OVERVIEW

Intraoral Digital Scanners

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(Editor's Note: In this regular column, JCO provides an overview of a clinical topic of interest to orthodontists. Contributions and suggestions for future subjects are welcome.)

The replacement of alginate and polyvinyl siloxane (PVS) impressions with intraoral digital scanners represents a paradigm shift in orthodontics. First introduced as an outsourced technology for storage of three-dimensional electronic study models, the digital scanner has evolved into an in-office tool with a variety of applications. Using this technology, orthodontists can more accurately and efficiently fabricate clear aligners, custom braces, indirect-bonding trays, and laboratory appliances without the unpleasant experience of conventional impressions.

The advent of intraoral digital scanners coincided with the development of computer-aided design and manufacturing (CAD/CAM) technology and the 1984 introduction of chairside economical restoration of esthetic ceramics (CEREC).[1] In 2001, Cadent introduced the OrthoCAD* system for the production of 3D digital models, vir-

*Trademark of Align Technology, San Jose, CA; www.aligntech.com.


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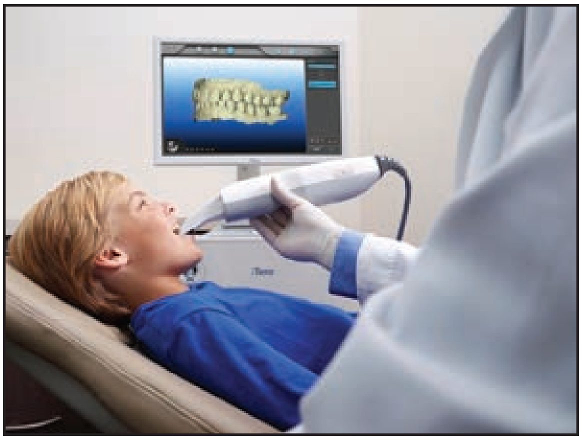

Fig. 1 iTero intraoral digital scanner in use.

tual setups, and indirect-bonding trays. A patient's stone models or PVS impressions were mailed to the OrthoCAD scanning center, where they were processed into a digital file that was downloaded to the doctor's office network. In 2006, Cadent developed the in-office iTero* digital impression system, which by 2008 was capable of full-arch intraoral scanning (Fig. 1); in late 2009, Cadent launched the iOC* system for iTero users. Align Technology purchased Cadent in 2011, allowing clinicians with iOC to begin submitting 3D digital scans in place of physical impressions for the fabrication of Invisalign appliances.

In October 2012, 3M ESPE introduced the True Definition** scanner, enabling orthodontists to submit digital scans for Incognito** custom lingual braces. Six months later, Ormco released the Lythos*** digital impression system for its Insignia*** and Clearguide*** appliance systems. In January 2014, after much demand for further interoperability between manufacturers, the True Definition scanner qualified for Invisalign case submission, so that True Definition scans could now be used for Invisalign submission and iTero scans for the Incognito appliance system.

Despite the growing popularity of intraoral digital scanners, questions remain regarding their applications and the differences among manufacturers. This article will review the use of intraoral digital scanners in the orthodontic office, including an in-depth examination of the iTero, True Definition, and Lythos devices.

*Trademark of Align Technology, San Jose, CA; www.aligntech.com.
**Trademark of 3M Unitek, Monrovia, CA; www.3Munitek.com.
***Trademark of Ormco, Orange, CA; www.ormco.com.

Advantages of Digital Scanning

Alginate and PVS impressions have been associated with problems such as pulls, tears, bubbles, voids, tray-to-tooth contact, separation from the impression tray, temperature sensitivity, limited working time, material shrinkage, inaccurate pouring, model overtrimming, and breakage during shipment[2] (Fig. 2). Impression taking also heightens anxiety and discomfort for patients of all ages, particularly those with sensitive gag reflexes. In vitro studies have shown that full-arch digital scans are as accurate as conventional impressions,[3] without these drawbacks.

