journal of prosthodontic research 64 (2020) 109–113

Contents lists available at ScienceDirect

Journal of Prosthodontic Research

journal homepage: www.elsevier.com/locate/jpor

Review

Accuracy and practicality of intraoral scanner in dentistry: A literature review

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ARTICLE INFO

Article history:
Received 8 May 2019
Received in revised form 17 July 2019
Accepted 22 July 2019
Available online 30 August 2019

Keywords:
Intraoral scanner
Desktop scanner
Digital impression
Digital dentistry

ABSTRACT

Purpose: The digitization of the dental field has been vigorously promoted in recent years. An impression using an intraoral scanner is considered to significantly change future dental treatment. The purpose of this review is to evaluate accuracy and practicality of various intraoral scanners and verification method of intraoral scanners.
Study selection: This review was based on articles searched through the MEDLINE and PubMed databases. The main keywords that were employed during the search were “Oral Scanner, Intraoral Scanners, Desktop Scanner, and Digital Impression”.
Result: It was reported that illuminance and color temperature affected trueness and precision of intraoral scanners. The repeatability of intraoral scanners indicated the possibility of producing fixed prostheses within the range of being partially edentulous. It is considered difficult to use intraoral scanners in fabricating cross-arch fixed prostheses. However, with intraoral scanners, it may be considered possible to fabricate mouth guards and dentures equivalent to those of desktop scanners. Current intraoral scanner scans are considered more comfortable than traditional impressions that use irreversible hydrocolloid and elastomeric impression materials.
Conclusion: Since the intraoral scanner is an evolving device, further improvement in accuracy is expected in the future. In addition, verification of the accuracy of intraoral scanners must be conducted accordingly.

1. Introduction

The most significant change in the dental field in recent years is, without a doubt, the development of digital dentistry [1–5]. Regarding the fabrication of prostheses, with computer-aided design-computer-aided manufacturing (CAD-CAM) systems, it became possible to mill frameworks designed by a computer and to use aesthetic materials such as alumina and zirconia ceramics, which cannot be cast [6–11]. More recently, fabrication of prostheses using three-dimensional (3D) printing has also been reported [12–17]. In clinical application of final impressions, it has also become possible to employ an intraoral scanner as an alternative to conventional impressions using a vinyl polysiloxane material [11,18–26]. The advantages of digital impressions using an intraoral scanner include it being effective for patients with strong vomiting reflexes, and it being possible to overwrite only the part where the impression is not clear. When considering remaking and polymerizing, it was reported that total clinical treatment time was reduced [27–29]. Recently, data of patients can be transmitted to dental technicians using the Internet, therefore, there is no longer any need to send stone models. Thus, there is no risk of the model breaking in transit. In the field of orthodontics, intraoral scanners are considered to be a paradigm shift as an alternative to irreversible hydrocolloid and polyvinyl siloxane impressions [30]. Most orthodontic treatments require long periods of treatment, and the first diagnostic model needs to be stored during the said period. The digital models acquired from intraoral scanners do not occupy any physical space as in conventional gypsum models, and there is no doubt that the digital model obtained by the intraoral scanner is effective in terms of securing storage space.

Also, digital dentistry, especially digital models, has several benefits, such as quick access to 3D diagnostic information, and transfer of digital data for communication with specialists [30–33]. Intraoral scanners have many advantages as compared to

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https://doi.org/10.1016/j.jpor.2019.07.010

conventional methods in relation to the fabricating process of prostheses. It is possible to eliminate all fabricating errors encountered by conventional methods, such as the distortion of impression material [34,35], expansion of plaster, deviation when attaching a model to an articulator, and casting shrinkage. From an educational point of view, a recently revised predoctoral implant curriculum at the University of Illinois at Chicago College of Dentistry integrated digital dentistry into both the preclinical dental implant course and clinical activities [36]. Furthermore, to evaluate preparing natural teeth, students can check the abutment tooth by scanning it [37–40]. By evaluating the preparation objectively, it will be possible to learn more efficiently.

However, at present, it is not well known how large of a prosthesis can be manufactured by the intraoral scanner. Intraoral scanners have been marketed by various manufacturers, but their superiority is not well understood. In addition, it is also currently not well understood as to what degree of accuracy intraoral scanners provide as compared to desktop scanners. As for the assessment procedure, it has not been verified whether the method, such as a superimposing method and the like, is appropriate. The purpose of this review is to evaluate accuracy and practicality of various intraoral scanners and verification method of intraoral scanners.

