Implementing a contemporary, in-office complete digital workflow within a clinical implant practice: intraoral scanning, virtual design, and 3D printing

Dr. Michael D. Scherer summarizes a contemporary approach incorporating intraoral scanning into a dental implant practice including integration with cone beam CT technology and in-office 3D printing to enhance restorative visualization and surgical guide planning

Synopsis/abstract

Intraoral optical scanning (IOS) technology is not new to clinical practice; however, the integration of this technology has been slow because it is often viewed as challenging, cumbersome, and with a cost that is out of the reach of most clinicians. This article seeks to describe a contemporary, yet affordable, approach to integrating IOS into dental implant practice including digital superimposition with cone beam CT radiography, computerized surgical guide fabrication, and 3D printing models for using in a private practice setting.

Introduction

Technological innovation and implementation of contemporary digital techniques in methods and materials in clinical practice is both exciting and challenging for private practice practitioners. In busy dental implant practices, the justification of utilizing cone beam computed tomography (CBCT) for treatment planning is easy to justify. Taking the next step of including optical image fusion with the CBCT scans for the purposes of fabricating computerized surgical guides and immediate restorations is a big one for many. In this author's experience, the biggest barrier to taking this step is the lack of confidence that the systems will work because they are either too confusing, cumbersome, or expensive. The reality is that these systems have been around for years but are just now becoming rapidly embraced by clinicians.

Michael D. Scherer, DMD, MS, FACP, is an Assistant Clinical Professor at Loma Linda University in California, a Clinical Instructor at University of Nevada, Las Vegas (UNLV), and maintains a practice limited to prosthodontics and implant dentistry in Sonora, California. He is a fellow of the American College of Prosthodontists and has published articles related to implant dentistry, clinical prosthodontics, and digital technology with a special emphasis on implant overdentures. As an avid technology and computer hobbyist, Dr. Scherer's involvement in digital implant dentistry has led him to develop and utilize new technology with CAD/CAM surgical systems, implement student-facilitated CBCT implant planning, and outside-of-the-box radiographic imaging concepts. Dr. Scherer has served as the director of the implant dentistry curriculum at UNLV and is actively engaged in guided surgical placement and prosthetic restoration of implants in private practice. Dr. Scherer also maintains "LearnLODI" and "LearnLOCATOR" — interactive YouTube channels on standard and narrow diameter dental implant procedures.

Machining and reductive-style CAD/CAM technology like CEREC® (Sirona Dental USA) has been available to private practice practitioners since 1987.[1] This technology was exciting because at its implementation, both computers and the internet were in their infancy, yet a private dental office could make a photograph of a tooth preparation, and minutes later, mill an esthetic ceramic restoration. At the publication of this article, almost 30 years later, it is interesting that approximately 14,000 U.S. and 24,000 worldwide dentists utilize this technology within their offices.[2] While this may seem like a large figure, when comparing the total number of dentists in each respective group, these figures represent an implementation of 8% in the United States (186,000 total dentists) and 1% worldwide (1.8 million total dentists).[2-4] The most likely reason for this low implementation rate? The high initial cost. At approximately $100,000 USD, the high cost of this technology can be a substantial barrier, not to mention having to qualify for a loan, paying interest on the practice loan, and yearly software updates. Finally, this technology makes a clinician change the way he/she practices including the types of materials used (PFM versus ceramics) and daily routine (prep/temp versus prep/design/cement final ceramics).

The important question to ask is, How can we implement contemporary technology that's accessible to more dentists by having a lower initial investment and also one that fits into a clinician's everyday schedule and flow? The purpose of this clinical article is to describe implementation of intraoral scanning and three-dimensional (3D) printing into a private clinical implant dental practice.

Intraoral scanning

Intraoral optical scanning (IOS) technology was first popularized with the introduction of the CEREC system and has progressed parallel to the development of this system.[1] Standalone intraoral scanning units, however, were not introduced until around 2006, and the technology has rapidly become popularized due to the lower cost of the scanning units compared to the CAD/CAM machining systems. In addition, the growing segment of dentists placing implants with the help of CBCT and computerized-guided surgery has created a demand to incorporate optical scanning.

