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An Overview of Digital Intraoral Scanners: Past, Present and Future - From an Orthodontic Perspective

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Digital intraoral scanners(IOSs) have become the ongoing trend in contemporary digital orthodontics. This article aims to elaborate the past, present, and future of IOSs from an orthodontist's perspective. We summarized the comparison between digital and conventional impression in literatures. Also, we discussed about the imaging principles and characteristics of different IOSs. Although unable to recommend the single best option, a checklist of consideration when choosing an IOSs was developed after trailing the mainstream commercial products. With technology revolution, embracing the IOSs may be essential for those interested in future digital orthodontic workflow. ***(Taiwanese Journal of Orthodontics. 30(3): 148-162, 2018)***

Keywords: digital orthodontics; intraoral scanner; digital impression.

INTRODUCTION

We are currently in a new era of digital orthodontics. This technological revolution has made orthodontic daily routines less reliant on paper, radiation, and dental casts. With the underlying aim of simplifying the conventional laboratory workflow as well as reducing discrepancies when fabricating dental casts and arranging their storage, the use of digital intraoral scanners (IOSs) has led to a variety of clinical in-office applications.[1] The last few decades have seen a dramatic increase in research comparing scanners and the issue of conventional versus digital approaches. However, this article aims to provide an overview of the latest commercially available digital IOSs from an orthodontist's perspective. In addition to the comparisons often presented in prosthodontic articles, we also summarize and highlight issues requiring consideration when IOSs are incorporated into daily orthodontic practice.

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Historical review

In 1973, the concept of computer-aided design/computer-aided manufacturing (CAD/CAM) was first introduced in dental applications by Dr. Francois Duret in France.[2,3] A prototype device for digital impression was later presented by Sirona Dental Systems for restorative dentistry in 1987, known as the Chairside Economical Restoration of Esthetic Ceramics (CEREC®) system.[3] The CEREC system proved to be a pioneering device in the CAD/CAM dental industry.[4] Although the scanning or milling quality may have seemed imperfect, it represented the state-of-the-art at the time, with no competitors arriving until 2008, when the Cadent iTero digital impression system, first launched in 2006, was announced as being capable of full-arch intraoral scanning.[1] Shortly thereafter, Align Technology acquired Cadent in 2011, then integrated iTero into data transmission for Invisalign therapy. Almost every major dental company has since focused efforts in this field in attempts to manufacture superior IOSs. At the 2017 International Dental Show in Cologne, more than 14 scanners were demonstrated. Further progress in intraoral digital scanner systems is expected to be achieved in the coming decade.

Why goes digital?

This is probably the principal question that most clinical practitioners ask, particularly those who are more familiar with conventional impression techniques. Similarly to when digital cameras and digital radiographic films were first introduced in the field of dental applications, most practitioners' express doubts.

The benefit of digital IOSs is an easier and faster digital impression method with greater efficiency and accuracy but less waste and, typically, lower cost.[5] Although some of these proposed advantages continue to be scrutinized, most digital techniques have proven equal to or better than the conventional method.[6] The use of IOSs was primarily restricted to restorative and prosthetic dentistry, such as the well-known CEREC CAD/CAM system; restorations could be designed to fit an abutment using digital impressions.[7] A collaborating laboratory or milling machine could then be used to accomplish single-appointment all-ceramic prosthesis treatment. In the modern era of implant dentistry, this new technology can be adopted for implant-retained or implant-supported prostheses.

Most orthodontists have concerns about stacking multiple model casts because of problems related to either storage space or keeping the fragile gypsum intact. The digitalization of impressions incorporated into orthodontic work not only allays these concerns but also expands the horizon of treatment modalities such as clear aligners, customized appliances, and, of course, retainers.[8,9]

Digital versus conventional approaches

In the last decade, intraoral scan systems have grown in popularity. From 2008 to 2017, at least 32 articles compared intraoral scanning and conventional impression, as well as the differences among different intraoral scan systems, regarding accuracy, working time, and patient preferences. Most of these studies were in vitro, with only six being conducted in vivo.[10-15] In addition to randomized controlled studies, three systematic review articles were published in 2016 and 2017 in professional journals of orthodontics and prosthodontics,[16-18] aiming to review the accuracy, reliability, reproducibility, and efficiency of IOSs while comparing them with traditional impression methods.