2. Study selection

This review was based on articles searched through the MEDLINE and PubMed databases. Also, the articles were published between the years 2010 and 2019. The main keywords that were employed during the search were “Oral Scanner, Intraoral Scanners, Desktop Scanner, and Digital Impression”.

3. Affecting the accuracy of the intraoral scanner

The intraoral scanner is a device that senses asperities of an object and captures it as 3D data. In general, the object is irradiated with a laser to acquire three-dimensional data, and the data is then converted into polygon data, which is a set of triangular surfaces. In short, objects that absorb the laser or do not reflect the laser well are considered objects for which it is difficult to acquire data. In 2017, it was reported that illuminance and color temperature affected trueness and precision of intraoral scanners [41]. The paper also concluded that the 3900 K and 500 lux condition was the most appropriate lighting condition for taking a digital impression. Also, in relation to a powder for use in intraoral scanners, Prudente et al. suggested powder application influenced the marginal discrepancy of crowns [42]. Much of literature on intraoral scanners have used models, but the experimental environment is perhaps a better environment than the actual environment in the oral cavity. Therefore, it can be said that there are no extraneous factors such as saliva, blood, degree to which the mouth is open, motion of patients, the mouth being a moist environment, and so on. Further studies are needed to validate the factors.

4. Reproducibility of standard triangulated language (STL) data by intraoral scanner in relation to scanning range

Much of the past literature on intraoral scanners have verified the trueness and precision to confirm the reproducibility of the scanner [19,43–50]. Trueness indicates the closeness to a true value, and precision indicates the level of repeatability. With regard to the measurement site, there are differences in the literature, with some measuring relatively short distances such as in the case of being partially edentulous, and others measuring long distances as in the case of being edentulous. Among the literatures, there are a few studies examining both partially edentulous and totally edentulous models (Table 1). In a 2018 article, four intraoral scanners (Trios, iTero, Cerec, True Definition) were used to measure totally edentulous and partially edentulous models [43]. In the study, the one that exhibited the best trueness for the partially edentulous model was Trios (20.6 μm), followed by True Definition (23.2 μm), iTero (31.7 μm) and Cerec (36.4 μm). The one that exhibited the best trueness for the totally edentulous model was True Definition (32.1 μm), followed by Trios (55.3 μm), iTero (94.5 μm) and Cerec (98.3 μm). Also, Imburgia et al. used four intraoral scanners (CS 3600, Trios 3, Cerec Omnicam, True Definition) to validate the trueness and precision of dental implants in edentulous and partially edentulous models [44]. The study used STL data obtained by desktop scanners as a reference and verified the accuracy by superimposing the experimental groups on the control. The results of measuring the partially edentulous model were as follows: CS 3600 (44 ± 44 μm), Trios 3 (48 ± 52 μm), Cerec Omnicam (57 ± 66 μm), and True Definition (57 of ± 52 μm). The best trueness was obtained when measuring the edentulous model using CS 3600 (50 ± 81 μm), followed by Trios 3 (57 ± 89 μm), Cerec Omnicam (63 ± 87 μm) and True Definition (84 ± 89 μm). Mangano et al. used 4 intraoral scanners to validate both partially and totally edentulous models [48]. In the study, the intraoral scanners showed similar results for both partially and totally edentulous models.

With the exception of one study, the results showed that the longer the scan range, the larger the error. In most of the articles that measured partially edentulous models, some intraoral scanners confirmed a trueness of less than 50 μm. If the passive fit on a screw-retained implant-supported prosthesis or cement space of the prosthesis is set to over 50 μm, the intraoral scanner may be able to produce the prosthesis of a partially edentulous part of two teeth. However, when fabricating a cross-arch fixed prosthesis, a significant amount of correction may be considered because intraoral scanners had a trueness of around 50–250 μm.

5. Verification method for reproducibility of intraoral scanner

There are different verification methods for the reproducibility of intraoral scanners. To verify the STL data, many studies have superimposed the STL data of the control and the STL data of the experimental group [43,44,46–48,51]. Other studies have measured the distance on the model as a control and verified the STL data by comparing the same with the control [45,49]. Many studies have used superimposing software for verification (Table 1) and the results of the studies indicate the sum of the errors in the measurement sites of the model. As a result, these studies are considered useful in the verification of prostheses, such as mouth guard or complete denture, that require the compatibility of the entire model.

