THE CUTTING EDGE

This quarterly column is compiled by JCO Technology Editor W. Ronald Redmond, DDS, MS. To help keep our readers on The Cutting Edge, Dr. Redmond will spotlight a particular area of orthodontic technology every few months. Your suggestions for future subjects or authors are welcome.

In this thought-provoking article, Mark Barry reviews the various methods of creating digital study models: intraoral scanners, model scanners, impression scanners, and cone-beam computed-tomography scans. All these methods have a common limitation: the product exists only in a digital format. Fabrication of appliances still requires a physical model, and most orthodontic labs do not have the technology to produce an accurate physical model from digital data. The current technologies employed to produce physical models include various "additive" resin printers, subtraction milling, and the most frequently used, stereolithography. The Invisalign system is based on the latter process.

The author also lists a number of features that should be looked for in any digital-model software system—measurement tools, study-model bases, segmentation of the teeth for virtual setups, and analyses related to ABO certification. Equally important is the often-overlooked lack of "portability of data", which locks a user to one provider, and its fees, through the use of proprietary software.

Mr. Barry's contribution will help you prepare for and implement a smooth transition to digital study models while avoiding frustration and unwise capital expenditures. WRR

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In-Office Digital Study Models

For about two decades, orthodontists have been able to choose among several companies to digitize plaster models or impressions. Software allows users to view their models, conduct diagnostic analyses and measurements, present cases to patients and colleagues, and retrieve the virtual models at the click of a button. Eliminating the need to store plaster models can free up many square feet of space in the orthodontic office.

More recently, in-office scanners have allowed practices to create their own digital study models. Three types of systems are available: intraoral scanners, model scanners, and impression scanners. It is also possible to extract digital study models from cone-beam computed-tomography scans, although the radiation dosage needed to achieve a suitable level of detail may be excessive for clinical use.

Intraoral scanners utilize a scanning unit or wand to record a series of three-dimensional (3D) snapshots of each tooth, which then produce a digital representation of the dentition. Some systems require a powder coating to be applied to the teeth before scanning. If the company processes the data offsite, a high-resolution file in a proprietary format is returned to the orthodontist electronically, often involving a per-scan fee. The most obvious benefit of intraoral scanners for both patient and practitioner is that digital study models can be created without the need for impressions. A physical working model is still required to fabricate an appliance or retainer, however, and at least for the time being, the most efficient and practical method of producing a working model is to pour a plaster cast from an impression. It follows that in the majority of cases, an impression will still be required, even if an intraoral scan has been

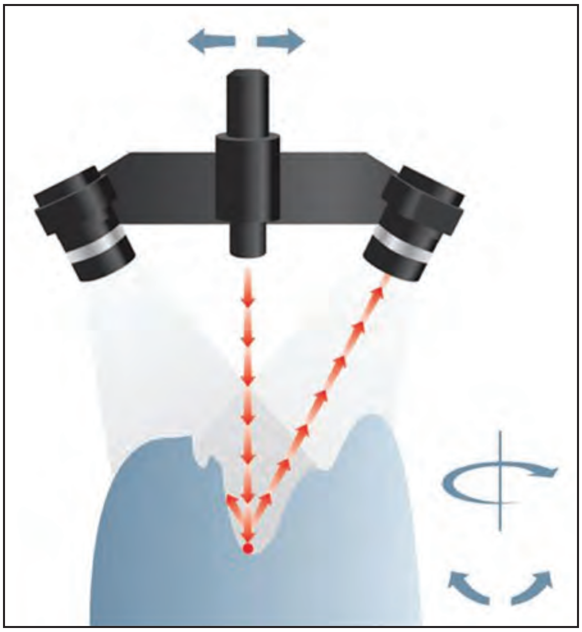

Fig. 1 Laser and two cameras of R700 scanner* used to view impression cavity.

taken. Until improved technology allows the efficient and economical production of a working model from the digital model, traditional impressions will continue to play an important role in the orthodontic office.

One in-office model scanner, the R700,* also has the ability to scan impressions. The technology used in this system has been proven in many specialized medical and dental applications, such as scanning impressions of ear canals for customized hearing aids and scanning dental models and impressions for dental restorations.

