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Review Article

Intraoral scanners in Orthodontics

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ABSTRACT

Rapid advancements in digital technology have changed a number of sectors in recent years. Artificial intelligence (AI) and robotics are two examples of advanced technology that have been adopted into the medical industry. The intraoral scanner is a portable device with a tiny optical camera that collects virtual dental models that is widely employed in dentistry that works by projecting structured light (white, red, or blue). The program then compiles the individual photos or video that are captured after identifying certain locations of interest. The points of interest captured from various perspectives are then matched to create a 3D model. One of the biggest benefits of intraoral scanning is that it eliminates all the painful parts of taking a traditional impression and allows for the simple rescanning of certain areas that may not have been recorded completely. Hence, this review article will be discussed on principles of imaging, different brands of IOS, advantages and advancements in IOS.

KEYWORDS: Intraoral scanners, light source, impression, advancements

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INTRODUCTION

A paradigm shift in orthodontics has occurred with the advent of intraoral digital scanners as a replacement for alginate and polyvinyl siloxane (PVS) impressions. The digital scanner was first developed as an outsourced technology for the storage of three-dimensional electronic study models, but it has since transformed into an office tool with a wide range of uses. The development of CAD/CAM technology and the launch of chairside economical restoration of aesthetic ceramics (CEREC) in 1984 coincided with the introduction of intraoral digital scanners (1).

HISTORY

Dr. Francois Duret (France) was the first to apply the idea of computer-aided design/computer-aided manufacturing (CAD/CAM) to dental applications in 1973 (2,3). In 1987, Sirona Dental Systems unveiled a prototype digital impression tool for restorative dentistry under the name Chairside Economical Restoration of Aesthetic Ceramics (CEREC®) system. The CEREC system established itself as a ground-breaking tool for the CAD/CAM dental sector. Despite the scanning or milling quality appearing to be imperfect, there were no competitors until the Cadent iTero digital impression system was introduced in 2006 which was later in 2008 revealed to be capable of full-arch intraoral scanning (2). Soon after, in 2011, Align Technology bought Cadent, and shortly after that, iTero was included into the data transfer for Invisalign treatment. Since then, nearly every significant dental manufacturer has concentrated its efforts on this area in a quest to provide better IOS. The 2017 International Dental Show in Cologne featured demonstrations of over 14 scanners. In the upcoming ten years, it is anticipated that intraoral digital scanner technologies would advance even further (2).

INTRAORAL SCANNERS (IOS)

Three components form the foundation of CAD/CAM development: the data acquisition unit, the data processing and design unit, and the manufacturing unit. Data processing and acquisition for the system are part of the CAD phase, whilst the manufacturing unit operates under the CAM phase. The digital impressions can be recorded by the doctor with the use of CAD/CAM technology.

There are benchtop scanners and intraoral scanners available in the market. The foundation of optical technology is the emission of light at the dental element's surface and the subsequent capture of the reflected ray. The quality and sharpness of images captured can be impacted by an excessive reflection phenomenon brought on by factors like saliva, metal reconstructions and crowding. This may cause the impression to gradually distort by more than 100 µm, which will lower the overall trueness of the impression's especially in the molar area. Furthermore, even the smallest hand movement during scanning increases the chance of inaccuracy in the digital data capture.

BENCHTOP VS INTRAORAL SCANNERS

Benchtop scanners are capable of creating a digital three-dimensional picture of the mandibular and maxillary arches from pre-existing plaster models or impressions. A few years later, Sirona Dental Systems first developed a chair-side scanning system that used CAD/CAM technology and was sold commercially.

Benchtop scanners	Intraoral scanners
3 shape - R series	The TRIOS intraoral scanner marketed by 3SHAPE
AGE solutions maestro 3D dental scanner	The LythosTM intraoral scanner marked by ormco
Dental wings scan and design systems	The True definition scanner marketed by 3M ESPE
Ortho Insight 3D Desktop Scanning System	iTero intraoral scanner marketed by Align Technology Inc.

THE IMAGING PRINCIPLES

There are three components to all intraoral digital scanning systems: image acquisition, data processing, and display scan output. The first component, or image technology, has the biggest impact on how well certain scanner's function. The following are the four imaging concepts that have been applied the most frequently in the creation of an IOS.