For the orthodontist, advantages of digital scanning include improved diagnosis and treatment planning, increased case acceptance, faster records submission to laboratories and insurance providers, fewer retakes, reduced chairtime, standardization of office procedures, reduced storage requirements, faster laboratory return, improved appliance accuracy, enhanced workflow, lower inventory expense, and reduced treatment times. Benefits to the patient include an improved case presentation and a better orthodontic experience with more comfort and less anxiety, reduced chairtime, and easier refabrication of lost or broken appliances, as well as potentially reduced treatment time.

Scanning Technology

Digital intraoral scanners are considered Class I medical electrical devices, designed and constructed in accordance with the standards of ANSI/IEC 60601-1. Every scanner has three major components: a wireless mobile workstation to support data entry; a computer monitor to enter prescriptions, approve scans, and review digital files; and a handheld camera wand to collect the scan data in the patient's mouth. To gather surface data points, energy from either laser light or white light is projected from the wand onto an object and reflected back to a sensor or camera within the wand. Based on algorithms, tens or hundreds of thousands of measurements are taken per inch, resulting in a 3D representation of the object's shape.

The technology used by the wand to capture surface data determines the measurement speed, resolution, and accuracy of the scanner. Four types of imaging technology are currently employed:

Triangulation, used in CEREC,[4] measures the angles and distances from known points with projected laser light (Fig. 3A). The distance between the laser source and the sensor is known, as is the angle between the laser and the sensor. As light reflects off the object, the system determines the angle of reflection, and therefore the distance from the laser source to the object's surface, according to the Pythagorean theorem. To provide uniform and predictable light dispersion, this technology requires a thin coating of opaque powder to be applied to the target tissue.

Parallel confocal imaging projects laser light through a filtering pinhole to the target tissue (Fig. 3B). The sensor is placed at the confocal (in-focus) imaging plane relative to the target, and a small aperture in front of the sensor blocks any light from above or below the plane of focus. Only focused light reflecting off the target tissue will reenter the filter and reach the sensor for processing; out-of-focus light (bad data) is eliminated, thus maximizing the accuracy of the scan. A parallel confocal system tomographically slices the object and stitches together thousands of slices of data to create a complete picture—a process referred to as "point-and-stitch reconstruction".

Accordion fringe interferometry (AFI) uses two light sources to project three patterns of light, called "fringe patterns", onto the teeth and tissue (Fig. 3C).[5] As a fringe pattern hits the surface, it distorts and takes on a new pattern, based on the unique curvature of the object. This distortion in the fringe pattern is referred to as "fringe curvature". Surface data points of the fringe curvature are recorded by a high-definition (HD) video camera that is offset from the projector by about 30°. Because the differences among the three precision optical measurements determine the distance measurement, the differential measurement is unaffected by changes in tooth colors and materials.

