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RESEARCH ARTICLE

INTRAORAL SCANNING SYSTEMS - A CURRENT OVERVIEW

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Abstract

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Intraoral scanners (IOSs) are devices used for capturing direct optical impressions in dentistry. IOS eliminates the errors that are encountered with the conventional impression making procedures. The last decade has seen an increasing number of optical IOS devices, and these are based on different technologies. The objective of this review article is to discuss intraoral scanners with regards to its technology, generation systems, scanning paths, necessity of a powdering medium, accuracy (Trueness and precision), intermaxillary relationship registration, commercially available IOS, clinical recommendations, advantages, disadvantages, indications and contraindications. Digital impressions with IOS is likely going to be a routine procedure in dentistry in the near future.

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Introduction:-

Since the eighteenth century, conventional impression techniques have been used to register the three dimensional geometry of dental tissues. [1-3] A passive fit is a primary factor for the long term clinical success and survival of an implant-supported fixed dental prosthesis (FDP). The precise transfer of the three-dimensional (3D) intraoral implant relationship to the master cast is a critical step to achieve a passive fit. [4-5]

Despite being considered a trivial and well-established procedure in dental practice, a number of problems are encountered like incorrect impression tray selection, separation of material from impression tray, tears or voids with the impression materials or cast, tray to tooth contact, material shrinkage, bio-safety norms for disinfection ,temperature sensitivity, limited working time, inaccurate pouring and expansion of dental stone. Over trimming of the casts and breakage during shipment could lead to substantial loss of patient data. [6-7] Other than the above problems any compromise in the manual steps during prosthesis fabrication also may lead to misfit of the prosthesis.[4,5,8] Some patient's perceive the conventional impression making procedure as an unpleasant treatment experience. Extra in-office space will also be required If physical models are to be stored. [9] Although most of the above technical, mechanical, and biological problems can be reduced by standardization of work sequence, they cannot be entirely eliminated.[4,5,8] Digital impression making using intraoral or extra oral scanners may be an approach to improve the accuracy of dental restorations, as by their nature these processes tend to eliminate the errors caused by the conventional impression making procedures, simplifies the oral rehabilitation procedures and eliminates the requirement of physical storage space.[10,11]

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Intraoral Scanner Technologies:
The IOS is a medical device composed of four main components: the measurement probe, the control or computing system, the machine that handles the movement of the probe and the measurement software. [12]

The goal of IOS is to record with precision the three-dimensional geometry of an object. [13]

Digital impressions can be made using two methods, directly using an intraoral scanner, which allows the clinician to directly acquire the data from the prepared abutment without the need to make conventional impressions and pouring the casts, and thereby results in a 3D virtual model. The second method is by using an extra oral laboratory scanner, which involves scanning of the dental impression or gypsum casts to create a 3D model. The restoration is then designed on a computer using the acquired 3Dvirtual model, with specially designed software, and then 3D printed. Both the impression techniques (done using intraoral and extra oral scanners) need to be accurate to deliver an accurately fitting prosthesis. [14]

The most widely used digital format is the open STL (Standard Tessellation Language) or a locked STL-like Format. This format is used in many industrial fields and describes a succession of triangulated surfaces, where each triangle is defined by three points and a normal surface. However, other file formats have been developed to record color, transparency, or texture of dental tissues (such as Polygon File Format, PLY files). Irrespective of the type of imaging technology employed by IOS, all cameras require the projection of light to record individual images (These systems have a field of view in the form of a cone, so they cannot collect information from those hidden surfaces, being necessary to make several shots of the same area to collect all the information) or videos(It records the scanned areas in a similar way as a video camera through sequential shots at high speed) and are compiled by the software after recognition of the POI (points of interest).[13,15,16]

The intraoral scanning systems currently available are differentiated by characteristics such as the operating principle, the light source, the need to eliminate the shiny surfaces, the operating system and the export file formats. [17]

Generations of Intra Oral Scanners:
There has been a gradual evolution to five generations of the system. [18]