While conventional impression techniques are an accurate way to reproduce the details necessary to fabricate surgical guides and indirect restorations, they are also technique-sensitive, cumbersome, and can also be subjected to laboratory error. Intraoral

Figure 1: Chairside intraoral optical scanner (3M™ True Definition Scanner, 3M ESPE)

scanning uses optical imaging technology, including making multiple image scans of the teeth/tissues and then mathematically calculating the differences between images to generate a 3D image. One system, the 3M™ True Definition Scanner (3M ESPE), uses a technology called "active wavefront sampling" in which distances between objects on the scan coincides to a focal length of the lens (Figure 1). Upon focusing the video-feed image, the difference between the focused and non-focused image is calculated and distances are reported as a 3D image. Live image acquisition is acquired and displayed on a computer monitor, giving instantaneous feedback on accurately capturing all of the details of teeth and tissues (Figure 2).

The optical impression technique is in contrast to that of conventional impression techniques using impression materials such as polyvinylsiloxane (PVS), where a series of viscosities are mixed together and placed onto teeth/tissues and held in one place until fully polymerized. After polymerization, the impression is removed and examined for accurate representation of the teeth/tissues. If a capture error is found with this conventional technique, the only recourse is to remake the impression. With intraoral scanning, the clinician can scan a capture a segment of the dentition, stop for a moment to complete the scan, and then scan an additional segment. These multiple segments can be joined together to form a single image (Figure 3). This approach is valuable for mandibular scans, where the tongue can difficult to control; with patients with high saliva production; and with patients who tire easily from staying open. Additionally, for crown and bridge applications, a second scan can be joined to the first scan if a margin was missed (Figure 4). This technology, known as image fusion or superimposition, is especially exciting because it allows for joining of tooth/tissue optical scans and CBCT radiological scans.[5]

Image fusion and joining optical and CBCT scans

CBCT imaging utilizes multiple two-dimensional (2D) radiographic slices that virtually join together to form a 3D image to facilitate viewing. Historically, the 3D image was used only for visual reference, and clinicians traditionally relied upon a 2D interpretation of bone volumes to analyze for proper implant placement (Figure 5). This approach serves an important function giving substantially more information than a periapical or panoramic radiograph; however, it relies upon the clinician estimating implant placement during surgical procedures with assistance of a model-based standard surgical guide. CBCT-based surgical guides allow for precise drilling at the angle, depth, and position based on the virtual-planned implant positions versus estimation of these parameters during surgical procedures with model-based surgical guides.

Implementing optical scanning into an implant practice is facilitated by optical fusion technologies allowing visualization of a tooth/tissue optical scan virtually on a CBCT radiograph. A challenge of visualizing a 3D rendering of an arch with CBCT alone is problems related to artifact induced by metallic objects such as crowns or amalgam fillings, inadequate soft tissue

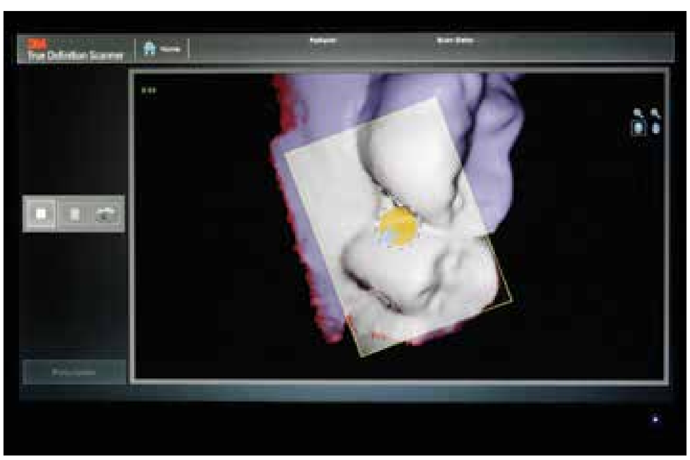

Figure 2: As the scanner optically reads the tooth and tissue contours, visual display of the images on the computer monitor give the clinician instantaneous feedback

Figure 3: Multiple intraoral scans can be captured and joined together to form a single image, allowing for easy reproduction of detail in challenging patients

Figure 4: Joining together multiple scan attempts is extremely beneficial for having to refine and recapture crown margins