Data Acquisition with the R700

The R700 projects a laser line onto the surface of the model or impression, and two high-resolution charge-coupled-device cameras, one on either side of the laser, observe the profile of the line as it falls on the object (Fig. 1). The laser and cameras "sweep" over the object, and the cameras take snapshots of the laser profile at predetermined spatial increments. Since it is not possible for the cameras to "see" every detail on the object from a single position, the object is rotated and tilted through several orientations, and the data acquired during each scan are aligned to produce a 3D digital representation. Data-quality checks compare the accuracy of points that have been captured by both cameras and either ignore or average the data points, as appropriate, for better accuracy. The two-camera system reduces scanning time, because less reorientation of the model is required to capture surface detail that would be missed by a single camera due to shadowing.

The key to capturing as much detail as possible is to make the surface visible to both the laser and at least one camera at the same time. This is reasonably easy to achieve when scanning models, but more complicated when scanning the deep and narrow anatomical details of impressions. Variability in the size, position, and inclination of teeth, not to mention the intricacies associated with crowding, means that simply scanning the impression at several standard orientations will not work. Increasing the number of standard orientations would increase the scan coverage, but would also increase the scanning time to an impractical level. To overcome these problems, the R700 utilizes a unique program called "adaptive scanning": a series of scans is performed at predefined orientations, the scanned data are assessed for surface coverage, and the software identifies any missing surface detail, determining the object orientation required to capture the surface detail in that location. The scanner then reorients the object, and only the area of the missing detail is rescanned. This process is repeated until all visible surface detail is captured. The impressions do not need to be cut to reveal surfaces; all soft tissue remains intact on the impression and appears on the scanned model (Fig. 2).

The system is suitable for scanning most types of stone models and polyvinyl siloxane (PVS) or alginate impressions, although there are some minor limitations: The red laser line will not produce a clear scan of a model or impression made from red material. Highly polished models may yield poor scans, because the laser line will not be clearly defined on the surface. Small accu-

*3Shape A/S, Holmens Kanal 7, Copenhagen K, Denmark; www.3shape.com. Distributed by ESM Digital Solutions, Ireland, and in North America by 3Shape, Inc., 571 Central Ave., Suite 109, New Providence, NJ 07974.

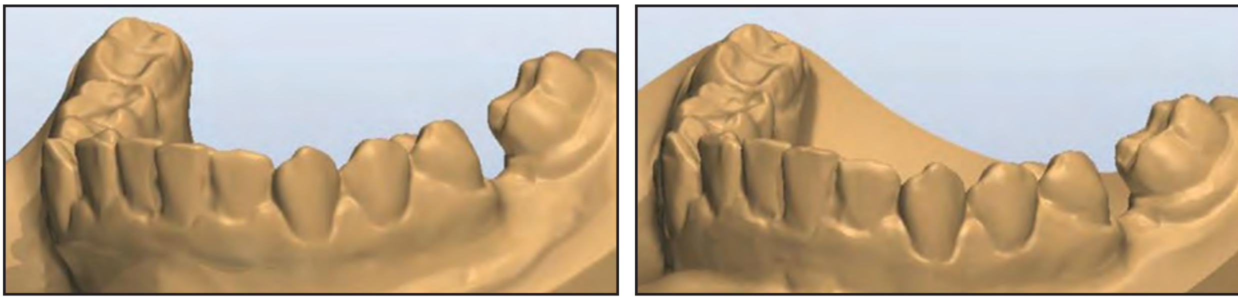

Fig. 2 R700 digital images from scanned plaster model (left) and scanned impression (right) of same patient.

mulations of moisture—for example, at the incisal edge of the impression—and surface moisture on impression materials, which have a similarly reflective effect, should be removed with a paper towel or compressed air.

Whether the study models are plaster or digital, an accurately defined occlusion is required for diagnosis and treatment planning and for evaluating the success of treatment. Three scans are performed by the R700: the full maxillary model, the full mandibular model, and the models together in occlusion. The software uses a "best-fit" algorithm to automatically fit the individual full scans with the occlusion scan to produce on-screen digital models with a highly accurate occlusion.

A similar procedure is followed for scanning impressions, except that the occlusion scan is replaced by a scan of the bite registration. Ideally, the bite-registration material should be opaque, non-reflective, thick (to capture anatomical details), and rigid at room temperature (to resist distortion when mounted for scanning). Good results can be obtained by using either PVS or thick horseshoe wax with a foil inner layer. As with the impression material, most colors work well except for red shades.

Application of Orthodontic Bases

Some systems, including the R700, allow the addition of a base to the digital model so that it resembles a conventional orthodontic study model. This process usually involves simple digital trimming of excess flash from the scanned impression, then sizing and orienting one of the default bases to the digital image. The software then merges the anatomical detail with the base to produce a complete digital study model.