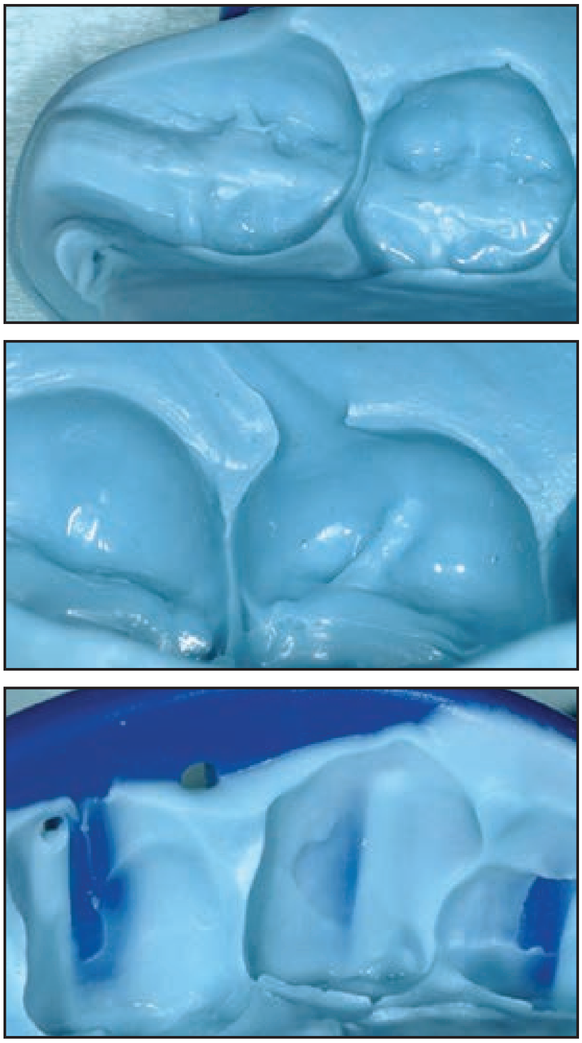

Fig. 2 Problems seen with conventional impressions.

Three-dimensional in-motion video uses an HD video camera with trinocular imaging—three tiny video cameras at the lens—to capture three precise views of the tooth (Fig. 3D). A complementary metal-oxide semiconductor (CMOS) sensor behind the cameras converts the light energy into electrical signals. The distances between two data points

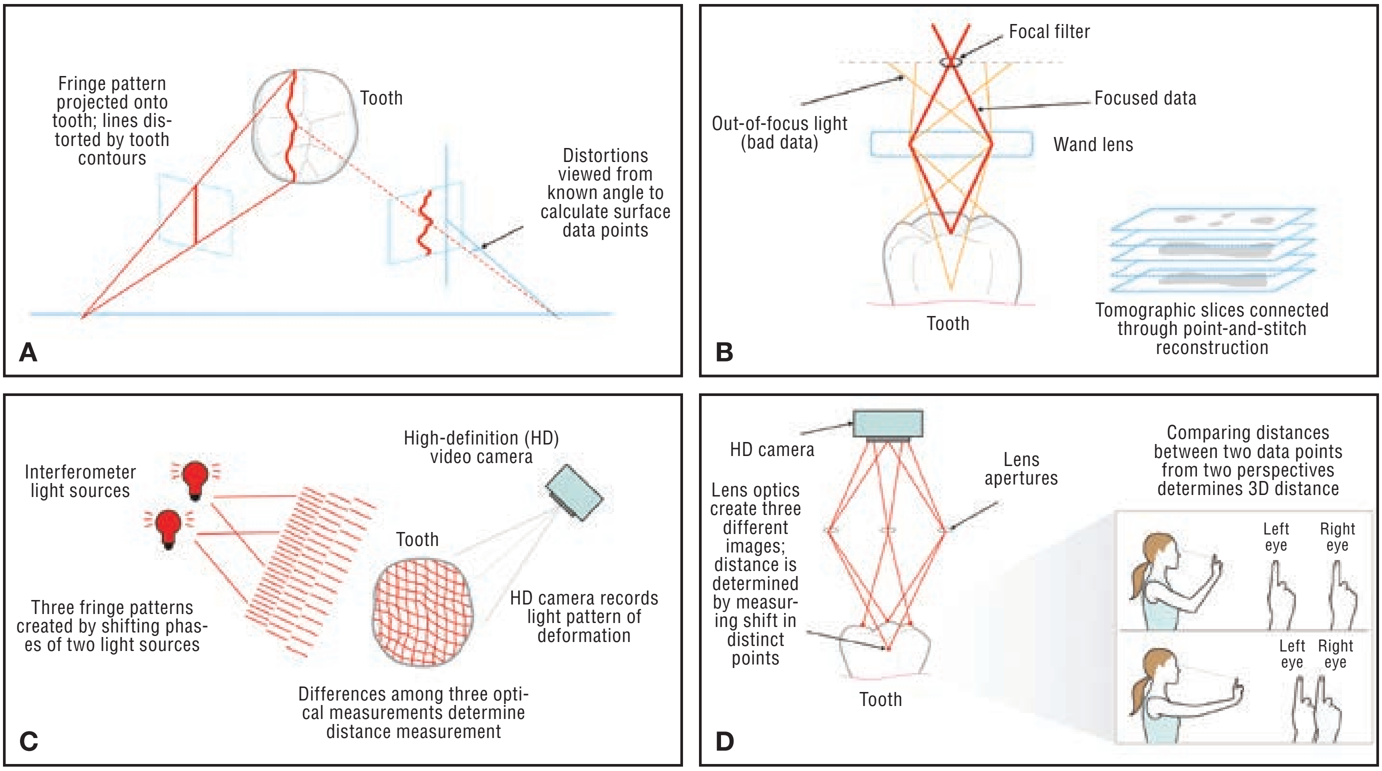

Fig. 3 Common digital imaging technologies. A. Triangulation. B. Parallel confocal imaging. C. Accordion fringe interferometry. D. Three-dimensional in-motion video imaging.

