ASDJ
AINSHAMS DENTAL JOURNAL

Print ISSN 1110-7642
Online ISSN 2735-5039

AIN SHAMS DENTAL JOURNAL
Official Publication of Ain Shams Dental School
September 2024 Vol. 35

Four Digital Intraoral Scanners versus Conventional Impression Technique: An In-Vitro Evaluation of Fit Accuracy on Multiunit Abutments for Cross Arch Implant Restorations

Reham Ragab Saad[1], Atef Shaker Ibrahim[2], and Mohamed Amr ElKhashab[3]

Aim: This study aimed to compare the passive fit of a full-arch implant zirconium superstructure using conventional impressions versus digital impressions with four intraoral scanners.

Materials and methods: Four implants were installed in an epoxy resin mandibular cast in canine-molar regions bilaterally. Twenty-five frameworks were fabricated; in Group 1, twenty milled frameworks were fabricated using 4 intraoral scanners (IOS) (Cerec primescan(G1P), Cerec Omnicom(G1O), Medit i700(G1M), and 3Shape Trios4(G1T)), while in Group 2(G2), five conventional frameworks were fabricated using a conventional splinted open tray impression technique. The passive fit of all 25 frameworks was evaluated using the Sheffield test, and the marginal gap distance was measured using a stereomicroscope when all implant screws were tightened.

Results: All frameworks were considered passive using the Sheffield test. Cerec Primscan showed the lowest marginal gap values when evaluated using a stereomicroscope. 3Shape Trios4, Cerec Omnicom, and Medit i700 showed similar gap values, while the highest gap values were presented in the conventional impression group (G2).

Conclusions: Intraoral scanners can be used efficiently with scan bodies in the fabrication of cross-arch implant restorations. Cerec primscan proved to be higher in precision than other tested intraoral scanners.

Keywords: Implant restoration, Marginal accuracy, Gap distance, Intra-oral Scanners, Passive fit.

1. Dentist at the Ministry of Health, Egypt.
2. Professor of Fixed Prosthodontics Department, Faculty of Dentistry, Cairo University, Egypt.
3. Lecturer of Prosthodontics Department, Faculty of Dentistry, Cairo University, Egypt.
Corresponding author: Mohamed Amr El Khashab, email: mohamed.elkhashab@dentistry.cu.edu.eg

Introduction

Several implant impression techniques have been employed to produce a definitive cast for accurately fabricating an implant restoration. As of now, the standard treatment approach for complete-arch implant restorations involves taking the implant impression with elastomeric impression materials conventionally, obtaining a master cast, digitizing it with a laboratory scanner, and then proceeding with the digital production steps. Unlike tooth impressions, implant impressions face inherent challenges due to possible displacement of components, given that impression copings are connected to implants or replicas.[1] As a result, impressions involving multiple implants may accumulate greater errors compared to impressions of single implants.[2,3]

The introduction of the optical scanning technology has greatly influenced the data acquisition concept in prosthodontics. Intra-oral scanning has simplified the impression procedure by reducing the patient discomfort and the number of production steps[4]. This enhances precision, reduces treatment time, and ultimately results in better restoration fit compared to conventional impressions.[5–7]The use of scan bodies allowed to capture the 3d positions of the dental implants and transferring them to the digital systems. However, the accuracy of intraoral scanners tends to decrease as the size of the area to be scanned increases. As a result, while intraoral scanners are a suitable alternative to conventional impressions for partial arches, they still pose challenges for complete-arch impressions,[8] although certain devices have demonstrated comparable results.[9,10]

Different digital intraoral impression systems utilize various scanning technologies.[11] Regardless of the technology employed, all intraoral digital scanners generate 3D models by capturing multiple images from the oral cavity and stitching them together. The stitching process is critical, as it involves a best-fit alignment where several errors may arise, potentially compromising accuracy.[3,12]The accuracy of intraoral scanning is influenced by numerous factors, contributing to the varying findings and wide range reported in the literature. These factors include operator experience, intraoral conditions and strategy, interimplant distance and angulations, as well as the types of scan bodies used.[13] Furthermore, additional studies have indicated that the accuracy of intraoral scanners may decrease in clinical conditions due to patient-specific factors such as anatomical restrictions, movement, saliva, and soft tissue, all of which impact the accuracy of scans.[14,15]