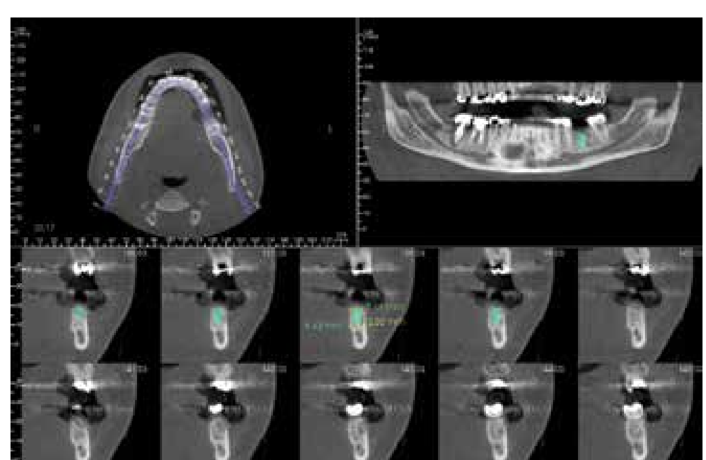

Figure 5: Traditional implant planning techniques involve a 2D interpretation of the 3D CBCT scan

visualization, and digital tresholding controls (Figure 6). Overlay of an optical scan on the CBCT allows for overcoming of these limitations of conventional CBCT visualization and greatly enhances visualization of dental arches in relation to bone volumes (Figure 7).

The workflow of image fusion begins with initial planning of an implant procedure (Figure 8). While this initially seems complicated to many clinicians, it is easy to do once completed successfully a few times. First, an intraoral optical scan is made of the arch (Figure 9). This often takes approximately 3-4 minutes to complete, and depending upon dental regulations within various communities, can be delegated to a dental assistant. The scan is uploaded and processed into a stereolithography data file (STL), which is the 3D optical image file, similar to a JPG or GIF format that is used for 2D photographic images. Second, a CBCT scan of the patient is made with cotton rolls placed to separate the occlusal surfaces and tissues (Figure 10). The CBCT scan digital imaging and communications in medicine (DICOM) files are opened in a dental implant planning software (Invivo, Anatomage), and a dental implant is tentatively planned according to best fit within the bone volume (Figure 11). The implant plan (.INV file) and optical scan (.STL file) are uploaded to a central processing server where the images are fused together (Figure 12). Alternatively, some software packages allow for the clinician to perform image fusion without having to send it to a

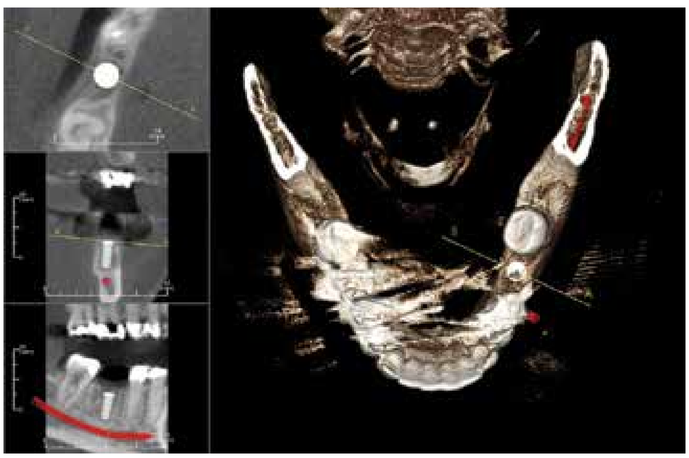

Figure 6: CBCT images are subject to artifact scattering due to metal artifacts such as amalgam restorations, crowns, implants, and posts making interpretation of implant-tooth position more difficult

Figure 7: Same patient as depicted in Figure 6, however, an optical image of the dentition is overlaid on the CBCT scan, giving the ability for a clear and precise interpretation of the dental structures surrounding the proposed implant site

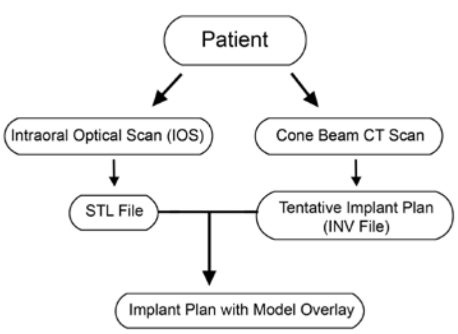

Figure 8: Workflow outlining the steps to generate a superimposition of an optical image on a CBCT scan

Figure 9: Intraoral scan of a patient immediately after tooth preparation for proposed implant sites Nos. 3, 4, 5, and 10