are simultaneously calculated from two perspectives to determine the 3D data, which are captured in a video sequence and modeled in real time. Although powdering is required to capture surface data points, only a light dusting is needed compared to the thicker coating for triangulation.

Both AFI and 3D in-motion video imaging use HD video cameras rather than a sensor to rapidly capture images in real time, as opposed to the slower point-and-stitch reconstruction of surface data. AFI scanners have a higher dynamic range of luminosity, allowing reflective surfaces to be scanned without powder coating.

Powdering

Multiple translucent layers of tooth and restorative material will disperse light at unpredictable angles. Because scanner algorithms are unable to account for this inconsistency, some digital scanners require the application of a thin layer of contrast powder coating, also referred to as "dusting" or "accent frosting", over the target tissue (Fig. 4). The powder—an opaque mixture of titanium dioxide or, less commonly, zirconium oxide, with amorphous silica and aluminum hydroxide—is applied to the target tissue using a handheld spray dispenser with a removable powder well, blown out in small puffs to deposit a thin layer on the surfaces to be scanned.

The purpose of powdering is to enhance scanning accuracy by increasing the number of surface data points and providing uniform light dispersion. The opaque coating reflects light at predictable angles regardless of the surface, providing a strong visual pattern that is more easily captured by the scanner sensor. Therefore, even scanning systems that are promoted as powder-free will benefit from a light dusting of contrast powder, particularly in regions of poor surface anatomy such as the mandibular incisors or on highly translucent porcelain-fused-to-metal crowns or ceramic brackets.

Fig. 4 Powder dispenser used with True Definition scanner.

Since no optically based digital impression system can scan through tissue or saliva, proper retraction and isolation are essential for accurate capture of surface data.[6] Full-arch scanning may require the use of retractors, dri-angles, saliva ejectors, and even a second coating of powder if saliva washes the powder off some surfaces.

The iTero Scanner

Cadent's iTero, the front-runner of intraoral digital scanning technology, produces accurate, powder-free digital impressions by means of parallel confocal imaging and point-and-stitch reconstruction (Fig. 5A). Because the iTero software uses an open-source file type known as Landlord.stl, its standard triangulation language (STL) files are compatible with the Invisalign, Harmony,**** Incognito, Insignia, and SureSmile† systems.

The 117lb iTero unit consists of a 22" liquid-crystal-display monitor; a handheld scanner wand; a built-in, sealed, antiseptic keyboard; a wireless mouse; and a wireless foot pedal that frees the operator's hands to hold the wand. A mobile cart enables the unit to be moved between treatment chairs, which is a particular advantage during busy times of the day. A dedicated wireless router synchronizes data with the cloud.

The iTero wand is relatively large and bulky, weighing about 1.5lb, but has a central notch that positions the operator's hand at the optimal balance point. Single-use disposable sleeves fit over the scanning end of the wand to protect the laser light source and prevent cross-contamination. The scanner sleeve is also useful as a retractor for cheeks, tongue, and soft tissues. A gentle stream of air from the wand demists the lens and also displaces saliva for more accurate scanning. The parallel confocal technology allows the data-capture wand to rest directly on the tooth surface, which helps steady and lighten the wand. It is important not to contact the soft tissues, however, as this could cause discomfort. The patient does not need to open the mouth wide and may even feel comfortable gently biting on the wand tip.