Although the research methodologies varied among these scientific studies, lessons can still be learned from them. Generally, most of the tested IOSs have now been accepted in routine clinical use.[19] Although some early types may have seemed inadequate for the pace of traditional workflow,[20] as optical technology has improved, they have all achieved both high accuracy and fast scanning times.[21] In 2014, a series of studies was conducted by Patzelt et al. to verify the accuracy and efficiency of three to four IOSs.[22-24] They concluded that

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most of these scanners had comparable accuracy and the digital workflow was more time-efficient.

Ender et al. repeatedly investigated the accuracy of IOSs.[10,20,25-27] For example, they examined the in vivo precision of complete-arch impression using five conventional impression and seven digital techniques. They revealed that even with some local deviation in complete-arch test results, digital scanners still achieved higher precision (range, 42.9–82.8 μm; average, 50 μm) than conventional alginate impressions (162.2 μm). Nevertheless, digital techniques must continue to be improved to surpass the most precise conventional impression methods (17.7 μm).[13] A similar study recently compared the accuracy (trueness and precision) as well as the scan speed of seven digital scanners. It not only showed the rank order but also indicated that accuracy and scan time are highly related.[28]

In addition to comparisons with traditional impression protocols, some studies have addressed the difference in accuracy between intraoral and extraoral digital scanners,[29,30] and even model scans generated from cone-beam computed tomography.[31,32] Although the outcomes are not the same, they share a trend of higher accuracy that can be acquired by extraoral digital scans, particularly in clinical situations.[9,33] Because of the clinical limitations encountered during intraoral scanning (e.g., saliva or uncontrolled cheek and tongue), achieving the same level of accuracy attainable in vitro may be difficult. Table 1 summarizes other issues in the comparison of conventional impression and digital scan approaches.[3,5,8,9,11,12,34-39]

BEHIND THE TECH– THE IMAGING PRINCIPLES

Regardless of brand, intraoral digital scanner systems can be divided into three parts: image capture, data processing, and onscreen scan results. The major factor that influences the performance of different scanners is the first part (i.e., the imaging technology). The three imaging principles most commonly used throughout the development of an IOS are as follows.[40,41]

Confocal laser scanning

The emitting laser is projected through a filter with tiny pinhole to the target. The confocal imaging plane is known because only the light reflected from the object in focus will be captured. Out-of-focus data are not recorded. Thus, the whole 3D structure is reconstructed by retrieving 2D images at different confocal planes. Thus, this imaging process is also known as "point-and-stitch reconstruction." iTero and TRIOS are the two scanners that use this technique.

Triangulation technique

The triangulation method has long been used in the CEREC system. It is composed of three points: the laser emitter, sensor, and object surface. With known distance and angulation, calculated using the Pythagorean theorem, the object surface information can be acquired. However, to obtain more detail and avoid unpredictable light dispersion, the tooth surface may need to be covered with a thin layer of radiopaque powder, unifying the surface texture[3] (e.g., Optispray® by CEREC, primarily comprising titanium oxide).

Active wave-front sampling (3D-in-motion video recording)

This optical sampling method refers to 3D information gathered using a single-lens imaging system for measuring the depth on the basis of the defocus of the primary optics. Lava Chairside Oral Scanner (COS) and True Definition both use this technique in their 3D-in-motion video recording technology. Three internal complementary metal–oxide–semiconductor (CMOS) sensors capture 3D information from different perspectives (i.e., image triplets).[6] In addition to the high

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Table 1. *Comparison of conventional and digital impression*