1. First generation scanners consisted of a single radiation source and a single detector and information was obtained slice by slice.
2. The second generation was introduced as an improvement and multiple detectors were incorporated within the plane of the scan.
3. The third generation was made possible by the advancement in detector and data acquisition technology.
4. Fourth generation included a moving radiation source and a fixed detector ring. Angle of the radiation source was taken into account. More scattered radiation was seen in this system.
5. Fifth generation scanners were developed to reduce “motion” or “scatter” artifacts. [18]

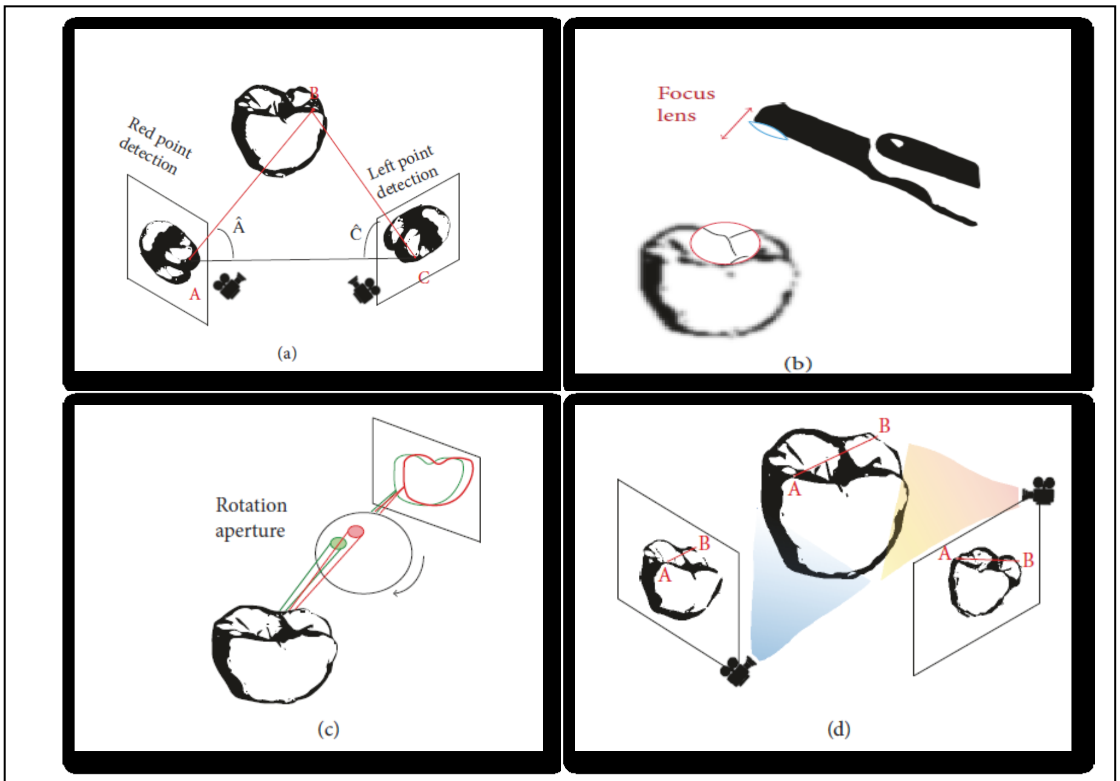
Light Projection and Capture:
Within the 3D reconstruction field, there is a clear distinction between passive and active techniques. Passive techniques use only ambient lighting to illuminate the intraoral tissues and they rely on the texture of an object. Active techniques use white, red, or blue structured lights projected from the camera onto the object that is less reliant on the real texture and color of tissues for reconstruction. In active techniques, a luminous point is projected onto an object and the distance to the object is calculated by triangulation. An alternative is the light pattern projection, such as line or mesh projections. The surface reconstruction can be achieved with a compilation of images or videos. [13, 16]

