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INTRAORAL SCANNERS: A NARRATIVE REVIEW

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ABSTRACT

Objectives: Accurate impressions are essential in fabricating dental restorations and fixed dental prostheses. During the last decade, digital impression systems have improved substantially. The objective of this narrative review is to discuss the recent research on intraoral scanners with regards to it's technology, accuracy and applications for fabrication of dental restorations and fixed dental prostheses.

Materials and methods: A search strategy was performed in MEDLINE/PubMed, Scopus and Google Scholar with keywords - intraoral scanners, accuracy, applications, dentistry.

Results: 395 articles were retrieved. After hand search a total of 415 articles were identified. Ultimately, 30 articles were selected and summarized and discussed as they met the selection criteria.

Conclusion: Within the scope of this review, reported literature showed that digital intra-oral impressions have presented an achievement in the dental market as they reduce time required and simplify the clinical procedures with better communication with the technician and the patient. The current intraoral scanners (IOS) are sufficiently accurate for capturing impressions for fabrication of prosthetic restorations (inlays/onlays, copings and frameworks, single crowns and fixed partial dentures) on both natural teeth and implants; in addition, they can be used for smile design, and to fabricate posts and cores, removable partial prostheses, obturators, orthodontic aligners and custom made devices. The use of IOS in long-span restorations with natural teeth or implants is still a challenge.

INTRODUCTION

Since the eighteenth century, conventional impression techniques have been used to register the three-dimensional geometry of dental tissues. However, there are various potential errors due to deformed impression, incorrect tray selection, inadequate water-powder ratio and expansion of dental stone. Despite being considered a trivial and well-established procedure in dental practice, a number of problems are encountered like bio-safety norms for disinfection, obtaining accurate and reliable reproduction of the oral structures, discomfort to the patients with severe gag reflex, storage space for the plaster models, plaster chipping or breakage which could lead to substantial loss of patient data .[1-5] To overcome these, Digital techniques have been applied in dentistry to simplify oral rehabilitation procedures. These systems

can utilize intraoral scanners (direct digitalization) or extraoral scanners (indirect digitalization). The breadth of applications and the numerous advantages has led to a greater interest in these devices in recent years. [6-10] They allow the immediate determination of the quality of the impression; virtual 3D models of patients can be obtained, saved on computer without making a plaster model. It can be used as a powerful marketing tool for more effective communication with the patient [11-13]. In the last decade, there has seen an increase in the number of intraoral scanners (IOS) with different technologies.

These devices capture the shape and size of the dental arches (or the position of dental implants) through the emission of a light beam. They project a light source (structured light or laser) onto the dental arches, tooth surface or implant scan bodies through high-resolution cameras[10,14]. The information collected by these imaging sensors is processed by powerful scanning software that reconstructs the three dimensional (3D) model of the desired structures by generating point clouds which are triangulated by the same software [15-17]. The 3D surface models of the dento-gingival tissues are the result of the optical impression and are the 'virtual' alternative to traditional plaster models [18-19].

This review discusses the advantages, disadvantages, technology, accuracy and clinical use of Intraoral Scanners.

STUDY SELECTION

This review was based on articles searched through the MEDLINE/PubMed, Scopus and google Scholar databases. The search was augmented by hand search of the relevant journals unavailable through electronic database and the list of references of the included studies.. The main keywords that were employed during the search were" intraoral scanners, accuracy, applications, dentistry".

A total of 415 articles were retrieved which included narrative reviews, systematic reviews, clinical reports, Randomised Control Trials, in-vitro and in-vivo studies. Ultimately, 30 articles were selected, summarized and discussed as they met the selection criteria.

INCLUSION CRITERIA

1. Peer reviewed articles in English only.
2. Full text articles-Reviews, reports and studies.

EXCLUSION CRITERIA

1. Abstracts only on the Databases searched.
2. Unpublished reports or abstracts or case reports as well as reports that did not cover both conventional and digital impression techniques.