Figure 10: Tooth and soft tissue separation is achieved by strategically placing cotton rolls around the teeth in the following orientation: 3 buccal, 2 lingual, 2 occlusal

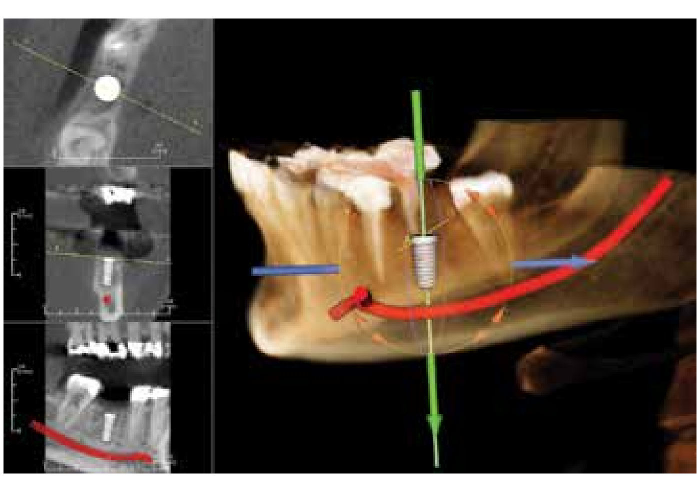

Figure 11: An implant is initially placed in the planning software (Invivo, Anatomage) according to best fit within the bone volume

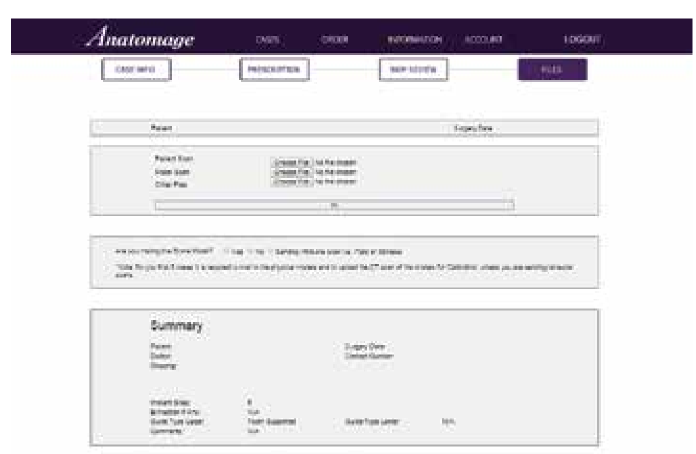

Figure 12: The planning file (INV) and optical scan (STL) are uploaded to a central server for image processing

central server (Blue Sky Plan®, Blue Sky Bio) (Figure 13). The final plan with image-fused scans is downloaded and checked to ensure that the proposed implant trajectory is within the desired restorative contours. A virtual restoration can be created, allowing for a more precise positioning of the implant to the proposed restorative plan (Figure 14). Proposed guide sleeve positions are verified, and a computerized surgical guide is finalized by uploading the final, verified planning file (.INV) through the central server (Figure 15). The guide is tried in, and the implant is placed (Figure 16).

In-office 3D printing

Until just a few years ago, 3D printing remained in the realm of large dental laboratories and facilities that can own and operate large and expensive equipment necessary to adequately print for dental models. Similar

