosthesis directly within the mouth. Ultimately, this approach provides a simple clinical process to ensure a passive-fitting prosthesis.

CLOSING COMMENTS

Full-arch reconstruction with dental implants is a challenging surgical and prosthetic procedure that, in order to be done successfully, should be thoughtfully executed and performed. Digital dental technology permits the surgeon and/or the restorative doctor to enhance prosthetic outcomes without enhancing the complexity of the procedures. Combining intraoral scanning, digital design, 3-D printing, milling, and LOCATOR F-Tx abutment systems permits the clinician to greatly simplify surgical and restorative full-arch clinical procedures.✦

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Disclosure: Dr. Scherer is a clinical consultant for Zest Dental Solutions.