ADVANTAGES OF INTRAORAL SCANNERS

1. Enhanced patient compliance as patient discomfort is reduced.[10]
2. Can be used in geriatric patients, and in patients with strong gag reflex, trismus, 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.[18]

3. Scanning can be repeated if unsatisfactory.[17]
4. Reduced clinical time for the clinician. The time required for obtaining optical impressions with an IOS is similar to that of conventional impressions. However, the time required for pouring the impressions, making stone casts and sending the cast to the dental laboratory via courier or mail is saved with the use of intraoral scanners. The scanned images can be emailed to the dental technicians directly. If IOS is combined with CAD/CAM technology for delivering chair side restorations and prosthetic appliances, enormous amount of time is saved and treatment can be done with more accuracy and precision. [19]
5. Simpler clinical procedures with no plaster casts. [20]
6. 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. [21]
7. Digital impressions have approximately the same accuracy for single tooth restorations and short span fixed partial dentures when compared to conventional impression techniques.[22]

DISADVANTAGES OF OPTICAL IMPRESSIONS

1. Deep marginal lines of prepared teeth are difficult to detect with IOS. [23]
2. Difficult to scan with bleeding tissues. [24]
3. Difficulty in learning the working of IOS and operator related errors. [25]
4. Expensive [26]
5. Reflection caused due to saliva and powder application can affect the accuracy of impressions.[27-28] Reflective

surfaces like enamel crystals or polished surfaces also disrupts the accuracy of the digital impressions due to overexposure. This can be overcome by changing the angulation of the camera to increase the diffuse light or by using cameras with polarizing filter.[29] 20-40μm powder coating is also used in some cameras during impression making to reduce reflectivity. The powder thickness may decrease the file accuracy but the software of the IOS is capable of taking an average thickness into account.[30] Powder-based digital impression has been proved to be very accurate for partial impressions.[30-31] However, 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.[32] Moreover, concerning full-jaw scans, IOS using powder free technologies appears to be recommended due to the difficulty to maintain powder coating on all the teeth for the duration of the scan. [10]

INDICATIONS

In prosthodontics for Single tooth restorations, resin inlays/onlays, zirconia copings, post and core, removable partial dentures, fixed partial dentures, smile designing, implant prostheses and guided implant surgery.[33-42]

In orthodontics for diagnosis and treatment planning, aligners and custom made devices.[18]

CONTRAINDICATIONS

1.Long span fixed partial dentures and implant prosthesis.[43]
2. Complete removable prosthesis. [44]

IOS TECHNOLOGIES

IOS is a medical device composed of a handheld camera, a computer and a software. The IOS records with precision the three-dimensional geometry of an object. The most widely used digital format is the open STL (Standard Tessellation Language) or locked STL-Like. Irrespective of the type of imaging technology employed by IOS, all cameras require the projection of light to record individual images or video and are compiled by the software after recognition of the POI (points of interest). [45]

1. LIGHT PROJECTION AND CAPTURE

Within the 3D reconstruction field, there is a clear distinction between passive and active techniques. Passive techniques use only ambient light for the intraoral tissues and 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 [46]. In active techniques, a luminous point is projected onto an object and the distance to the object is calculated by triangulation. Light pattern projection, such as line or mesh projections can also be used as an alternative and the surface reconstruction can be obtained with a compilation of images [47-49]

2. DISTANCE TO OBJECT TECHNOLOGIES

a. 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.[45]

b. Confocal- Distance to the object is determined according to the focal distance. [45]

c. AWS (Active Wavefront Sampling)- AWS 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. [46]

d. Stereophotogrammetry- It is a technology that generates files by algorithm analyzing numerous pictures.[45]

3. RECONSTRUCTION TECHNOLOGIES

One of the major challenges of 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, but a similarity calculation is more often used to determine the point of view of the image.[45]