Distance to Object Technologies:
Triangulation:
Triangulation is based on a principle that the position of a point of a triangle (the object) can be Calculated knowing the positions and angles of two points of view. These two points of view may be produced by two detectors, a single detector using a prism, or captured at two different points in time.[13] (Ref fig a)

Confocal:
Confocal imaging is a technique based on acquisition of focused and defocused images from selected depths. This technology can detect the sharpness area of the image to infer distance to the object that is Correlated to the focal length of the lens . The object can then be reconstructed by successive images taken at different focuses and aperture values and from different angles around the object. [19, 20] (Ref fig b)

Active Wave front Sampling (AWS)-It is a surface imaging technique, requiring a camera and an off-axis aperture module. The module moves on a circular path around the optical axis and produces a rotation of POI (Point of interest). Distance and depth information are then derived and calculated from the pattern produced by each point. [21] (Ref fig c)

Stereophotogrammetry:
This technology estimates all coordinates (x, y, and z) only through an algorithmic analysis of images.[16] It relies on passive light projection and software, the camera is relatively small, its handling is easier, and its production is cheaper[13] (Ref fig d).



Determining distance to the object. (a) Triangulation: Distance BC could be determined according to the formula BC = AC × sin (^A)/sin (^A+^C) (b) Confocal: distance to the object is determined according to the focal distance. (c) AWS requiring a camera and an off-axis that moves on a circular path around the optical axis and produces a rotation of interest points. (d)Stereophotogrammetry is a technology that generates files by algorithm analyzing numerous pictures.

Reconstruction Technologies:
One of the major challenges in generating a 3D numerical model is the matching of POI taken under different angles. Distances between different pictures may be calculated using an accelerometer integrated in the camera. Using algorithms, similarity calculation defines POI coincident on different images. This POI can be found by detection of transition areas, such as strong curvatures, physical limits, or differences of grey intensity ("Shape fromSilhouette").[22] A transformation matrix is then calculated to evaluate similarity between all images such asrotation or homothety. Each coordinate (x, y, and z) is extracted from the projection matrix, and a file is then generated. [13]

Scan Paths:

In addition to the different technical modes employed forfunctioning of the various scanners, a correct scan path is decisive for successful scanning results at the present state of the technology.Various scientific analyses have showed that the scan path influences the accuracy of the data captured when using conofocal scanners, in both invitro and invivo studies.[23,24] Scan path means that the intraoral scanner must be moved according to a specific pattern in order to obtain the greatest possible precision of the virtual model.This is to ensure that the individual images generated by the optical system are superimposed with sufficient accuracy.[25]

Practitioners also have to maintain a fluid movement, always preserving a steady distance and the tooth centered during recording. The camera should be held in a range of between 5 and 30mm of the scanned surface depending on the scanners and technologies.[13] Especially for the capture of large areas such as quadrants and full-arch,a sufficient data volume must be generated not only in the mesiodistal direction but also by adding lateral images to complete the scan path and above all,to close it again by crossing over the occlusal surface and returning to the starting point of the scan movement.The capture of structureless areas and or in the areas with a steep downward slope (anterior mandibular area),often proves to be difficult. This in turn, requires particular system-dependent strategies. Rather than relying solely on the technical specifications, it is therefore also important for users to try out for themselves the scanning systems in which they are interested.[25]However,with the aid of guided scanning procedures,the user is instructed step-by- step during the scan as to how to guide the intraoral scanner over the dental arch.Guided scanning procedures facilitate the implementation of the procedure.[13]

Powdering:

A trinocular imaging is done using a HD video camera. Three accurate views of the tooth are recorded by the three tiny video cameras at the lens. [26] A light dusting of powder is needed in a thin layer of about20–40 µm; the coating is done during the digitizing process to reduce reflectivity from multiple translucent layers of the tooth and restorative material at unpredictable angles. [27] This powder coating enhances scanning accuracy by increasing the number of surface data points and providing uniform light dispersion. Titanium dioxide opaque mixture, Zirconium oxide with amorphous silica and aluminum hydroxide are the powders used. [28]

Another strategy to overcome this difficulty employed by some systems is to use cameras with a polarizing filter. Accordion fringe interferometry (AFI) uses two light sources to project three patterns of light, called “Fringe patterns”, onto the teeth and tissues. As a fringe pattern hits the surface, it distorts and takes on a new pattern based on the unique curvature of the object. Distortion in this fringe pattern is known as “Fringe curvature” (Ref fig e).

