A New Virtual World of Dental Treatment

Advances in imaging, CAD, digital manufacturing, and new materials simplify diagnosis and improve outcomes.

Digital imaging, layered manufacturing and CNC milling are creating a new virtual world of treatment for dentists. Data sets from multiple scanning systems can be joined in computer space and motion can be recorded digitally to reproduce complex jaw function. Almost all aspects of a patient's treatment can be virtually planned before any treatment begins. This means that all members of the treatment team can be involved in a meaningful way.

New cone beam computed tomography (CT) imaging systems are simple to use, less expensive than conventional medical CT, and require as little as 20–40 sec to complete a scan of a patient's head. These scanners also expose patients to much less radiation than conventional CT. Other scanning systems that do not use radiation are also becoming common in the dental clinic and laboratory. Light, laser, contact, ultrasound, and holography are just a few of the digital methods being used. Combining these tools in a meaningful diagnostic, treatment planning, and manufacturing process improves outcomes, reduces cost, and ensures quality.

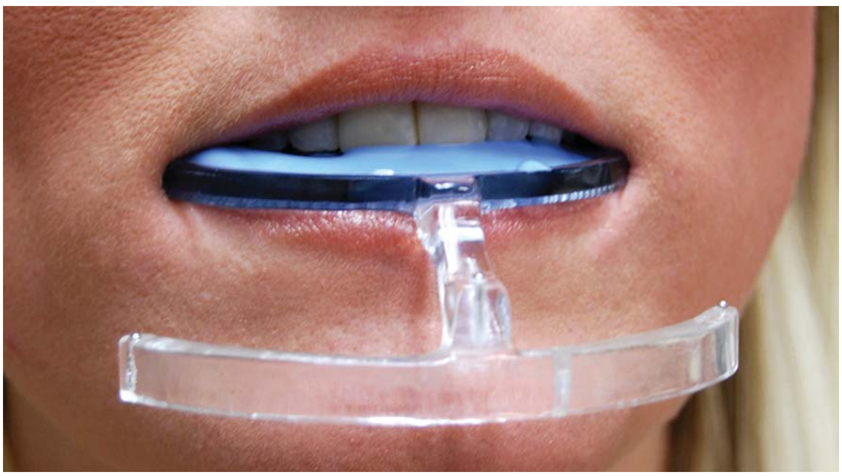

Figure 1. CT Byte device.

Raw data from CT scanning systems is frequently reformatted and saved in the DICOM (Digital Imaging and Communications in Medicine) format. This global information standard is used worldwide; the present standard was developed in 1993, and is designed to ensure interoperability with software systems. The DICOM data represent the scan data as 2-D grayscale bitmaps with a known distance between each 2-D image. Specific anatomic structures can be selected if their grayscale value is different from surrounding tissues. Teeth, for example, are more dense than bone, and as a result the pixels that represent teeth are lighter (more white) than pixels that represent bone. Algorithms have been developed that join all of the pixels that are in a similar grayscale range throughout the numerous slices of data to produce a 3-D representation of the 2-D data. This

Stephen M. Schmitt, DDS
Voxelogix Corporation
San Antonio

Steve Schmitt and Voxelogix's Haas Mini Mill with a five-axis trunnion.

representation of the teeth, or any other structure, can then be saved in any number of 3-D formats. For medical image data, the .stl file is commonly used.

Scanning dental patients with CT can sometimes create images that are distorted due to scatter. If a patient has crowns, bridges, implants, or fillings, these objects can cause the 3-D rendering of the raw data to be distorted, especially around teeth. We have developed a device called a CT Byte that is placed in the mouth during the CT scanning procedure (Figure 1). Three small radiographic markers are attached to the device that can be located in the CT scan data. If impressions of the teeth are made and scanned, or if the teeth are scanned directly in the mouth, these small markers can be located and used to move or join the data sets from the CT with other scanning-device data. All objects scanned in the lower jaw can be joined, and then moved to reproduce the motion of the lower jaw.