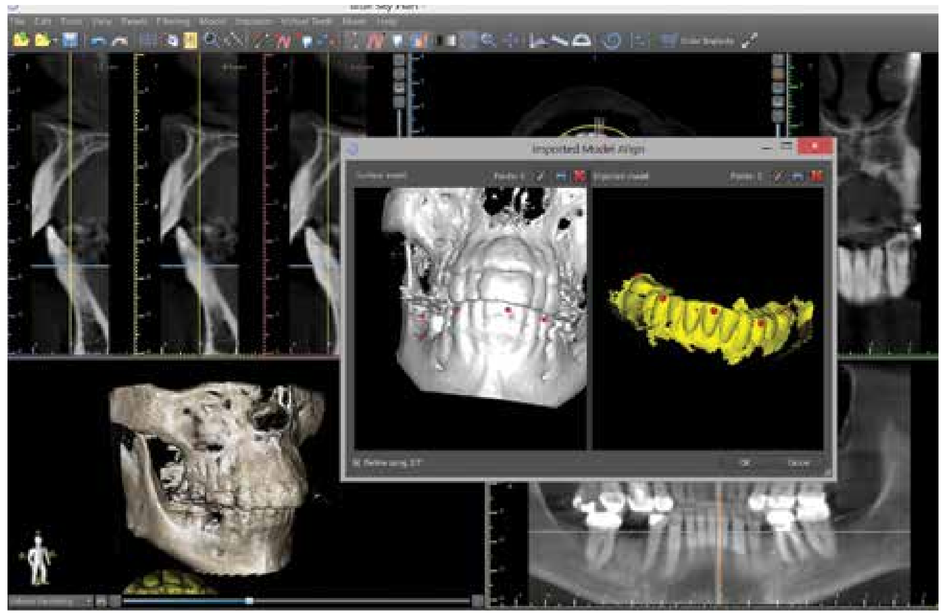

Figure 13: Some software packages allow for the user to superimpose optical images on CBCT scans (Blue Sky Plan, Blue Sky Bio)

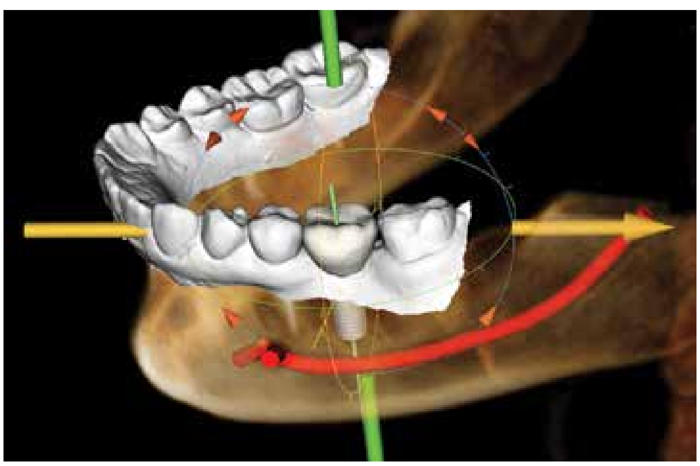

Figure 14: Virtual restorations can be easily visualized and planned with superimposed optical images

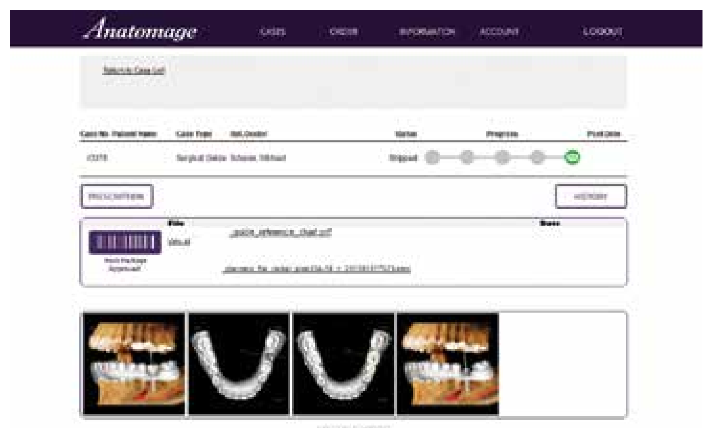

Figure 15: Changes are made to the planning file and uploaded to the central server for guide fabrication