Scanning is done by quadrants, starting in the lower left buccal quadrant at the most distal molar. The wand is held at a 45° angle to the gingival margin, so that it will capture both the buccal and the occlusal landscape, and moved mesially one tooth at a time, with an overlap between consecutive scans. The sequence is repeated on the

****Distributed by American Orthodontics, Sheboygan, WI; www.americanortho.com.

†Trademark of OraMetrix, Inc., Richardson, TX; www.suresmile.com.

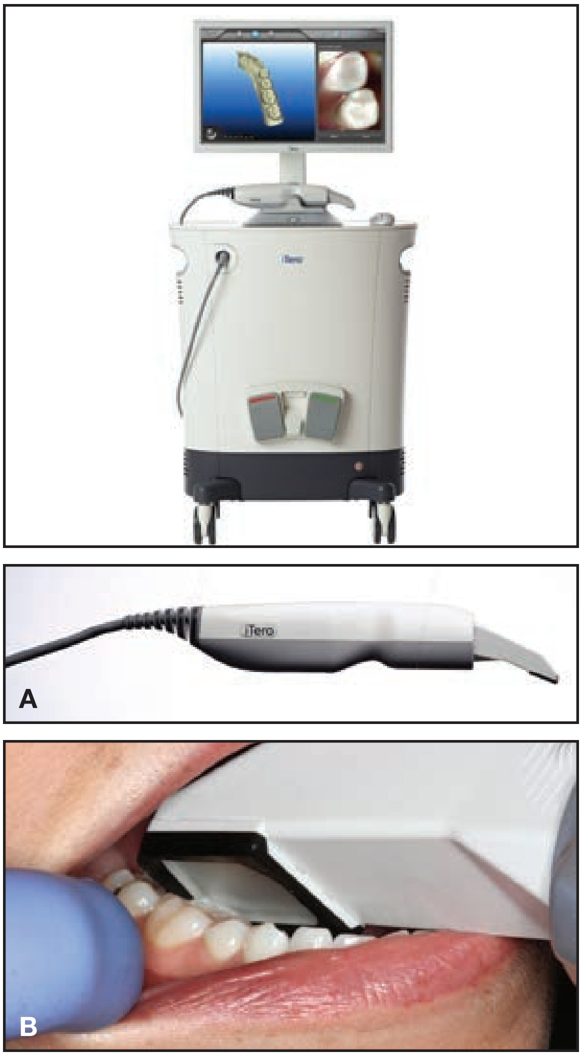

Fig. 5 A. iTero intraoral scanner with sealed keyboard, wireless mouse, and wireless foot pedal; parallel confocal imaging enables powder-free scanning. B. Wand held at 45° to capture both lingual and occlusal surfaces.

lingual side (Fig. 5B), beginning with the lower left lingual quadrant. Although a full-mouth scan and bite registration takes 10-15 minutes, Align has indicated that this time will be reduced in the near future.

A unique feature of iTero is its Outcome Simulator, which allows a virtual Invisalign treatment plan to be presented to the patient. The Outcome Simulator can be viewed within minutes after scanning is completed; the operator can manipulate the teeth on the screen to demonstrate changes to the movement setup.

The True Definition Scanner

The 3M ESPE True Definition scanner, which uses the revolutionary 3D in-motion video imaging technology, is currently the only third-party scanner that has been qualified for use with Invisalign (Fig. 6). Similarly, Align's iTero scanner is qualified for fabrication of the 3M Unitek Incognito system.

The True Definition setup comprises an HP‡ workstation with a 22" touchscreen display, a lightweight wand, a powder dispenser, and a wireless Internet connection for uploading to the cloud. The unit weighs 73lb and, like iTero, is built on a rolling cart for easy transport. The large touchscreen display eliminates the need for a horizontal surface with a keyboard and mouse, resulting in a slimmer workstation. It also serves as a virtual digital loupe, enabling the operator to view, rotate, and magnify the 3D model to scrutinize the scan before approving the digital prescription. Once the scan has been sent, the clinician can log in to Invisalign's doctor site and access the patient's scan in a few moments.