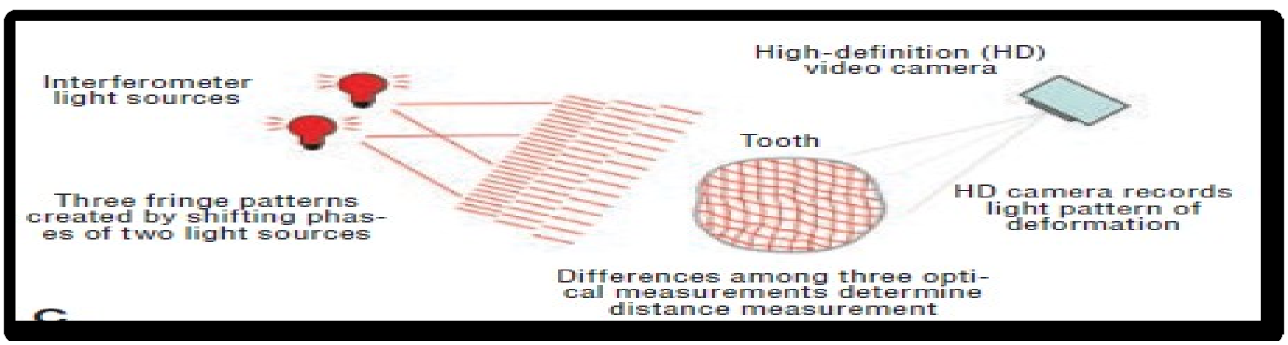


Fig e: Accordion fringe interferometry.

A high definition video camera records the surface data points of fringe curvature. These scanners have a higher dynamic range of luminosity, allowing reflective surfaces to be scanned without powder coating. Both AFI and 3D in motion video imaging use HD video cameras rather than a sensor to rapidly capture images in real time. [28]

Accuracy of Intraoral Scanners:

Accuracy is an important factor for the success and long term survival of the prosthesis. According to ISO 5725-1and -2, the accuracy is described by two measurement methods: Trueness and Precision. Trueness indicates the closeness to a true value and precision indicates the level of reproducibility when the process is repeated. [29, 30]

According to the research of Gimenez et al[20]: The accuracy of a digital impression system when considering clinical parameters like experience of the operator, the angulation, and the depth of the implants didnot necessarily dependent upon the performance of the operator or his experience. The distance from which the object is scanned, affects the predictability of the accuracy of the scanner and the error increased with the increase in the length of the scanned section[20]. Guth et al: The mean trueness of conventional impression using a polyether was 77 µm (SD 36 µm) and for digital impression was 89 µm (SD 48 µm) with True Definition. [31] A study by Ender et al. concluded that the accuracy of the IOS is widely studied and accepted within the clinical parameters in those cases scanned for single unit prosthetics and quadrants. However, there is some controversy as to the accuracy in the registration of full-arch impressions. The precision of the IOS is limited in most of the in vitro studies to the accumulated error from the conventional impression taking, elaboration of the model, scanning of the master model with the IOS and superposition using the software [24]. Muller et al. reported that the zigzag strategy for intraoral scanning has a lower trueness value but a better precision value than buccal–occlusal‑palatal strategy[32]. Hussam et al., from his study stated that none of the technologies reached the required trueness and precision values and were considered unreliable for multiple implant impression[33]. This leads us to believe that if more in vivo studies were carried out, this accumulation of errors would decrease since so many steps would be reduced and the accuracy of these scanners could be more reliably assessed.