Issues	Conventional impression	Intra-oral scan/digital impression
Patient comfort, experience	Gag reflex, unpleasant smell from the impression material, and greater discomfort[34]	Some large scanning wands also have difficulty in gag reflex, distal end teeth, or limited mouth opening.
Quality of impression	Lacerations over the margin, large undercut area, or brackets when the impression is removed[3]	Less tearing laceration, but regional deviation in full mouth scans
Impression tray or scanner wand	Necessity of stocking different size impression trays, increased waste with disposable types	Some sleeves can tolerate auto-claving or can be disinfected whereas others are still disposable, one-size scanner wand of each brand only
Repeatability	Flaws require whole impression to be performed again, model must first be poured out before verification of whether a repeat is necessary	Instant zoom-in feature enables immediate correction, imperfect region alone can be rectified without a whole new scan
Real-time 3D information	Impression must be poured into gypsum casts, leading to dual dimensional changes (impression material shrinkage and gypsum stone expansion) and a long setting time	Real-time 3D information is clearly shown onscreen, facilitating communication among doctors, doctors and technicians, and patients and doctors.[5]
Technique sensitivity	High technique sensitivity and limited reproducibility for some high-precision impression materials	Scanning strategy, experience, and skill affect results; different machines / imaging principles with varying performance and learning curves[11,12,35]
Archiving/storage	Space required for numerous casts, risk of damage to fragile stone casts	Digital archiving saves space, caution required in storage back-up; 3D-printed resin models are stronger than stone models[8,9]
Treatment planning	Need more impressions or duplication for model set-up	Virtual set-up available for multiple treatment plans,[3] virtual surgical planning can be combined with cone-beam computed tomography
Efficacy, productivity	Higher productivity per unit time, multiple patients can have conventional impressions at the same time in clinics	Limit to the number of machines per clinic prevents scans on many patients simultaneously[17]
Cost, time	High cost of impression materials and gypsum, more time required for clinical and lab work (from tray selection to pouring stone) and patient-visit appointments	High cost of each unit as well as maintenance and upgrade fees, less chairtime and fewer patient visits required[36]
Workflow	Impression → cast pouring → model trimming → additional applications, more time-consuming (particularly when including shipping requirements)	Digital scan → post-processing → direct clinical application via digital data transmission, including online or cloud-storage communication with laboratories
Soft tissue and color recording	Border molding enables registration of soft tissue (frenum, vestibule, palate, mouth floor) but not color	Advantages in recording intraoral surrounding soft tissue, capable of color scans for shade selection reference and clinical finding documentation[37]
Application customization	Customizable, but more complex and less accurate during the customization process	Easier customization and wider applicability of customized applications (indirect bonding trays, clear aligners, appliances, retainers), and simpler re-order procedure for lost appliances/retainers (ahead of visit)
Clinical use history	Long-lasting clinical usage, more reliable for experienced dentists, more acceptable to most patients	New technology requiring more effort to gain the confidence of both doctors and patients, more accepted by dental students and newly graduated dentists[38,39]

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Table 2. *Comparison of four recent popular digital intraoral scanners*

Brand	iTero Element		TRIOS 3 (Wireless)		True Definition / Mobile True Def.		CEREC Omnicam AC
Manufacturer	Align Tech.		3Shape		3M		Sirona
Listing date	2015.03		2015.03 (wireless: 2017.03)		2012.10	2016	2012.08 (2016 update)
Imaging principle	3D video, confocal laser scan, red laser (680 nm), white LED		Ultrafast Optical SectioningTM, confocal laser scan, LED		3D-in-motion video, active wavefront sampling		Continuous filming, triangulation, white LED
Capture speed	6000 frames (20 scans) / sec		3000 images / sec		20 image triplets (60 images) / sec		unknown
Color scan	✓		✓ / Mono		✗ (another channel)		✓
Powder-free	✓		✓		✗		✓
Scan distance	Directly contacts tooth		Directly contacts tooth		0-17 mm above surface		0-15 mm (ideal: 5 mm)
Hardware	Wheel	Counter	Cart[B]	Pod[B]	Cart	Tablet (Mobile)	Cart
Overall size (H*W*D cm)	131.7*62.5*59.5	55*48*23	113*45*59	9.5/3.2 *13 (pengrip/handle)	108.2*73.4*48.7	25.8*36.8*15.2	121*35*47
Weight	25 kg	14 kg	45 kg	950 g	34 kg	2.75 kg	44 kg
Wand tip (H*W*L)	69.8*53.5*338.5 mm		20*21*276 mm		14.2*16.2*254 mm		16*16*228 mm
Wand weight	470 g (17.6 oz)		340 g (12 oz)		233 g (8.2 oz)	253 g	313 g (11.04 oz)
Cable length	1.75 m		2.5/5/8 m or wireless (range: 5m)		2m		Unknown
Screen size	19”		19”		21.5”	12.2”	19”
Equipped PC	All-in-one, specification unknown		Intel i7 Quad 3.6 GHz Win 7 64 bit, 240 GB HDD **Pod:** depends on the connected computer		Intel i5 Quad 16 GB RAM Intel Iris graphic system Linux, 512 GB SSD		Intel i7 5820K 8 GB DDR4-RAM*2 AMD R9 285 Win 7 64 bit, 1 TB SSD
Software	Outcome Simulator, Progress Assessment, OrthoCAD		Ortho Analyzer™, Ortho Planner™, Appliance Designer™, IDB Planners…[C]		✗		inLab, CEREC, CEREC Ortho
Output	STL (export)		Open STL, DCM		Open STL		Open STL[H]