ACCURACY OF IOS TECHNOLOGIES

According to the International Organization for Standardization (ISO), accuracy is evaluated in terms of trueness and precision (ISO5725-1) [50]. Trueness indicates the closeness to a true value and precision indicates the level of reproducibility when the process is repeated. Trueness and precision of

digital impressions using IOS depends on the operator, equipment used and calibration, the time elapsed between measurements, and the environment (temperature, humidity, etc.). However, the methods to calculate precision and trueness for IOS are limited due to the quality of references and the measurement technique used. For instance, in vitro, a plaster model scan using extra oral scanner is the reference, but it is difficult to compare these results with in vivo files as for the latter a plaster scan obtained from indirect physicochemical impression will consist of inaccuracies [51-52]. Some studies have compared distances between STL (Standard Triangulated Language) generated from a plaster model and those generated with IOS manually, whereas other studies have used an algorithm to align two different files and calculated the distance between them [52]. In 2017, it was reported that illuminance and color temperature affected trueness and precision of intraoral scanners. [53] According to the in-vivo study by Sason et al intraoral scanner has higher precision and trueness as compared to extra oral scanner [54]. Ali AO compared the accuracy of digital impressions obtained from various digital impression systems and concluded that there was a significant difference in accuracy amongst the Intraoral scanners used and it could be attributed to the surface scanning materials (liquids and powders) and the data capturing techniques.[55] The findings in the study by Takeuchi Y et al indicated that use of digital impression systems with intraoral scanners for fabrication of dental restorations and fixed dental prostheses requires that the operator understand the characteristics and adaptations required when using

intraoral scanners, as these systems can reduce patient discomfort during impression-making.[56] Similarly Ahmed et al conducted a study to assess the average full-arch scanning time, perception and likelihood of future adoption of technology by final-year dental students using three different Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) intraoral scanning systems and drew a conclusion that full arch Intraoral scanning performance of novice users varied significantly and was dependent on the scanning system used and was overall perceived positively as it was time saving and determined the likelihood of future adoption of its use.[57]

Study done by Renne et al to evaluate accuracy of sextants and full arch impressions using 7 digital scanning systems and also the relationship between speed and accuracy, yielded the conclusion that Intraoral scanners are remarkably accurate; nevertheless, each scanner has its pros and cons that should be considered, in that no one scanner proved to have the best combination of accuracy and speed.[58] Mack S et al evaluated and compared the digital dental models generated from 2 commercial intraoral scanners with manual measurements when performing 3-dimensional surface measurements along a curved line (curvilinear) and drew a conclusion that they were comparatively accurate.[59] According to Ender A and Mehl A, for full arch impression, the trueness and precision of conventional impression evaluated from stone casts was 20–55 mm and 13–61 mm respectively and that of digital impressions obtained using an intraoral scanner was 40–59 mm and 31–60 mm respectively and the mean

trueness of various IOS technologies is between 20 and 48 μm and the precision is between 4 and 16 μm, when the impression is partial and compared to conventional impression [60]. In a study by Hayama et al, digital impressions taken using intraoral scanners for partially edentulous patients showed superior trueness, but inferior precision, as compared with conventional impressions but the accuracy could be improved by using larger scanning heads [61]. Medina-Sotomayor et al conducted a study on the accuracy of different intraoral scanners for long span impressions using scanning strategies like exterior-posterior, quadrants sextants and sequential and derived at a conclusion that the digital impression systems provided sufficient flexibility in acquiring 3D images without affecting the accuracy of the scanner.[62] Nedulco et al concluded from their study that Intraoral scanners can be used as a replacement for conventional impressions when restoring up to ten units without extended edentulous spans. [25] The results obtained from Wesemann et al study suggests that for prosthodontic use an indirect digitalization with desktop scanner gave good results for full arch but with intraoral scanners, less than a quadrant with 3 additional teeth can be scanned.[63] Based on the findings of Abduo and Elseyoufi's systematic review similar conclusions were drawn that for whole arch scanning, the IOS is prone for more deviation. The studies indicated variable results for the different IOS systems. Although the accuracy of IOS systems appears to be promising and comparable to conventional methods, they are still susceptible to inaccuracies. For prosthesis fabrication, the IOS accuracy is improved by reducing

the span of scanning, thus ensuring the scanned surfaces exhibit minimal irregularities.[64] Bohner et al concluded from their systematic review that Current scanning technologies offer an acceptable accuracy for specific applications, although this depends on the scanner technology, object shape, and scanning strategies and the scanning of the edentulous arch still represents a clinical challenge. [65]