Software Considerations

All outsourced scanning services and in-house scanners are supported by software that allows the digital models to be viewed, measured, and analyzed in the orthodontic office. The program is commonly integrated with practice-management software, meaning that the digital-model software can be opened directly from the patient's computerized record.

When evaluating digital-model software, consideration should be given to the following features (all of which are included in the R700 scanner software, OrthoAnalyzer**).

Viewing: The program should allow the user to view the models not only in occlusion, but in an open-mouth view that displays the occlusal surfaces of both models at the same time. The user should be able to click a series of icons for standard views, but should also have the ability to freely rotate the models, zoom in and out, and click and drag the models across the screen. Some software programs include a transparency mode that makes the models appear semi-transparent—perfect for assessing overbite—and a perspective mode that adds a real sense of depth and three-dimensionality.

Measurement: Tools should provide accurate and reliable point-to-point measurements in two and three dimensions.

Cross-section tools: These tools permit the user to slice models on-screen so that crossbite can be assessed, overjet and overbite measured, and any interference between the lower incisors and the palate easily identified (Fig. 3).

Occlusion manipulation: This feature moves the models relative to each other to correct the occlu-

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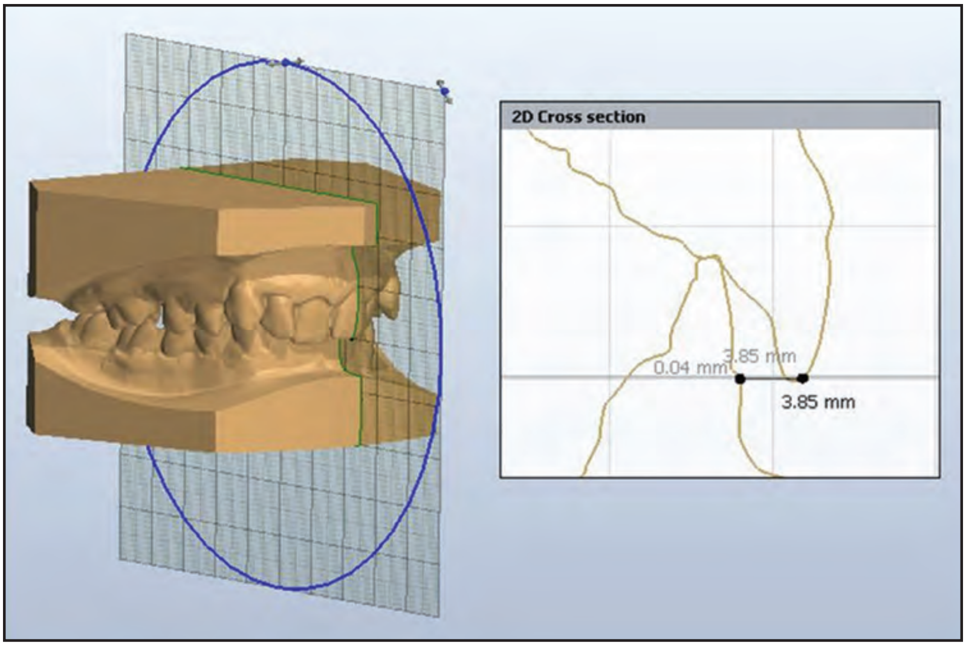

Fig. 3 Cross-sectional assessment of overjet.

sion or to simulate orthognathic surgery or the use of a functional appliance. Because digital study models have hollow surfaces, however, there is a chance that the models may intersect during manipulation, resulting in an impossible occlusion. Collision detection and correction functions in the software can prevent this situation.

Segmentation and virtual setups: Scanned models appear as single objects on the computer screen. Some software programs offer the ability to segment teeth and treat them as separate entities, so they can be moved around to simulate diagnostic setups (Fig. 4). The patient can be presented with a range of possible treatment outcomes—for example, treatment with or without extractions. Standard archform templates can be saved and used as guides to align the teeth on-screen.

Superimposition: The ability to accurately superimpose models is highly useful as a tool for research and for visualization of real or planned tooth movements. Superimposition can be performed either by selecting discrete landmarks on the pair of models or by selecting points that should remain stable throughout treatment, such as ridges on the palatal rugae.

Analyses: Different programs provide different options, but standard analyses include Bolton, ABO, Moyers and Tanaka, Johnston, and anterior space analysis. OrthoAnalyzer is the only program that currently allows a customized analysis design, which can greatly reduce the time required for data collection and analysis when large volumes of cases need to be assessed. This feature is ideally suited to clinicians and researchers with specific analysis requirements.