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Brand	iTero Element	TRIOS 3 (Wireless)	True Definition / Mobile True Def.	CEREC Omnicam AC
Communications	Incognito, Invisalign, Sure smile	**3Shape Connection** TRIOS® Ready Ortho, Incognito, Invisalign[D] Sure smile, Clear correct···	**Trusted Connection** Incognito, InvisalignF Sure smile, Clear correct···	**Sirona Connection** CEREC (CAD/CAM), CERC Ortho, Invisalign, Clear correct··· Dolphin, OnyxCeph···
Official price	NT $1,300,000[A]	NT$1,080,000–1,220,000[C,E]	NT$1,000,000[G]	NT$2,400,000[I]
Appearance	 	 	  	 
Specifications	A. Three-year warranty is included in this price.	B. Pen-grip or handle type are both available with the Cart or Pod model. C. Only includes basic software; others must be purchased separately. D. A contract between Align Tech and 3Shape for accepting digital scans from TRIOS scanners was terminated in the US on Jan 31, 2018. E. Annual fee is an additional charge.	F. Trusted connections with Invisalign® only in the Advanced Data Plan G. The first-year annual fee is included in this price.	H. STL not natively available without additional cost.[28] I. Includes CEREC Ortho
General notes	J. Communication services from the providers listed may vary among regions. K. All of the above information acquired from the official websites, press releases, and product brochures of the four scanners. L. Photos shown in Appearance were sourced from official websites or brochures; all copyright belongs to the original companies. M. All data relate to the latest update, as of January 2018. N. Information interpretation may differ slightly from the origin, in order to present a unified comparison table. O. Further resources listed in the References.			

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accuracy it can provide, high data redundancy is one of the unique characteristics. According to 3M ESPE, their active wave-front sampling has evolved into a next-generation technique, 3D-in-motion technology, which has three critical features: active wave-front sampling, breakthrough image processing algorithms, and real-time model reconstruction. A thin layer of powder dusting before scanning is recommended to serve as a connector for location reference.

MAINSTREAM COMMERCIAL PRODUCTS

Here we discuss some scanners from the dozens of new IOSs on the market in terms of their market popularity, clinical reputation, and performance as reported in academic articles.

iTero Element – Align Tech

iTero is a pioneering classic; since Align Technology acquired Cadent, iTero has benefited from its association with Invisalign®. According to an official statement, the number of cases treated with Invisalign was more than 5 million by the end of 2017, which helps in promoting iTero to Invisalign practitioners. The new iTero Element, which shares the same technology, can now offer operators a real-time outcome simulation (Simulator) and assess the progress of Invisalign patients (Progress Assessment). iTero Element enables various forms of communication and offers open source STL export.

The scanner uses parallel confocal technology. The scan procedure is powder-free and the scanner tip can contact the tooth surface directly. It also features in-built air flow to demist the lens. However, the scanner wand is relatively bulky compared with other recent scanners. The manufacturer claims that a larger wand can obtain a wider view, thus enabling shorter scan times and higher accuracy. They emphasize that their lens has a unique reflective mirror design incorporated into the wand, such that even the most distal tooth would be easy to approach. Another unique feature of the scanner wand is a disposable sleeve covering for easy prevention of infections.

TRIOS 3 / TRIOS 3 Wireless – 3Shape

Founded in 2000 by two graduate students, 3Shape is a fast-growing company riding the wave of digital scanners. They not only provide IOSs, but also produce bench-top extraoral scanners for dental labs. The first edition of TRIOS was launched in 2010, with TRIOS 3 launching in 2015 with profound improvements. Unlike the previous version that still had problems with poor efficiency in defogging of the wand, TRIOS 3 can scan immediately after the machine is turned on. Because the new scanner tip is automatically preheated, operators no longer have to wait for the lens to be warmed up by the laser. Furthermore, the scanner wand is dramatically downsized compared to its predecessor. Unlike iTero, the TRIOS scanner wand sleeve is autoclavable.