1. Confocal laser scanning
2. Triangulation technique
3. Active wave-front sampling (3D-in-motion video recording)
4. Accordion fringe interferometry (AFI)

Confocal Laser Scanning

The target is exposed to the emitting laser through a filter that has a small opening in it. Since only the light reflected from the object is known, the confocal imaging plane in sharp focus will be recorded and data that are not focused will be excluded. As a result, by obtaining 2D pictures at various confocal planes, the entire 3D structure is rebuilt. Consequently, another name for this imaging technique is "point-and-stitch reconstruction." The two scanners that employ this method are TRIOS and iTero (1) (2). (Figure 1)

Triangulation Technique

The CEREC system has long employed the triangulation technique. The laser emitter, sensor, and object surface make up its three parts. This method uses projected laser light to estimate the angles and distances from known sites (Fig. 3A). Both the length and the angle of the laser's path from the source to the sensor are known. The Pythagorean theorem states that as light bounces off an item, the system calculates the angle of reflection and, consequently, the distance between the laser source and the object's surface. Thus the Pythagorean theorem can be used to determine distance and angulation so that the object's surface information can be obtained.

To even out the surface roughness of the tooth, a thin coating of radiopaque powder can be required, nevertheless, in order to gain greater information and prevent unpredictable light dispersion (for example, Optispray® by CEREC, which is mostly composed of titanium oxide) (2). (Figure 2)

Active Wave-Front Sampling (3D-In-Motion Video Recording)

This optical sampling technique refers to 3D data obtained with a single-lens imaging system to calculate the depth based on the primary optics' defocus. Both True Definition and Lava Chairside Oral Scanner (COS) employ this method in their 3D-in-motion video capturing technologies. This method takes three exact images

of the tooth using an HD video camera equipped with trinocular imaging (three small video cameras at the lens) (Fig. 3D). Behind the cameras, a complementary metal-oxide semiconductor (CMOS) sensor transforms light energy into electrical impulses. The 3D data, which are recorded in a video sequence and modeled in real time, are determined by concurrently calculating the distances between two data points from two angles.
Along with high accuracy it also provides, high data redundancy. As per 3M ESPE, their innovative image processing algorithms, real-time model reconstruction, and active wave-front sampling have been integrated into 3D-in-motion technology. It is advised to apply a little dusting of powder prior to scanning in order to act as a connector for location reference (2). (Figure 3)

Accordion fringe interferometry (AFI)

Two light sources are used in accordion fringe interferometry (AFI) to project three patterns of light onto the teeth and tissue (Figure 4). As a fringe pattern strikes the surface, it deforms and assumes a new pattern, based on the particular curvature of the object. This distortion in the fringe pattern is referred to as "fringe curvature," and surface data points of the fringe curvature are recorded by a high-definition (HD) video camera with a offset from projector about 30˚(1).

ADVANTAGES OF INTRAORAL SCANNERS

Less patient discomfort

Because of the difficulties and annoyance caused by the materials placed on impression trays, traditional physical impressions may temporarily create discomfort for the patient. Certain patients—such as those with strong gag reflexes or young patients—don't seem to be able to handle the traditional technique (3). Compared to typical physical impression, optical impression significantly reduces patient suffering and eliminates the need for materials and impression trays.

Time efficiency

Comparing optical impressions to traditional impressions, several studies have demonstrated that optical impressions are more cost-effective and time-efficient due to the ability to reduce working times (4).

Despite recent improvements in IOS technology, the newest devices on the market can capture a full-arch scan with optical impressions in less than three minutes. This eliminates the need to pour stone casts and obtain physical plaster models; instead, the patient's 3D virtual models (proprietary or STL files) can be emailed directly to the dental laboratory, negating the need for courier or regular mail delivery. This makes it possible to save a time and money during the working year

Simplified procedures for the clinician

Intra oral scanning facilitates the impressions taking in complex situations, such as those involving many implants or deep undercuts that might make it hard and sneaky by a traditional impression

The end of plaster castings

The physician will directly save money by not using traditional impression materials since the cost of consumables will be lower.

Improved contact with the dental assistant

The dentist technician and the clinician may evaluate the impression's quality in real time using IOS (5).

Better communication with patients

With optical impressions, patients feel more into their treatment and have effective communication with them. This improves patient’s oral hygiene.

The features of some of the most popular intraoral digital impression tools now on the market are listed here, with an emphasis on their classifications, guiding concepts, and modes of use in orthodontics.