Intermaxillary Relationship Registration:

A complex clinical step is a common source of error due to cumbersome and imprecision of bite registration materials. By contrast, impressions using IOS only require a new acquisition of vestibular faces when the patient is in occlusion. Maxillary and mandibular arches are then aligned with a matching process. Even if this complex algorithm requires coincident areas positioned under different planes. A recent study reported that only one left and one right lateral occlusal record is required for software alignment, with a minimum dimension of 12 × 15mm.[34,35]

Commercially Available Intraoral Scanning Systems:

Some of the commercially available intraoral scanners are listed in table 1. [11, 25, 36-40]

Table 1:- Commercially Available Intraoral Scanners.

Intraoral scanner	Company	Working principle	Light Source	Imaging Type	Necessity of coating	In-office milling	Output format
CEREC AC blue cam	Sirona Dental System GmbH (Bensheim, Germany)	Active triangulation and optical microscopy	Visible blue light	Multiple images	Yes	Yes	Proprietary
CEREC-omnicam	Sirona, (Bensheim, Germany)	Triangulation	LED	Images	No	yes	Closed System
Itero	Cadent Inc (Carstadt, NJ)	Parallel confocal microscopy	Red laser	Multiple Images	No	No	Proprietary or selective STL
E4D	D4D Technologies, LLC (Richardson, TX)	Optical coherence tomography and confocal microscopy	Laser	Multiple Images	Occasionally	Yes	Proprietary
LAVA-COS	3MESPE (St.Paul, MN)	Active wavefront sampling	Pulsating visible blue light	Video	Yes	No	Proprietary
LAVA-True	3M ESPE, Seefeld,	Active wavefront Sampling	Visible blue	video imaging	Yes	Yes	STL

definition	Germany	Active triangulation	light	technolog y			
TRIOS (TS)	3Shape A/S (Copenhagen, Denmark)	Confocal microscopy	LED	Multiple Images	No	No	Proprietar y or STL
Planscan	Planmeca, Richardson, Texas,united states	Confocal Microscopy Or Triangulation	Blue Laser Emission	Image or video acquisitio n	No	Yes	STL
3D Progress	MHT Spa (Verona, Italy)-MHT Optic Research AG (Niederhasli, Switzerland)	Confocal microscopy	Moire a kind of structure d light	3 images	Occasionall y	No	STL
IOS Fastscan	IOS Technologies,Sa n Diego,CA.	Active triangulation and scheimpflug principle	LASER	Image acquisitio n	Yes	No	STL
Carestrea m 3500(cs)	Carestream Dental, Atlanta, Georgia, United State	Triangulation	Unique light guidance system	image acquisitio n	No	YES	STL
ZFX intrascan	Zfx GmbH, Dachau, Germany	Confocal Microscopy and moiré effect detection	LASER	Image or video acquisitio n	No	No	STL
MIA3D	Densys Ltd (Migdal HaEmek, Israel)	Active stereophotogrammet ry	Visible light	2 images	Yes	No	ASCII
DPI-3D	Dimensional Photonics International, Inc (Wilmington, MA)	Accordion fringe interferometry (AFI)	Wave length 350 to500 nm	Multiple Images	No	No	STL

STL – Standard Tesselation Language , LED – Light Emitting Diode, LASER – Light Amplification by Stimulated Emission of Radiation , ASCII – American Standard Code for Information Interchange

Clinical Recommendations:-

From the conflicting outcome of various studies, the scanning systems, scanner acquisition process and powder application do not appear to be major influencing factors on the accuracy of IOS. The multiple variables which can influence the accuracy of IOS are span length, scanning sequence and scanned surface morphology. While IOS can be safely used to acquire diagnostic models and treatment planning purposes, some recommendations are required for definitive prosthesis fabrication. According to the current evidences, IOS should only be used for short-span prosthesis that follows a confirmative occlusal relationship with the opposing arch. This is facilitated by scanning the maxillary and mandibular arches when they are at maximal intercuspation. For longer span prosthesis, in addition to accurately recording the tooth surface, the occlusal relationship has to be registered, which is very difficult to record by IOS after preparing several teeth. This recommendation is supported by clinical studies which indicate that 3 or 4-unit prostheses fabricated by IOS impressions exhibited similar accuracy to the prostheses fabricated by conventional techniques.