TRIOS 3 uses the Ultrafast Optical Sectioning technique, based on the confocal laser principle. The confocal plane is changed periodically at a certain frequency, such that the operator is not required to move the scanner head position to maintain a relative distance from the object while scanning. Therefore, the scanner has been praised as offering an optimal balance between scan speed and scan accuracy by Renne et al.[28]

At the 2017 International Dental Show, this innovative enterprise announced the world's first wireless intraoral scanner. In the past, the cable between the wand and the computer cart has restricted the flexibility of scanners. A wireless wand design and hands-off remote control enables operators to have a more fluent, less-tangled scanning procedure. In addition to this hardware revolution, they have also developed a treatment simulator and a function for recording dynamic occlusion built into the scanner.

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Lava C.O.S. – 3M

This is a classic intraoral scanner, offering remarkable performance for its time. 3M applied active wavefront sampling technology in it, and consequently it remains comparable to newer scanners, despite being released in 2008.

True Definition – 3M

The True Definition scanner produced by 3M inherited and improved on the specialties of Lava C.O.S. Mobile True Definition is the newer portable option launched in 2016, with the same hardware/software as the original True Definition.

This scanner has demonstrated high accuracy in several comparative studies. It also possesses the smallest wand with the same size and weight as a conventional dental handpiece. However, spraying a thin layer of powder is suggested to gain superior outcomes. Some clinicians have claimed that a few seconds of dusting is warranted for higher accuracy. Another point differentiating True Definition from other scanners is that it does not offer real-time full-color scans.

3M focuses primarily on machine development rather than the accompanying software packages, but a variety of applicable choices are available through Trusted Connection and other open source communications, such as Incognito, Invisalign, Sure Smile, and Clear Correct.

CEREC Omnicam – Sirona Dentsply

The CEREC system has the longest history in the CAD/CAM industry. On the basis of the triangulation imaging method, Omnicam differs from the previous Bluecam.[42] Omnicam incorporates video streaming rather than stitching of static images. Powder spraying before scanning is also unnecessary for this generation of CEREC.

The CEREC system has gained a strong reputation in restorative dentistry by offering abundant related laboratory communication features. Orthodontic applications have also now been developed. In addition to Omnicam expanding the feasibility of full jaw scans, the CEREC Ortho software strives to meet clinicians' expectations.

ITEMS OF NOTE

It is our intention to summarize the available scanners and present the optimal model for orthodontists. However, recommending a single option for all buyers is impossible. Hence, the specifications of four relatively popular and recent scanners are summarized in Table 2.[28] After trialing iTero element, TRIOS 2 mono, TRIOS 3 color, TRIOS 3 wireless, True Definition, and CEREC Omnicam, we developed a checklist for those choosing an intraoral digital scanner.

Quality of Scan

Accuracy

Scan quality comprises many aspects, and accuracy is undoubtedly the first priority.[16] According to ISO 5725-1, accuracy is composed of two parts: trueness and precision. Literally, trueness describes how truly the scanner can replicate actual dimensions. Precision refers to the reproducibility or intra-class deviation of a scanner. The concept is clearly explained by a picture of an arrow hitting or missing a bullseye, but hitting the same spot consistently.[28]

Most IOSs demonstrate high precision in vivo, with no significant differences among them.[10] More than one study has revealed that iTero and True Definition have higher accuracy than TRIOS and Omnicam,[15,28,43-45] but no study has directly compared iTero and True Definition.

The range of scanning also affects scan accuracy.[11,46] Needless to say, the full arch scanning procedure in orthodontics may be less accurate than partial or single abutment scanning.[14] Furthermore, the different technologies incorporated into IOSs influence the

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accuracy in different ways. For example, when applying the point-and-stitch method in the anterior teeth region, little structures can be registered, thus causing subsequent propagation of errors.[27]

Whether to powder is a controversial topic when considering accuracy. Previously, some scanners have been confined by the imaging principle, requiring a unified surface texture to record precisely. Conversely, improper spraying may reduce accuracy. Powder might also be prone to saliva contamination and lose its function easily. Nevertheless, almost all IOSs are now powder-free, with the exception of True Definition, which still suggests its user to apply a thin coating to increase accuracy.