COMMERCIAL BRANDS	MANUFACTURER	IMAGING PRINCIPLES	SCAN DISTANCE	SOFTWARE
iTero scanner [(6)] (Figure 5)	Align Tech.	3D video, confocal laser scan, red laser (680 nm), white LED	Directly contacts tooth	Outcome Simulator, Progress Assessment, OrthoCAD
The True Definition Scanner [(6)] (Figure 6)	3M	3D-in-motion video, active wavefront sampling	0-17 mm above surface	3M True Definition Scanner Software (latest Version 4.1)
The TRIOS Intraoral scanner marketed by 3Shape [(6)] (Figure 7)	3Shape	Ultrafast Optical SectioningTM, confocal laser scan, LED	Directly contacts tooth	Ortho AnalyzerTM, Ortho PlannerTM, Appliance DesignerTM, IDB Planners···C
CEREC Omnicam AC [(6)] (Figure 8)	Sirona	Continuous filming, triangulation, white LED	0-15 mm (ideal: 5 mm)	inLab, CEREC, CEREC Ortho
LythosTM scanner (Figure 9)	OrmcoTM	Accordion fringe interferometry	Directly contacts tooth	Ormco InsigniaTM Advanced Smile DesignTM soft ware

RESEARCHES IN IOS

On accuracy

Accuracy, as defined by ISO, consists of trueness and precision. In a literal sense, trueness refers to how accurately the scanner can reproduce real dimensions. The term "precision" describes a scanner's repeatability or intra-class variation. In a study conducted by Pahuja et al, comparison of the accuracy of intraoral scanners with stone models in establishing dental measurements in mixed dentition showed that dental models had a significantly higher intermolar width and decreased arch perimeter concluding that, intraoral scans have clinically acceptable accuracy, reliability, and reproducibility of the tooth measurements (7).

Pellitteri et al (8) compared the accuracy, in terms of trueness, between full-arch digital impressions of different intraoral scanning systems with conventional impression technique used as a reference. Their results showed that the Trios 3Shape was found to be the most accurate single-tooth scanner, while the Carestream CS 3600 showed better inter-arch diameter performance compared to PVS impressions.

Scanning time

The time needed for a digital impression obtained by an intraoral scanner is comparatively less than a conventional impression. Based on the clinician's experience the possibility to capture a full-arch scan ranges from 3 min – 12 mins thus making the intraoral scanning a time-effective tool in the hands of the orthodontist. Thomas et al concluded that experience of the operator is inversely proportional to the scanning time. He concluded that less experienced operators took more time to scan a subject and scanning with i500 IOS took more time than TRIOS (9).

Manipulation

Manipulation in conventional impression taking procedure includes operator preparation, tray selection, material dispensing, material cleaning, plaster pouring, die cutting and trimming of model. Alternatively, intraoral digital scanning can save dentists and technicians time and processes as compared to a traditional impression. In a research, Lee and Galluci evaluated the effectiveness, complexity, and operator preference of intraoral digital impressions (iTero) for single implant restorations and contrasted them with traditional impressions. According to the study, digital impressions with less difficulty level were remarkably more efficient than conventional impressions, and even though a higher volume was needed, digital impressions required less time for rescans (10).

Repeatability

A scanning device's credibility and stability are partially reflected in its repeatability. To enhance the impression quality, the digital imprint repeatabilty must reach a suitable level. Stimmelmayr et al assessed the producibility of implant scan bodies in an invitro research using two different scanning methods: indirect extraoral scanning on a stone cast model and direct intraoral scanning on an original polymer model. The findings demonstrated that the extraoral group (cast model) had mean differences of 11 µm and the intraoral group (original model) had mean discrepancies of 39 µm for the scan bodies among repeated scans (11).

For the original polymer and the stone cast model, the systematic error of the scanning models was 13 µm and 5 µm, respectively. The authors came to the conclusion that extraoral scanning was more reproducible than intraoral scanning. Conversely, an extraoral scan using a plaster model placed on a scanner platform might sustain excellent uniformity throughout numerous scans. Furthermore, the intraoral scan may become less accurate due to the powder spray. As a result, powder spraying scanning devices are preferred in order to enhance intraoral digital impression device performance.

EXPANDING APPLICATIONS OF IOS

Evaluation of Dental Wear

Dental wear involves both structural issues (loss of the vertical dimension of occlusion and support structures) and functional issues (increased tooth sensitivity, chewing, temporo-mandibular joint dysfunction, migraines, etc.) that might have an impact on general health and well-being. Kuhne et al investigated does wear measurement may be accomplished with intraoral scanners (IOS) as opposed to optical profilometry (WLP). A zirconia cast containing teeth (24–28) was created, and optical profilometry was compared by superimposing the STL data. The scans were performed using three distinct intraoral scanners: Cerec Omnicam AC, Trios 3, and True Definition. The scans were performed at baseline and at three distinct levels of simulated wear using a diamond bur. Their findings indicated that the three IOSs and WLP have errors of about 20 µm. They came to the conclusion that, notwithstanding the need to account for errors of up to 20 m per partial arch impression, digital impression systems offer a straightforward substitute for wear measurement based on WLP (12).