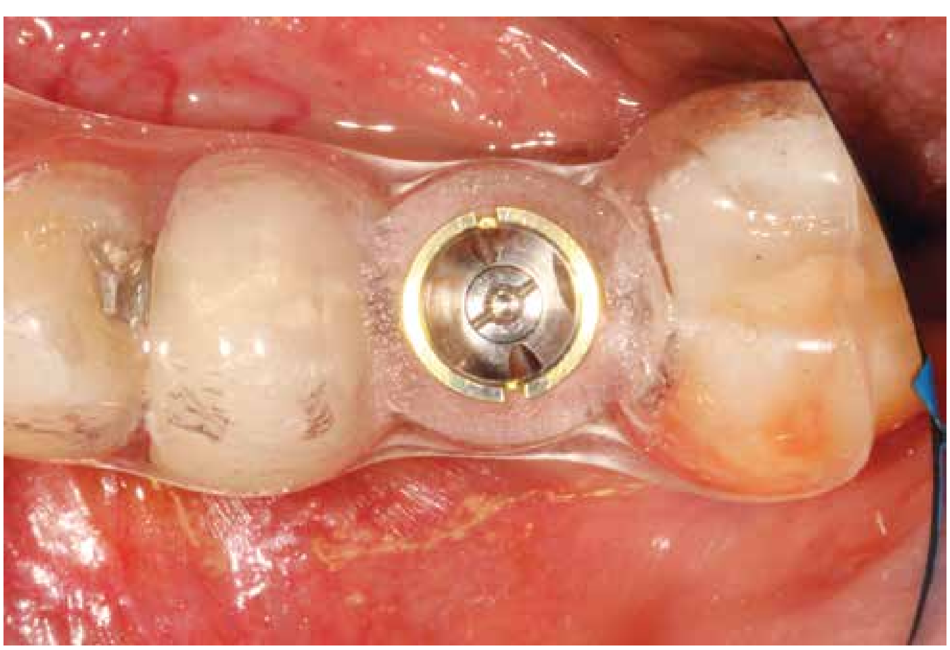

Figure 16: The surgical guide is tried in, and the implant is placed

Figure 17: Reasonably priced, consumer-grade, 3D printers (Form 1+, Formlabs) can be utilized in dental offices to fabricate models of teeth, edentulous ridges, and alveolar surfaces.

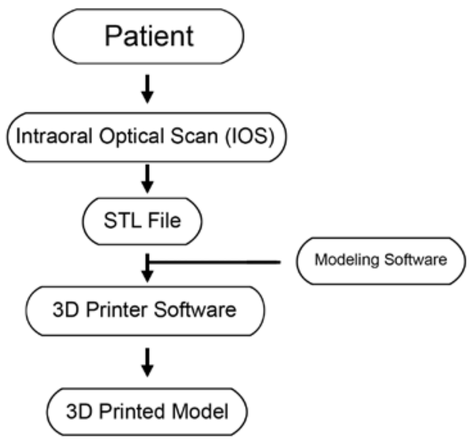

Figure 18: Workflow of integrating intraoral scanning and in-office 3D printing

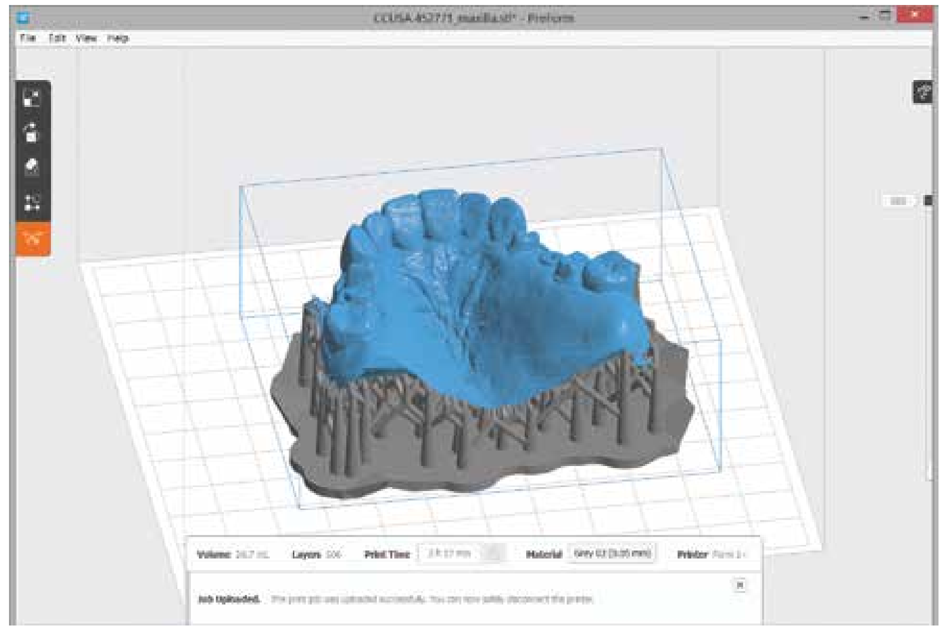

Figure 19: 3D printing software allows for orientation and preparation for printing