The intraoral environment always presents obstacles, and moisture control and defogging are major challenges in daily dental practice. Drying the teeth surface adequately is recommended before a scan procedure begins to reduce errors resulting from light dispersion caused by saliva or other fluids. Two solutions exist for defogging. One is to heat the scanner tip directly, as with Omnicam and TRIOS. The other is to emit airflow from inside the scanner tip, as with iTero.

Scanning time

In discussing accuracy, scanning time must also be mentioned because they are highly correlated.[28] Kim et al. advised caution as to whether the study condition is in vivo or in vitro.[12] According to a systematic review by Goracci et al.,[16] the scanning time varies for the same models among different studies because it can be calculated from either turning on the machine or when scanning actually starts.[34] Generally, scanning time decreases with increasing experience of the operator.

Operators have a unique learning curve for each machine.[35] One study indicated that iTero may have a longer scanning time, rendering it slower than the traditional impression method. However, clinical experience improves this limitation. Conversely, TRIOS is easier for less experienced operators, with a shorter scanning time than conventional methods, but more practice on TRIOS will not further shorten the scanning time.[12]

Full-color scanning

Full-color scanning is a new feature of the latest scanners, with the exclusion of True Definition. TRIOS also supplies mono-color scanners for those who do not need color scans. Coloring helps to differentiate the border between gum and tooth. Some brands also claim that their color capturing and expression is precise enough for shade selection.

Interference of scan accuracy

The material being scanned affects accuracy.[47] Metal and other reflective materials can be difficult to capture. Intraorally, this scenario applies to metal crowns, appliances, or orthodontic brackets. The powder technique is a perfect solution to improve scanning accuracy by generating surface homogeneity. Park et al. studied accuracy for brackets in vitro, revealing that lingual brackets are less accurate than buccal brackets. Both TRIOS and iTero performed well under these conditions.[48] Another clinical situation that can compromise accuracy is edentulous areas.[49] The lack of teeth as apparent anatomical landmarks for registration makes it difficult to acquire digital impressions accurately.

Hardware

Overall and tip size

When choosing a new machine, its size must be considered to determine whether it fits the office space and can easily be moved. Regardless of size, all IOSs are available as a basic type with wheel-stands. In addition, TRIOS Pod and Mobile True Definition are particularly light-weight and portable options for those without sufficient room for a large cart. Although previous models have been combined with dental chairs, these proved unpopular with buyers because being fixed into a certain unit despite updating IOSs contravenes the principle of flexibility.

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Another size issue is the scanner tip. In early models, tips were too big for patients with a limited mouth opening. Hence, later generations of IOSs feature a scanner tip that is as small as possible. 3M pioneered the downsizing of scanner wands to mimic conventional hand-pieces.

Infection control and potential hazards

Just as with other medical devices, infection control for IOSs should never be overlooked in daily practice. The first level of control relates to the tip; certain sleeves for scanner tips can tolerate a disinfection process under high pressure and temperature, whereas others are designed to be disposable. At the machine body, a normal cleansing procedure should be suitable. Any accessories of the machine used in the scan process, such as the keyboard, mouse, and the tracking ball for CEREC Omnicam or TRIOS Pod, may be a source of cross-contamination. Thus, touch screen and hands-off remote control offer advantages in avoiding unnecessary interruption during a scan procedure.

Another concern is the flashing light emanating from the scanner tip in some IOSs; accumulated exposure may represent an ocular hazard to the operator or patient.

Data processing and transmission

Real-time 3D model generation after scanning may rely on different imaging principles and internal computing ability. All present IOSs are built with adequate processing power, memory, and storage. TRIOS Pod allows the practitioner to decide how good the computing power is, since it is connected to an external optional laptop.

Data transmission speed typically depends on the network environment, but even for the same full-jaw scan on a single patient, different IOSs generate different file sizes because of various imaging principles. Larger file sizes cause longer transmission times. In particular, the transmission time of 3M Mobile True Definition is double that of the cart type (3M True Definition) because of the efficiency of the processor (3M Mobile True Def Scanner FAQs, Version Oct 2016).