Fukazawa et al. verified the accuracy of the intraoral scanner by measuring the center-to-center distance between the ball abutments of dental implant on experimental model [45]. The authors embedded dental implants in the model of the mandible, and tightened ball abutments for the dental implants. In the study, a contact measurement device (Computer Numerical Control Coordinate Measuring Machine: CNCCMM) was used to obtain a control value, and in the theoretical value, the distance error between the two ball abutments of the control was about 1 μm. Using CNCCMM as a control, four intraoral scanners, Lava C.O.S., True Definition (2nd generation), True Definition (3rd generation), and Trios, were compared. It is thought that the study which verifies the distance error can be directly reflected in the error of distance between the abutment teeth or the distance between the implants of the actual working model using an intraoral scanner. When verifying the manufacturing accuracy of a fixed prosthesis using intraoral scanners, it may be necessary to evaluate both superpose method and measuring distance method.

Table 1. Recent literature comparing the range accuracy of intraoral scanners.

Author (year)	Object	Method of verification	IOS	desktop scanner	Result (μm)				
					Trueness of partial alveolar ridge	Trueness of total alveolar ridge	Precision of partial alveolar ridge	Precision of total alveolar ridge	Others[b]
Mangano FG (2016)	Partial alveolar ridge and total alveolar ridge (with three and six implant analogues)	Superimpose (Geomagics 2012®)	Trios		72.1	71	51	67	
			CS 3500		47.8	63	40.8	55.2	
			Zfx Intrascan		117	103	126.2	112.4	
			Planscan		233	253	219.8	204.2	
Imburgia (2017)	Partially edentulous maxilla model and totally edentulous maxilla model (with three and six implant analogues)	Superimpose (Geomagics 2012®)	CS 3600		45.8	60.6	24.8	65.5	
			Trios 3		50.2	67.2	24.5	31.5	
			Cerec Omnicam		58.8	66.4	26.3	57.2	
			True Definition		61.4	106.4	19.5	75.3	
Fukazawa S (2017)	Partially edentulous maxilla model (with two implant analogues)	Measuring distance (CNCCMM[a])	Lava C.O.S.		15.438.1		1.013.0		
			True Definition (2nd)		7.227.3		0.411.3		
			True Definition (3rd)		14.221.3		0.34.6		
			TRIOS		1.08.1		0.612.6		
				KaVo ARTICA	0.24.1		0.22.0		
Bosniac P (2018)	Prepared natural teeth (Marginal gap)	Measuring marginal gap	CEREC AC Omnicam						86.09 ± 61.46
			TRIOS						88.95 ± 54.46
Bohner LOL (2017)	Prepared natural teeth	Superimpose (GOM Inspect)	TRIOS						37.4
			Cerec Bluecam						33.5
				D250					45.8
				Cerec InEosX5					42.2
Walter Renne (2017)	Custom complete-arch model	Superimpose (Geomagic)	Planscan			96.2		124.6	
			3Shape D800			43.6		69.2	
			CEREC Omnicam			101.5		133.4	
			Cerec Bluecam			140.5		194.2	
			iTero			56.2		89.4	
			CS3500			76		113.8	
			3Shape TRIOS 3			69.4		105.6	
Güth JF (2016)	Titanium testing model (Prepared teeth)	Superimpose (best fit alignment: Geomagic)	CS3500						14
			Zfx Intrascan						33
			CEREC AC Bluecam						29
			CEREC AC Omnicam						31
			True Definition						11
Medina-Sotomayor P (2018)	Maxillary dental arch (epoxy resin)	Superimpose (best fit alignment: Geomagic)	TRIOS		20.6	55.3	63.7	194.5	
			iero		31.7	94.5	85.9	246.8	
			Cerec AC Omnicam		36.4	98.3	93	261.8	
			True Definition		23.2	32.1	61.1	98.8	
van der Meer WJ (2012)	Mandibular dental arch (Stone model)	Measuring distance (Rapidform)	CEREC						80.6
			iTero						65.8
			Lava COS						19.1
Ajioka H (2016)	Partially edentulous mandibular model (with two implant analogues)	Measuring distance (CNCCMM*)	Lava COS		64.5		15.6		

[a] CNCCMM: Computer Numerical Control Coordinate Measuring Machine. [b] Others: Measurement site except alveolar ridge (e.g., abutment tooth).