Because a light coating of contrast powder is required prior to scanning, moisture control is critical. One technique is to place dri-angles into the cheek before positioning a cheek retractor; if a Nola†† retractor is used, a high-speed suction adaptor can be added to allow simultaneous use of the saliva ejector. The teeth (and soft tissues if needed) are then lightly dusted with powder by means of the handheld dispenser connected to the workstation.

True Definition's small, ergonomic wand, weighing only 7oz, mimics a conventional dental handpiece with a pencil grip. Instead of buttons, it uses double-tap activation. Since the wand is

‡Trademark of Hewlett Packard Company, Palo Alto, CA; www.hp.com.
††Distributed by Great Lakes Orthodontics, Tonawanda, NY; www.greatlakesortho.com.

Fig. 6 True Definition intraoral scanner with touchscreen monitor and lightweight wand; 3D in-motion video technology enables rapid video scanning in real time.

cleaned with sterile wipes and placed in a cold-sterile solution after each use, it is helpful to purchase a second wand. Six LEDs on the tip illuminate the field, and the wand is easy to rotate, allowing the operator to scan at all angles with a minimum of movement.

The True Definition scanner seamlessly captures data in real time. The operator simply traverses the anatomy with the handpiece and observes as the video 3D mesh is accumulated. During the scan, the wand is kept about 10mm (recommended 3-17mm) from the tooth surface. The clinician may choose from a number of scanning paths, but most begin on the posterior occlusal surface of the first premolar. Scanning is divided into sextants, moving from lingual to buccal and finishing back on the occlusal. This process is repeated in the anterior sextant, starting with the first premolar to ensure an overlap of at least one tooth. A full arch can be scanned in three sweeping passes, taking about five minutes. Data reconstruction occurs simultaneously.

The Lythos Scanner

Ormco's Lythos digital scanner was designed specifically for orthodontic use, based on technology originally developed for the aerospace industry (Fig. 7). The AFI method generally does not require powder coating, although a contrast medium may help with porcelain-fused-to-metal restorations. At present, iTero scans can be used for Ormco's Insignia system, but Lythos scans are not yet approved for Invisalign; better interoperability is expected in the future.

The most noteworthy feature of the Lythos scanner is its compact size. Weighing only 25lb, it rests atop a chairside delivery unit and can easily be transported from operatory to operatory or between offices. The unit consists of a small touchscreen monitor for data entry; a .7lb, medium-size ergonomic wand, and a wireless modem. The monitor can be raised as much as 15" with an extension arm for enhanced visibility. Software updates are downloaded via the Internet, and the system is Apple-compatible.

Single-use disposable sleeves fit over the scanning tip to protect the wand and prevent cross-contamination. A heated mirror, rather than compressed air, prevents lens fogging.

As with the True Definition scanner, images are captured by video in continuous motion. There is no foot pedal, so the operator must rely on visual and light cues from the monitor. A unique occlusal "backbone" scan serves as a reference registration: the occlusal surfaces of the entire arch are scanned first, enabling the system to pinpoint the locations of the images being acquired. The advantage of this registration method is that if the scan is interrupted, the Lythos system "knows" where it left off once the wand is placed back in the mouth. Following occlusal registration, the

Fig. 7 Lythos intraoral scanner featuring compact design and touchscreen monitor with extension arm; accordion fringe interferometry enables powder-free scanning at video speed.

scan is divided into quadrants, beginning on the buccal side of the lower right terminal molar. The wand is swept mesially, quickly capturing multiple teeth in real time. After three or more teeth are scanned, the operator should pause briefly to allow the data to process. The wand is then rotated to capture the lingual surfaces. A full-mouth scan takes about seven minutes.

Other Digital Scanners

Several other promising intraoral digital scanners are used primarily in dentistry. The Trios‡‡ system employs advanced parallel confocal imaging with rapid point-and-stitch reconstruction. As with Lythos, the wand has disposable tips and a heater to prevent lens fogging. The most intriguing aspect of the software is an auto-fill feature that can automatically patch areas of missing data, using information from an internal gyroscope to determine which area is being rescanned, and then stitch it seamlessly into the original scan. Full-color scanning is available for an extra fee, though the color is only for visual reference and does not improve accuracy.