Caries Detection

In clinical practice, it is difficult to identify non-cavitated caries and to track the earliest proximal lesions in the enamel only by visual inspection without the use of ionizing radiation. Near-infrared transillumination (NIRI) technology serves as the foundation for intraoral scanners like TRIOS 4. Here, enamel that is exposed to light in the near-infrared spectrum (wavelength 850 nm) looks darkly translucent, while dentin or caries lesions seem less translucent and brighter.

Amelie Schlenzhe et al. used three intraoral scanners to examine occlusal and proximal caries lesions in human permanent and primary teeth in order to comprehensively study new caries diagnostic tools and compare them to known diagnostic techniques. Techniques for diagnosing caries such as bitewing radiography, Diagnocam, Trios 4, iTero Element 5D, Planmeca Emerald S, and visual examination were compared. For primary and permanent teeth independently, the diagnostic techniques were examined and compared with reference µ-CT. The findings indicated that Planmeca Emerald S provided the greatest occlusal caries diagnosis for permanent teeth, whereas Trios 4 was the best option for primary teeth. This study concluded that intraoral scanners are a useful diagnostic tool for detecting Molar incisor hypomineralization (MIH), proximal and occlusal caries in primary tooth (13).

Plaque Detection

Jung and colleagues examined the suitability of 3D intraoral scan images for accurate planimetric plaque monitoring and measurements. In this study, plaque was measured using 3D intraoral scans and intraoral camera pictures and revealed at three distinct time points: habitual plaque (T1), after 72 hours without oral hygiene (T2), and after subsequent teeth brushing (T3). Using pictures from 3D intraoral scans of the oral and vestibular surfaces, the percentage of the whole surface area coated with plaque was calculated. Plaque percentage between the intraoral camera and the 3D intraoral scan pictures showed a very strong association. Results proved that IOS is an adequate tool for measuring plaque (14).

In Reconstruction of Structure and Function of Tooth

Eom et al has demonstrated how to use optical coherence tomography (OCT) to create and evaluate a three-dimensional (3D) intraoral scanning probe in order to reconstruct the anatomy and function of human teeth. It consists of a scan probe that uses the OCT to get two-dimensional (2-D) cross-sectional pictures of the teeth. A set of 2-D photos that included internal and structural details of human teeth were combined to create the 3-D volume image. Sequentially acquiring and stitching partially overlapping 3-D volume pictures allowed the OCT device to be used as an intraoral scanner (15).

CONCLUSION

The future of healthcare provision is being shaped by technology, and orthodontics is no exception. To meet the requirements of any orthodontic laboratory, office, or clinic, a variety of benchtop and intraoral scanners are available. The devices that are available, the expenses associated with installation and upkeep, and any potential benefits that patients may receive over conventional impressions should all be known to clinicians.

FINANCIAL SUPPORT AND SPONSORSHIP

Nil

CONFLICTS OF INTEREST

There are no conflicts of interest

Figure 1: Confocal laser scanning

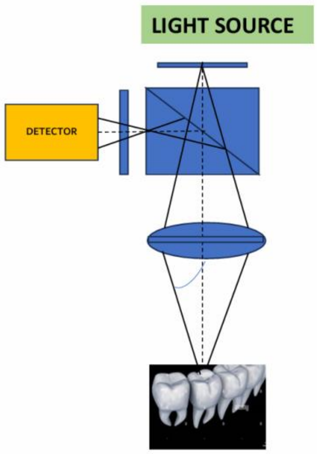


Figure 2: Triangulation technique

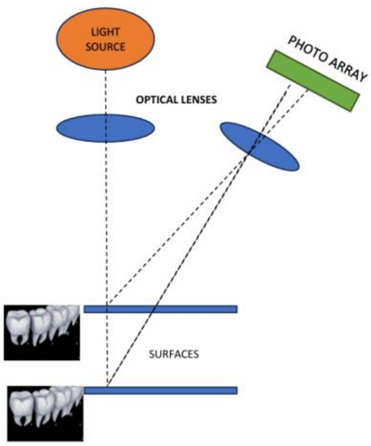


Figure 3: Active wave-front sampling (3D-in-motion video recording)