Yang X study showed that fit of a single crown using digital impressions was up to the clinical standards and concluded that digital impressions could be an alternative to conventional impressions for single crown manufacturing.[66] However, Shimizu et al drew a conclusion from their study that marginal and internal fit of the digital crowns fabricated using the intraoral scanner and CAD programs were inferior to those fabricated using the extraoral scanner and CAD programs.[67] Maeng J et al evaluated accuracy of two types of scanners through 2-dimensional analyses at five digital cross-sections (mesiodistal, buccolingual, high transverse, mid-transverse, low transverse) of single-tooth abutment and concluded that two-dimensional analysis can give a better understanding of the errors arising from single tooth abutment area. Appropriate approachability, depth, reflection angles leading to complete attainment of data is as important as the accuracy of the scanners. Dead space should be avoided, especially in proximal areas where errors are mostly made. In tooth preparation for digital impression making, it is important to have smooth planes without sharp edges as sharp edges result in high deviation during intraoral scanning.[68] Ultrasound has been suggested as an alternative to optical digital impression-taking since it is capable of penetrating soft tissue and fluids without causing physical or biological damage to the patient, thus it would enable impressions to be made without problems related to oral fluids and gingival covering the preparations. [69-70] With the ultrasound scanner, digital impressions of prepared teeth under subgingival conditions could be made. The corresponding crowns presented higher marginal misfit values than those of crowns produced from optical scanning without gingiva. This scanner was able to scan teeth with accuracy similar to that of conventional optical scanners when no gingiva was present.[71]

Kachhara S et al concluded in their systematic review that AWS technique shows a higher degree of accuracy for making multiple implant digital impression. The expertise of the user is also influences the accuracy of the digital impressions. Implant angulation and depth do not influence the accuracy of digital implants. [72] Papaspyridakos et al concluded that digital implant impressions were as accurate as conventional implant impressions. The splinted, implant-level impression technique was more accurate than the non-splinted one for completely edentulous patients, whereas there was no difference in the accuracy at the abutment level. The implant angulation up to 15° did not affect the accuracy of implant impressions.[73] Vandeweghe et al conducted an vitro study to test the accuracy of 4 intraoral scanners for multiple dental implants which drew a conclusion that the scanners differed in accuracy and one scanner did not meet the level of accuracy for impression making of long span implant supported prosthesis. Hence the clinician has to be aware that all intraoral scanners cannot be used for every situation.[74] Marghalani et al concluded from their study that both the impression techniques and the implant systems affected accuracy. However, the accuracy with all 3 impression techniques - Digital implant impressions with 2 different intraoral scanners – True definition and Omnicam scanners and conventional impressions for partially edentulous arches were within clinically acceptable levels. Conventional impressions showed statistically significant difference compared with both digital scanners.[75] An innovative full-digital protocol (SCAN-PLAN-MAKE-DONE) was devised by Mangano F et al for the design and fabrication of fixed implant-supported monolithic translucent zirconia crowns cemented on customized hybrid abutments, without any additional desktop scan, but only with a second intraoral scan of the actual position of the abutments in the mouth. This protocol exhibited a reliable treatment option, with an excellent marginal fit, lower occurrence of failures and complications one year after delivery. However more studies on a larger number of patients and dealing with different prosthetic restorations (such as implant-supported fixed partial prostheses) are needed to validate the results of this protocol.[76]

CONCLUSION

Intraoral scanners (IOS) are devices used for making digital impressions in dentistry. These scanners can be used in various fields of dentistry such as Prosthodontics, Orthodontics, Implant surgery etc. They are time-efficient, reduce patient discomfort, reduction in the volume of hardware,

enhance clinician- patient communication and simplify clinical procedures for the dentist. However, with IOS, the difficulties faced are to detect deep margin lines in prepared teeth and/or in case of bleeding, learning curve, and the purchasing and managing costs. Also the scanning of the edentulous arch still represents a clinical challenge.

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