The CS3500§ unit features parallax scanning technology, a derivative of parallel confocal imaging. An innovative light-guidance system aids in data capture, reporting whether an area was scanned successfully so that the operator can concentrate on the patient rather than the monitor. Similar to True Definition, the CS3500 uses autocapture with no foot pedal. What makes it unique is a direct USB connection that can be plugged into any computer, eliminating the need for a dedicated workstation. It also integrates with Orthotrac§ software. The scanner tips can be sterilized and reused as many as 20 times, and there are two tip sizes to accommodate children and adults.

Planscan§§ uses a sophisticated triangulation system that does not require powdering in the vast majority of cases. Point-and-stitch reconstruction occurs at video-rate speed. Other notable features include fog-free scanning with a heated mirror, sterilizable tips for infection control, active heat dissipation for full-arch scanning, adjustable-field-of-view software to optimize the target field, and a laptop-based design center for portability.

Laboratory Procedures

To produce a traditional impression, the orthodontist takes a mold of the dentition in alginate or PVS and mails either the stone cast or the impression to the laboratory for pouring, appliance fabrication, or digitization. The appliance or digital files are then sent back to the orthodontic office. With intraoral digital scanning, the ortho-

‡‡Trademark of 3Shape, Warren, NJ; www.3shape.com.
§Trademark of Carestream, Atlanta, GA; www.carestream.com.
§§Trademark of Planmeca, Roselle, IL; www.planmecausa.com.

dontist sends the digital file to the laboratory for appliance fabrication, thus reversing the flow of information.[7] The digital file immediately uploads to the scanner network, where any orthodontic laboratory with an open and trusted connection can access it. The orthodontist can access the file at any time by logging into the network and selecting the appropriate patient. Prescriptions are either completed online or faxed to the laboratory.

An "open connection" means the laboratory can work with any CAD/CAM system that accepts STL, the standard format. The laboratory can then use its own equipment for 3D printing. A "trusted connection" is a partnership between the scanner manufacturer and an orthodontic laboratory; in essence, the manufacturer recommends the lab, with both companies performing validation checks to assure seamless integration and high-quality production. Every scanner manufacturer provides a list of laboratories with trusted connections, and new connections with laboratories, as well as software and systems companies, are constantly being tested and validated for future integration. Open and trusted connections provide the benefits of an integrated system without the drawbacks of a proprietary format.

The ability to fabricate everything from indirect-bonding setups to retainers and soldered-band appliances from digital models may be the most exciting use of intraoral scanning. An acrylic appliance can be directly fabricated on a 3D-printed model as if it were a stone cast (Fig. 8). Banded appliances require no initial separation, although the palate may have to be captured, depending on the appliance design. At present, due to the possibility of melting a 3D-printed model, a soldered appliance requires the printed models to be duplicated in gypsum stone with the bands seated. In the near future, orthodontic labs will use milling machines to produce models out of a gypsum-like material that can be soldered.

Fig. 8 Acrylic plate made in office from digital scanner-generated STL file and 3D-printed model.

Integration with Other Technologies

Cone-beam computed tomography (CBCT) and digital imaging and communications in medicine (DICOM) files can now be merged with STL files from digital scans to create 3D renderings of the crowns, roots, and bone. An orthodontist can accurately visualize root positions at different stages of orthodontic treatment simply by scanning the teeth, rather than taking multiple CT scans that would expose the patient to higher doses of radiation.[8] CBCT and STL scanning files can also be merged to facilitate virtual treatment planning of orthognathic surgical cases, creation of surgical guides, placement of orthodontic miniscrews, exposure of ectopic teeth, or preparation for dental prostheses.[2]

Intraoral digital scanning is inevitably linked to in-office 3D printing—properly referred to as "additive manufacturing", or the deposition of

TABLE 1
COMPARISON OF INTRAORAL SCANNERS[11]