6. Comparison of intraoral scanner and desktop scanner

Although the number of articles is small, there are some studies that compare intraoral scanners with desktop scanners. In the first place, in the case of studies that were verified by superimposing the STL data, the desktop scanner had been the control in most studies. Consequently, the number of studies comparing desktop scanners and intraoral scanners has been naturally reduced. In a study by Bohner et al. where the abutment tooth model was superimposed, the accuracy of the intraoral scanner and the desktop scanner was compared with an industrial X-ray CT (Zeiss Metrotom; Zeiss) as a control [51]. In the verification method of the study, after dividing into three parts of the abutment tooth, axial surface part and occlusal surface part of the abutment tooth, the error of each measurement point was calculated and added. The results thereof showed that the intraoral scanner was more

Table 2. Literature that verified patient satisfaction with intraoral scanners and conventional impression methods.

Author	Year	Number of patients	IOS	Favorite impression method of patients
Sfondrini MF	2018	14	Trios	Intraoral scanner
Mangano A	2018	30	CS3600	Intraoral scanner
Burzynski JA	2017	180	Trios, iTero	Intraoral scanner
Vasudevan S	2010	30	Lava Cos	Intraoral scanner
Grünheid T	2014	15	Lava Cos	Conventional impression (Alginate)

accurate than the desktop scanner. Also, previous studies have verified the repeatability of the positions of four intraoral scanners and desktop scanners [45]. According to the study, among all the scanners including both intraoral scanners and desktop scanners, desktop scanners yielded the least error. Considering these papers, the reproducibility of the overall shape obtained from the superposition of the models may have been almost equal between intraoral scanners and desktop scanners. However, regarding the reproducibility of distance accuracy, it is considered that the desktop scanner has the better accuracy as compared to the intraoral scanner. Also, among the intraoral scanners above verified in this section, Trios had the best results in the studies and is considered to be closest to the performance of the desktop scanner. Extensive removable prosthesis such as mouth guards or complete dentures may be made using an intraoral scanner, but it may be difficult to make a cross-arch fixed prosthesis.

7. Patient satisfaction compared to conventional impression technique

A study of patient acceptance using Trios in 2018 examined comfort, time, instrument size, feeling of vomiting reflex, etc., in optical and conventional impressions [52]. In the study, impression making using the intraoral scanner had better results for all question items as compared to conventional impression. Also, Mangano et al. compared the conventional impression (irreversible hydrocolloid impression) and the optical impression with the visual analogue scale (VAS) method for 30 patients of orthodontic treatments [53]. The results showed that the optical impression was better than the conventional method in terms of comfort, vomiting reflex, and breathing at the time of impression. However, regarding the impression time, the results showed that the conventional method was slightly faster. Burzynski et al. performed three different types of impressions on 180 orthodontic patients [54]. Two of them were optical impressions using iTero and Trios, while the other was the traditional irreversible hydrocolloid impression method. In the study, optical impressions required longer impression times, but overall patient satisfaction was high regardless of the type of intraoral scanner. Vasudavan et al. performed optical and irreversible hydrocolloid impressions on 30 patients using Lava C.O.S. Patients in the study also favored optical impressions [55]. Furthermore, Grunheid et al. evaluated 15 orthodontic patients who had irreversible hydrocolloid impressions made in the past in terms of their acceptance of using Lava C.O.S [28]. There were more patients who favored traditional irreversible hydrocolloid impressions (Table 2).

In some of the studies using previous-generation intraoral scanner, patients preferred conventional impression such as irreversible hydrocolloid impression as compared to optical impression in relation to the operability, scan speed, etc. However, due to the improvement of hardware technology, the scan speed has been improved and the size of hardware devices has been reduced. Therefore, in recent research, many patients responded that intraoral scanner was more comfortable. The studies use irreversible hydrocolloid impressions as comparisons since they were easier to control than elastomeric impressions. Consequently, when comparing intraoral scanner with elastomeric impressions that are even more difficult to control than irreversible hydrocolloid impressions and in which impression times are longer, it is clear that intraoral scanner gives superior results as compared to elastomeric impression with regard to patient acceptance.

8. Conclusion

It was reported that illuminance and color temperature affected trueness and precision of intraoral scanners. The repeatability of the intraoral scanner indicated the possibility of producing fixed prostheses within the range of being partial alveolar ridge. Fabrication of cross-arch fixed prostheses is considered difficult with the current level of accuracy. However, with intraoral scanners, it is considered possible to fabricate extensive removable prosthesis, such as mouth guards and complete dentures, equivalent to those of desktop scanners. Researches on superimposing STL data are considered useful in the verification of prostheses that require the compatibility of the entire model. Therefore, to get verification of the manufacturing accuracy of a fixed prosthesis using intraoral scanners, it may be necessary to evaluate both superpose method and measuring distance method. Current intraoral scanner scans are considered more comfortable than traditional impressions that use irreversible hydrocolloid or elastomeric impression materials.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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