Software

Among the aforementioned IOS manufacturers, 3Shape has earned the greatest acclaim for developing user-friendly software. Ortho Analyzer by 3Shape can produce a standardized digital model, perform analysis, and even provide virtual model setups. Through integration with a 3D printer, doctors are capable of making their own customized clear aligners and appliances.[50] Other companies also have unique advantages. iTero has strong technological support from Invisalign. CEREC possesses great experience in CAD/CAM and restorative dentistry and offers educational training programs for technicians, assistants, and doctors. Conversely, 3M developed in the opposite direction, with an open system that allows more technical support.

Reality

Price and maintenance

The most basic issue is the cost of bringing an IOS into clinical practice. The normal listing prices of IOSs in Taiwan, as of January 2018, are summarized in Table 2. The prices range from at least NT$1,000,000 to approximately NT$2,500,000. The options available vary widely according to the different packages offered alongside the machine itself, which may include post-scan software solutions, warranties, or annual fees for upgrading the system.

IOSs require maintenance, in terms of both hardware calibration and software upgrades.[51] It is worthwhile to question the length of the repair period and the availability of a replacement if a scanner malfunctions. This information typically requires further inquiry with the salesperson when negotiating a purchase because the situation may be varied.

Potential cost

In addition to the price of the machine and the service, the potential cost for implementing such a

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new technology warrants further discussion.[39] Digital impression systems have a learning curve, but how long is this training period and how much opportunity loss accumulates during this period? Dentists must familiarize themselves with this new technology, during which time they could otherwise complete dozens of conventional impression procedures. Assistants and collaborating technicians must also take time to become efficient with the new workflow. Whether all doctors in an office are confident and willing to use an IOS is another issue. Lastly, will patients actually achieve greater overall satisfaction with digital impressions?

Despite certain disadvantages, some advantages warrant mentioning. Digital impressions may produce less waste from disposable supplies (e.g., gloves, disinfection wrappings) and reduce the need for stocks of conventional materials. Digital restorative workflow can offer additional check points while milling a restoration, further enhancing efficiency and productivity. The development of software that is more user-friendly and widely compatible will enhance the clinical performance of IOSs.

Critical thinking must be employed when considering the costly investment of IOSs. How long has the manufacturer been engaged in this market? How is the company's reputation? Can local dealers or agents offer sufficient technical support when necessary? Orthodontists should always discuss with experienced colleagues before making this monumental decision.[39]

WHAT'S NEXT?

After this review of almost every perspective on IOSs, the question of "what's next?" arises. The authors believe that a future revolution in contemporary dentistry is already underway, starting with digital workflow.

Digital orthodontic workflow

Many conferences and articles on digital dentistry have recently discussed this topic.[50,52,53] Digital orthodontic workflow begins from the first appointment and continues through the retention and follow-up stages (Table 3). Support from all kinds of suppliers enriches the treatment modalities through this workflow. Some hardworking orthodontists, such as Simon et al., have even made efforts to fabricate expander appliances in a brand-new fashion.[52,54] These examples are just the starting point of integrating IOSs into daily practice. We are optimistic about 3D printing material innovations (e.g., NextDent) and next-generation printers capable of constructing hybrid materials.

Table 3. Digital Orthodontic Workflow

Initial Consultation	Diagnosis	Treatment Plan	Treatment	Retention
Digital records (photos, X-ray/cone-beam computed tomography, intraoral scanning)	Analysis (radiographs, scan data)	- Virtual setup - Surgical treatment simulation	- Indirect bonding - Clear aligners - Customized brackets - Appliances	- Retainers - Outcome, follow-up comparison

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Furthermore, 3D cone-beam computed tomography images combined with digital scans will provide even more precise and detailed skeletal and dental information. In the near future, artificial intelligence and big data will influence the whole world, including the medical industry. In 3D CAD/CAM technology, the STL files that are currently used will be replaced by rising formats, such as AMF (Additive) or 3MF (3D Manufacturing Format).

SUMMARY

Our aim was to elucidate the past, present, and future of IOSs for anyone who is eager to join this movement. According to a market survey performed by 3Shape in 2016, 50% of dentists in the US were considering buying digital impression systems within the next three years.

In summary, we would like to quote Stewart Brand: "once a new technology rolls over you, if you're not part of the steamroller, you are part of the road." We do not suggest that everything must become digital; digital is not necessarily the optimal direction for every situation. Nonetheless, we hope you can embrace it. When the next wave hits, will you be ready for it?

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