Questionnaires: A customizable questionnaire option allows the user to gather subjective and objective data about each case. Formulae may be incorporated, and data can be cross-referenced to standard tables to produce common assessment templates such as the Index of Orthodontic Treatment Need (IOTN) and Peer Assessment Rating (PAR).

Open- vs. Closed-Format Files

The importance of open-format files is alarmingly underestimated in many areas of technology, including orthodontics. When selecting a technology for generating digital study models, it is important to be aware of any hidden long-term commitment. If the program produces model files of a closed-format, proprietary type, the user can generally view the models only by using software

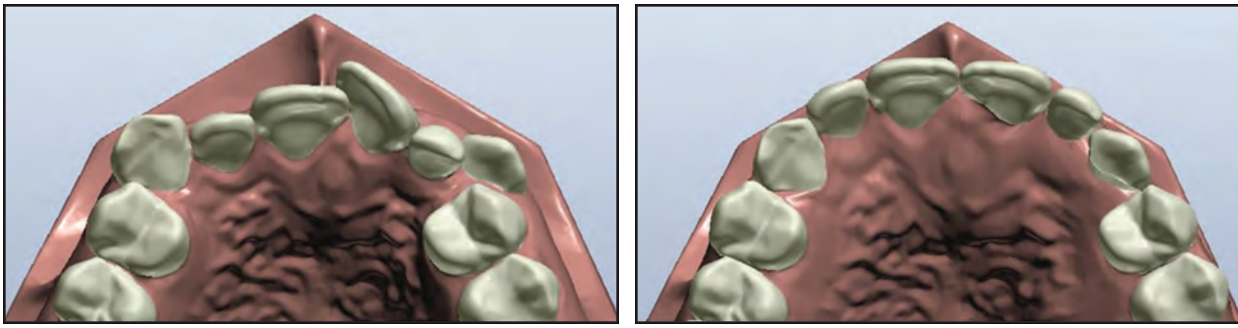

Fig. 4 Treatment prediction using segmentation and virtual-setup features of digital-model software.

provided by the supplier or the equipment that created the models, and digital records may be shared only with other users of the same system. The software may appear to be free, but the reality is that once a user starts to use the program, it becomes difficult to move to another system.

In comparison, with an open-format system, users have complete ownership of their data, can share files with anyone, and can use any software they desire. As more and more laboratories start to accept digital data for the manufacture of orthodontic appliances, users with open-format digital files will be able to choose freely among them, without fear of being tied to a single provider.

3D Printing

A popular question among doctors investigating digital study model systems is whether a physical model can be reproduced from digital data. The answer to this has always been "yes", although in the past the cost has been prohibitive. Vast improvements in recent years have made equipment that can "print" physical models from 3D data more readily accessible. Initially, these 3D printing systems were collectively referred to as "rapid prototyping" techniques, the first of which was stereolithography (SLA), developed by 3D Systems*** in 1986. Since then, many more 3D printing technologies have been developed, some of which far outperform SLA.

SLA works by using ultraviolet (UV) light to selectively cure thin layers of liquid photo-resin until a three-dimensional physical object is produced. The excess (uncured) liquid photo-resin is washed away, and the object is further cured in a UV oven.

Traditional manufacturing processes such as milling require material to be cut away from a block, and are therefore referred to as "subtractive" techniques. 3D printers are referred to as "additive" techniques, since the object is created by adding layers one on top of another. Other additive systems, such as those produced by Objet Geometries,† use technology similar to that of ink-jet printers: a liquid photo-resin is laid down in the desired pattern, and a UV light follows the printhead, curing the liquid. Powder-based systems like the ZPrinter‡ use a printhead to selectively lay a "binder" onto a bed of fine powder, thus forming a layer.

The implementation of these technologies into everyday practice will revolutionize the fabrication of orthodontic appliances. It will not be too long before a doctor will routinely send digital information instead of a physical impression to a commercial laboratory, and the lab will print a working model for fabrication of retainers or other appliances. The inconvenience, cost, and delays associated with shipping physical impressions will be history. And with the development of appliance-design software, it will soon be possible to print out a finished appliance using any of a number of 3D printers. The benefits of faster turnaround times, more appliance choices, innovative treatment techniques, and more precise control for the doctor will inevitably result in better care and more happy, smiling patients. ❑

***3D Systems Corporation, 333 Three D Systems Circle, Rock Hill, SC 29730; www.3dsystems.com.

†Objet Geometries, Inc., 5 Fortune Drive, Billerica, MA 01821; www.objet.com.

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