There is also some evidence that smooth surfaces are easier to capture by light scanners in comparison to irregular and corrugated surfaces. Thus, if IOS is planned to be implemented, it is reasonable for the clinician to modify the preparation design by ensuring smooth and regular surfaces with rounded line angles. The areas of sudden change of curvature may suffer from greater deviations. Therefore, sharp preparation edges, grooves and boxes are better to be avoided. Further, it is easier to replicate the rounded line angles by the CAM process on the prosthesis fitting surface. As the preparation is used digitally to design the prosthesis, it has to be easily read by the software. One of the frequently encountered limitations of CAD/CAM systems is the precision of the marginal area. Several studies have indicated that the prosthesis margins are vulnerable to inaccuracy. This may be attributed to difficulties in locating the prosthesis margin virtually. Nevertheless, more research is desirable to provide recommendations to the clinicians regarding preparation margin design, saliva control, cost efficiency and long term outcome. [37]

Advantages of Intraoral Scanners:

1. Enhanced patient compliance as patient discomfort is reduced.[41]
2. Can be used in geriatric patients, and in patients with strong gag reflex, trismus, and children or in patients who are not comfortable with impression materials and trays, in complex cases such as cases with multiple implants or severe undercuts.[42]
3. Simpler clinical procedures with no bite registration and gypsum casts and thereby no physical space is required for their storage.[43]
4. Reduces the environmental impact of disposing the materials required for conventional impressions.[18]
5. Provide improved precision and consistency.[18]
6. Provides a clean and streamlined impression method Without any complexity.[18]
7. It aids in visualization of the preparation on a computer display from many perspectives.[18]
8. Offers instant display and feedback for making corrections immediately.[18]
9. It allows the clinician to design the restoration on a computer, while visualizing the opposing dentition.[18]
10. Better communication with dental laboratory technicians and patients. The patient feels more involved when their scans are shown and discussed with them. This has an overall positive impact on the treatment.[44]
11. Digital impressions have approximately the same accuracy for single tooth restorations and short span fixed partial dentures when compared to conventional impression techniques.[45]

Disadvantages Of Intraoral Scanners:

1. Difficulty in detecting the sub gingival finish lines of prepared teeth. [46]
2. Difficult to scan with bleeding tissues. [36]
3. Difficulty in learning the working of IOS and operator related errors. [47]
4. Purchasing and managing costs- Expensive. [48]
5. Reflection caused due to saliva, surfaces like enamel crystals or polished surfaces also disrupts the accuracy of the digital impressions. [49]
6. Powder could be uncomfortable for patients, and additional scanning time is required when powder is contaminated with saliva during impression as this requires cleaning and re-application of powder. [49]

Indications:

Prosthodontics:

used for Single tooth restorations, resin inlays/onlays, zirconia copings, post and core, removable partial denture frameworks, fixed partial dentures, Digital smile designing and Obturators.[49]

Implantology:

Implant bridges (4-5 implants), Implant supported bars and guided implant surgery.[50]

Orthodontics:

Diagnosis and treatment planning, aligners and custom made devices.[49]

Contraindications:

1. Long span fixed partial dentures and or fixed full arches. (6-8 element bridges)[50]
2. Long-span implant supported fixed partial dentures and/or fixed full arches. (6–8 implants)[50]
3. Complete removable prosthesis.[50]

Conclusion:-

Intraoral digital scanners help in improving both practice efficiency and the patient experience better than conventional alginate and polyvinyl siloxane impressions. Digital impressions improve the effectiveness of treatment by reducing the visits, which would be beneficial to patients in terms of efficient planning and comfort. With such numerous advantages and benefits, digital impression will likely be a routine procedure in the near future and with a few more improvements will lead to its wide use in dentistry.

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