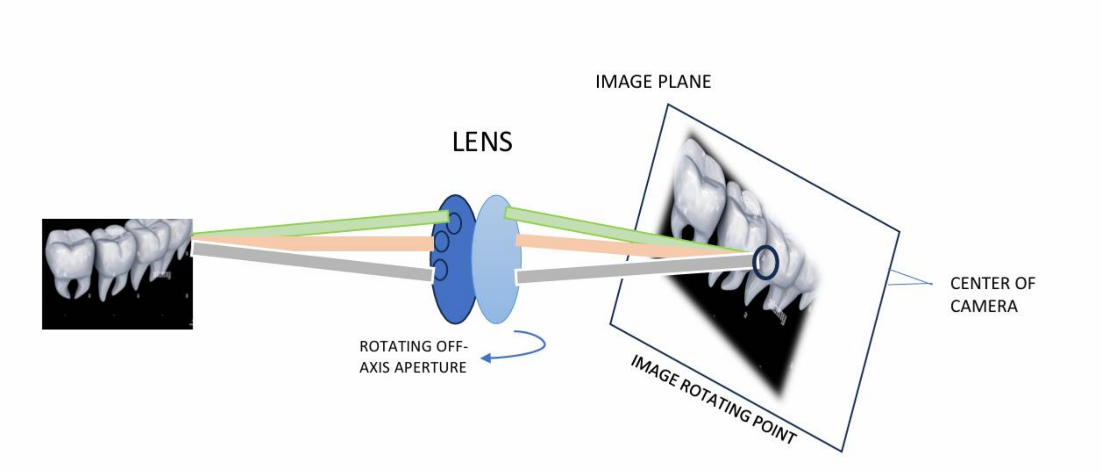
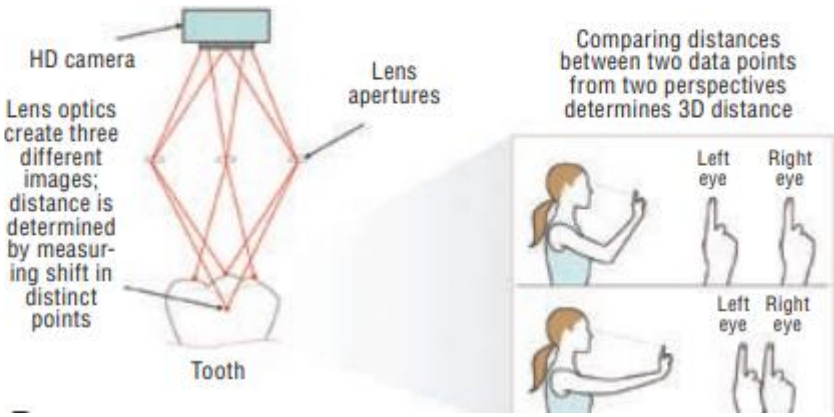


Figure 4: Accordion fringe interferometry (AFI)



(Pic courtesy - Kravitz ND, Groth C, Jones PE, Graham JW, Redmond WR. Intraoral digital scanners. J Clin Orthod. 2014 Jun;48(6):337-47.)

Figure 5: iTero intraoral scanner

(Pic courtesy - Kravitz ND, Groth C, Jones PE, Graham JW, Redmond WR. Intraoral digital scanners. J Clin Orthod. 2014 Jun;48(6):337-47.)

Figure 6: True Definition intraoral scanner with touchscreen monitor and lightweight wand

(Pic courtesy - Kravitz ND, Groth C, Jones PE, Graham JW, Redmond WR. Intraoral digital scanners. J Clin Orthod. 2014 Jun;48(6):337-47.)

Figure 7: The TRIOS Intraoral scanner

(Pic courtesy - Catherine B. Martin, Elsinore V. Chalmers, Grant T. McIntyre, Heather Cochrane, Orthodontic scanners: what's available? Journal of Orthodontics, Vol. 42, 2015, 136–143).

Figure 8: CEREC Omnicam AC

(Pic coutesy - Hwang, Henry Hann-Min; Chou, Chi-Wei; Chen, Yi-Jane; and Yao, Chung-Chen Jane (2018) "An Overview of Digital Intraoral Scanners: Past, Present and Future- From an Orthodontic Perspective," Taiwanese Journal of Orthodontics: Vol. 30: Iss. 3, Article 3)

Figure 9: LythosTM scanner

(Pic courtesy - Kravitz ND, Groth C, Jones PE, Graham JW, Redmond WR. Intraoral digital scanners. J Clin Orthod. 2014 Jun;48(6):337-47.

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