Model	Price	Annual Cost of Tips & Supplies[a]	Cost of Warranty	Annual Software Fee	Technology	Scan Time (Full Mouth & Bite)	Powdering
iTero	$24,999	$1,250	$4,000/year	NA	Parallel confocal	10-15 minutes	No
True Definition	$11,995	$7,500[b]	$6,000	$3,948 cloud fee	3D in-motion video	5 minutes	Yes
Lythos	$19,999	$1,250	$2,699/3 years	NA	Accordion fringe interferometry	7 minutes	Rarely
Trios	$30,200	$1,000	1 year free	$5,600[d]	Parallel confocal	8 minutes	No
CS3500	$30,000[c]	$500	$3,500/3 years	$660	Parallel confocal (parallax)	<10 minutes	No
Planscan	$25,000[c]	$500	$5,500/2 years	$1,620	Triangulation/ sampling	<10 minutes	Rarely

[a] For about 500 scans/year.
[b] No cost for tips or supplies, but a second wand may need to be purchased for $7,500.
[c] Does not include laptop.
[d] Variable, based on purchase price.

material to create an object. The printer reads the design from a printable STL file and lays down successive layers of liquid acrylic, powder, paper, or sheet material to build the model from a series of horizontal cross-sections. The material layers can be as thin as 10-150 microns.

Methods of additive manufacturing include stereolithography (SLA), fused deposition modeling (FDM), selective laser sintering, PolyJet§§§ photopolymer printing, 3D sand casting, syringe extrusion, and variants of these technologies.[9] Orthodontists are most familiar with SLA, which is used by Align Technology to create a customized physical model of each movement stage. FDM is the basis of the popular Stratasys§§§ printer. Until recently, 3D printers have been expensive and slow, limiting their use to professional dental labs. Technological advances now allow manufacturers to offer this equipment for prices in the tens of thousands of dollars with significantly faster print times, opening the door to private-office use. The progression toward in-office 3D printing to replace the gypsum lab is likely the next paradigm shift in orthodontics.

§§§Trademark of Stratasys Ltd., Minneapolis, MN; www.stratasys.com.

Return on Investment

Many orthodontists struggle to decide whether intraoral scanning technology is worth the price. Although digital scanners currently range from $12,000 to $33,000 (Table 1), this cost can quickly be recovered in reduced overhead and increased practice efficiency. For example, an internal survey by Align Technology indicated that 36% of dentists had to reappoint a patient for retaking of PVS impressions at least once a month.[10]

The cost effectiveness of intraoral digital scanners is demonstrated by a conservative practice model. A busy orthodontic practice with a large volume of Invisalign or Incognito patients may spend $800 per month, or $9,600 per year, on impression materials. Assuming $300 of hourly production, an average 15 minutes of chairtime savings computes to $75 of savings per production hour. Further assuming a conservative estimate of 200 scans per year, the practice can realize $15,000

TABLE 1 (cont.)
COMPARISON OF INTRAORAL SCANNERS[11]

Model	File Type	Cloud Storage	Integration with Invisalign	Integration with Incognito	Integration with SureSmile	Integration with Insignia	Notable Features
iTero	Open STL	Yes	Yes	Yes	Yes	Yes	Powder-free scanning; Invisalign Outcome Simulator
True Definition	Open STL	Yes	Yes	Yes	No	No	3D stereo viewing; Invisalign interoperability
Lythos	Open STL	Yes	No	No	No	Yes	Mostly powder-free; video imaging; Apple compatible
Trios	Open STL	No	No	No	Yes	No	Pseudocolor
CS3500	Open STL	No	No	No	No	No	Portability with USB wand
Planscan	Open STL	No	No	No	No	No	Ability to erase and rescan

in production savings. These inventory and chair-time savings total $24,600 over one year—roughly the price of an iTero scanner. Factoring in the costs for warranty coverage, scanner tips and supplies, and model fees, an intraoral scanner can pay for itself within two years. Clearly, the value of this technology exceeds the initial investment.

Conclusion

Intraoral digital scanners are becoming integral to the modern orthodontic office, improving both practice efficiency and the patient experience compared to conventional alginate and PVS impressions. Open and trusted connections with orthodontic laboratories, merging of CBCT and DICOM files, increasing interoperability among manufacturers, and in-office 3D printing have opened limitless possibilities for this technology.

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