The virtual model of a patient created using this method can be a very powerful tool. The contour and shape of the face can be rendered in relation to the underlying structures. Individual teeth can be modeled and virtually extracted from the jaw to provide surgeons with a view of the remaining bone for implant placement or grafting. Digital scans of the patient's teeth or dental models can be positioned over the skeletal model, and new artificial replacement teeth can be virtually positioned and used to design the permanent replacement prosthesis. This is also very helpful for patients, because they can see what their appearance will be like before any treatment has been started. This virtual model also helps patients understand specific problems they may have, and how they will be treated. Figure 2 illustrates several views of this virtual model. We call this visualization and treatment process NeXsmile. In those instances where a patient needs to have all her or his teeth removed, frequently the extractions are made, implants placed, and new artificial teeth attached to the implants in one surgical outpatient appointment. After a 3–4 month healing process new titanium-supported permanent teeth are attached to the implants.

Once all members of the dental team have approved the virtual treatment plan, it can be used to produce many of the devices used in patient treatment. This is especially true if the patient will be having their teeth removed and implants placed. The virtual plan can be used to produce drill guides with stereolithography, or for milling the dental cast with a five-axis mill. Artificial teeth can be robotically positioned, eliminating a tedious laboratory procedure. The artificial teeth can also be CNC-milled to have the correct shape and contour to join them to titanium or other types of substructures.

Direct digital manufacturing of titanium substructures with electron beam melting (EBM) is an excellent method for manufacturing permanent artificial teeth attached to implants. The use of titanium and titanium alloys for dental applications has increased dramatically in recent years due to titanium's many favorable properties. Over the past three decades, processing methods such as lost-wax casting, computer-aided machining, and EDM have expanded titanium's useful range of applications in dentistry. Unfortunately, making dental castings with titanium is difficult due to its high reactivity with investments, low density, high casting shrinkage, and porosity. Dental devices can be milled directly from stock titanium or titanium alloy, but there is a

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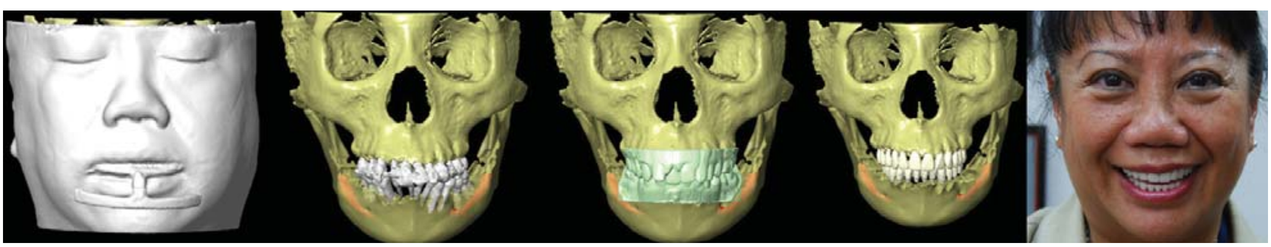

Figure 2.

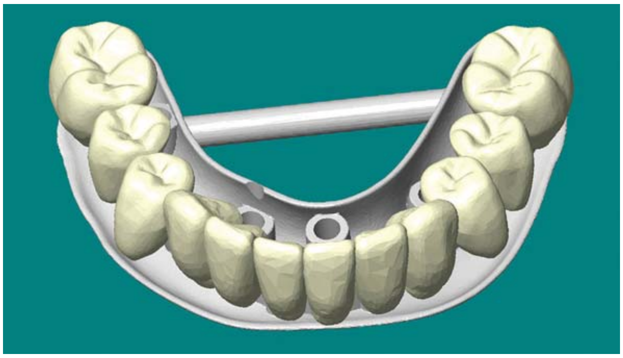

Figure 3. Patient-specific virtual model of titanium substructure.

large amount of waste with this process. EDM with graphite dies to erode the metal into a final shape is also possible, but inefficient and slow.