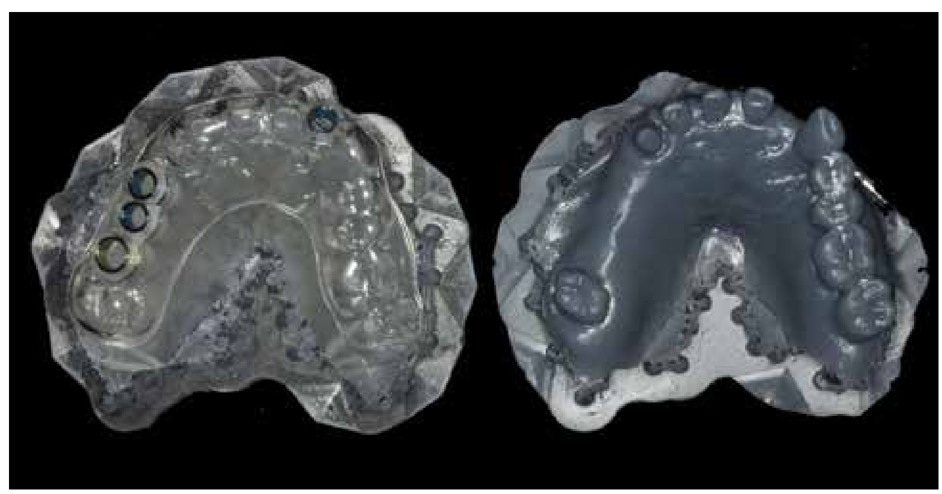

Figure 20: In-office 3D printed models allow for a variety of applications, including provisional models, surgical guide fabrication, and study models

to the previous example of in-office CAD/CAM, the high cost of this equipment has been a critical factor limiting the integration into private clinical practices.

Recently, 3D printing has become more accessible to practitioners due to the rapid development of consumer-grade stereolithography (SLA) printers such as the Form 1+ (Formlabs, Somerville, Massachusetts) (Figure 17). These consumer-grade printers, often costing just a few thousand dollars, are a significant departure from the currently available dental laboratory printers, which can cost almost 10-20 times more than a consumer-grade printer. The workflow for 3D printing begins with an intraoral optical scan of the dentition, and generation of a STL file and results in a 3D printed model (Figure 18). While some intraoral scanners do not allow for exporting of open STL file, this author uses a scanner that easily converts an intraoral optical scan into an open STL (3M™ True Definition Scanner, 3M ESPE). The STL file is opened in a digital-modeling software (netfabb basic, netfabb GmbH, Lupburg, Germany) where missing parts of the scan can be filled in and a base can be added. Alternatively, software that comes with a 3D printer will allow for automatic processing of an STL file to make it ready for printing (Figure 19) (Proform, Formlabs).

A variety of colors and physical properties are available with some offering printing accuracy of between 25-200µm. Greater accuracy prints require more time, often up to 2-4 hours per dental model, because they are printing in thinner layers that require more layers to fabricate a dental model. The STL file is imported into the printer software, and the resin tank is filled with liquid resin. The dental model is printed and can be used to work with planning, designing, and fabricating surgical guides (Figure 20). Following printing of the surgical guide, metal sleeves are incorporated in to the resin guide using a vacuum-forming processing, completing the fabrication process.

Conclusion

While originally out of the reach of many, contemporary digital techniques are being implemented into private practices, allowing a seamless, digital approach to everyday dentistry. Intraoral scanning, especially with being able to easily export open STL files, allows for the full digital control, whether simply for restoration visualization or for being able to fabricate guides. In-office 3D printing, while still a relatively new technology, is rapidly becoming part of everyday private practice. With advanced in dental implant CBCT interpretation and intraoral scanning, a paradigm shift in practice is rapidly occurring. The proposed workflow in this article describes just one of the many potential implementation strategies for this exciting technology. IP

Disclosure: Dr. Michael Scherer is a clinical consultant to Zest Anchors, BIOMET 3i™, and Keystone Dental.

REFERENCES

1. Mörmann WH. The evolution of the CEREC system. *J Am Dent Assoc.* 2006;137(suppl):7S-13S.
2. Puri S. A CAD/CAM picture is worth a thousand words. *CERECdoctors.com Magazine.* 2009;Q2:46-47.
3. Yamalik N, Ensaldo-Carrasco E, Cavalle E, Kell K. Oral health workforce planning part 2: figures, determinants and trends in a sample of World Dental Federation member countries. *Int Dent J.* 2014;64(3):117-126.
4. Dentists working. WorldMapper Web site. http://www.worldmapper.org/display.php?selected=218#. Published 2004.
5. Scherer MD. Presurgical implant-site assessment and restoratively driven digital planning. *Dent Clin North Am.* 2014;58(3):561-595.