The introduction of EBM technology by Arcam AB (Molndal, Sweden) has opened up new possibilities for fabrication of titanium parts directly from 3-D CAD models. NASA has also developed an EBM system that is much smaller, uses less energy, and requires less shielding than previous equipment of this type. The NASA system uses a wire-feed method rather than the powdered metal used by Arcam. At present, only prototype systems are available from NASA. EBM occurs in a vacuum (less than 10^{-4} mbar), and ensures a pure chemical composition. Highly reactive materials like titanium can be easily fabricated without the impurities (oxygen, nitrogen or hydrogen) caused by using the lost-wax casting process. Unique surface roughness and geometries can be created to retain dental veneering materials, and dental parts with undercut areas can be produced easily.

The virtual model of the titanium substructure is first created to fit to and support the artificial teeth used for a specific patient (Figure 3). Next, Boolean operations are used to create the holes and recessed areas that attach the titanium substructure to the dental implants. This virtual model of the final restoration can then be sent via the Internet to the dentist treating the patient, to confirm design intent. EBM can produce titanium substructures with physical properties equal to or better than stock metal. EBM also dramatically reduces the amount of milling time required to make a precise substructure. At our company, we have created a process that first creates the EBM part, then images the part, and finally positions it in a five-axis mill to machine the final precise shape and fit that is required. These parts frequently have many small recessed areas that can be easily created with EBM. Once the part is milled, the surface facing the teeth is covered with a pink opaque layer. Next, artificial teeth are positioned from the model data and processed to the titanium. Figure 4 illustrates the EBM part, milled part, and prosthesis in the mouth.

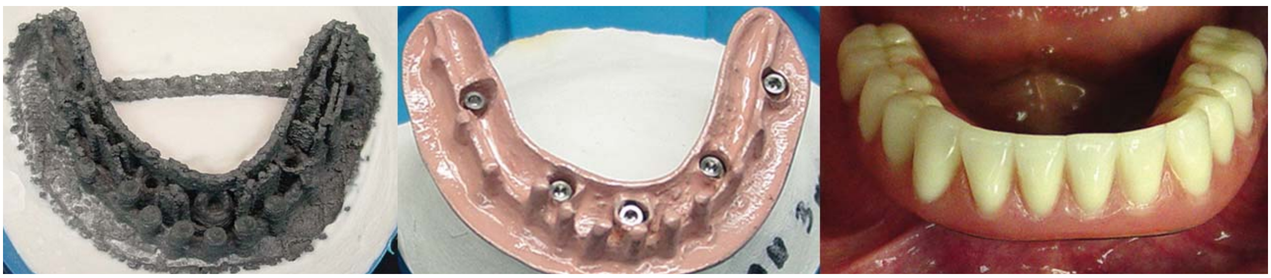

Figure 4.

About 11% of the US population (33 million people) has no teeth (edentulous). Another 20–25 million people will become edentulous for a variety of reasons as the "Baby Boom" generation ages. Dentures are a poor alternative to natural teeth, with only 5–10% of the chewing efficiency of natural teeth. This has long-term emotional, nutritional, and medical consequences for patients. Attaching artificial teeth to dental implants is a vast improvement over dentures alone. Implants stimulate the bone, preventing the continuous bone loss seen by denture wearers, and they provide biting forces at 65–95% of normal. New imaging, visualization, and manufacturing processes can dramatically simplify the diagnostic and treatment process, reduce cost, and improve the quality of life for this large segment of our population.

About the Author

Stephen M. Schmitt received his DDS degree from the University of Minnesota and his MS degree from the University of Texas. He is the former chairman of the Department of Prosthodontics and program director for the Graduate Prosthodontics Program at Wilford Hall USAF Medical Center. Schmitt is a diplomat of the American Board of Prosthodontics and a Fellow of the American College of Prosthodontics and the International College of Prosthodontics. As president of Voxelogix Corp., he is actively involved in the commercialization of additive manufacturing technologies in the treatment of dental and medical patients. A longtime active member of SME, Schmitt is an advisor for the Medical Applications Tech Group, part of the Rapid Technologies & Additive Manufacturing Community.