The precision of intraoral scanners (IOS) when used for scanning edentulous complete arches with scan bodies is crucial for the fabrication of implant-supported prostheses. Numerous studies have explored the accuracy of various types of IOS in this context, employing different impression techniques and assessment standards. Several studies[9,16–18] evaluated the accuracy of scanning 4 or more implants in an edentulous mandibular model and concluded that the accuracy of the intraoral scanner was comparable with that of the conventional direct implant impression technique. Conversely Kim et al [19] found that conventional full-arch polyvinyl siloxane impressions exhibited higher accuracy compared to different intraoral scanners. The precise positioning and orientation of the scan bodies significantly influence the accuracy of complete arch scanning. In situations involving edentulous arches, achieving precise alignment of digital scans can be more challenging due to the larger mucosal surface area with fewer distinguishing features. Even minor discrepancies in the placement of scan bodies can result in misfitting frameworks at the platform level, thereby jeopardizing the fit and functionality of the implant-supported prosthesis[20].

In previous studies, the accuracy of digital scans was assessed by digitizing the master model with scan bodies using a high-resolution industrial scanner. Subsequently, digital images obtained from intraoral scanners were superimposed on the digital image of the master model using the best-fit method. It's worth noting that the best-fit method inherently includes superimposition errors.[15] As a result, it is recommended for evaluating only partial-arch models to minimize the accumulation of superimposition errors.

Previous studies have evaluated the accuracy of digital scans by digitizing a master model with scan bodies using a high-resolution industrial scanner. Subsequently, digital images acquired from intraoral scanners were superimposed onto the digital image of the master model using the best-fit method[16,21,22]. It's important to note that the best-fit method inherently introduces superimposition errors. Therefore, this technique is recommended to assess only partial-arch models to minimize the accumulation of these superimposition errors.

The lack of accuracy in the definitive cast can lead to potential prosthesis misfit,[23] which cannot be compensated by peri-implant tissues as with natural teeth and periodontium. This may result in various restorative complications, such as screw, ceramic, or implant fracture, peri-implant bone loss or even implant failure.[24,25]While there have been numerous studies investigating the accuracy and precision of IOS in the literature, none of them have evaluated the marginal accuracy of the finished restoration. Hence, the aim of the current study was to evaluate the fit accuracy of full arch implant supported zirconia restorations manufactured by digital scanning versus conventional impression technique. The null hypothesis suggests that there will be no difference in the marginal gap distance between the restorations fabricated using 4 different IOS and the conventional impression technique.

Materials and methods

A mandibular epoxy resin cast (SEL models, Barcelona Spain) was fabricated to simulate a clinical condition of a completely edentulous mandibular arch restored with an implant supported full arch restoration. To replicate the 'All on four' concept, four dental implants (J Dental implant, Italy) were placed using a milling dental surveyor. This included two implants at the canine sites and two implants at the molar sites with a diameter of 4.1 mm. Following the implant insertion, each implant received a multi-unit abutment screwed at a torque of 10 N. A total of 25 zirconia oxide full arch restorations were fabricated for this study. According to a previous study,[26] the minimally accepted sample size was 5 per group, when mean ± standard deviation of precision in the study group was 35.5 ± 11.1 while estimated mean difference with the comparator was 20, when the power was 80 % & type I error probability was 0.05. The paired t test was performed by using P.S.power3.1.6. In Group 1(G1) twenty milled frameworks were fabricated using 4 digital intraoral scanners (CEREC Primescan(G1P), CEREC Omnicom(G1O), Medit i700(G1M), and 3Shape Trios 4(G1T)), while in Group 2 (G2) five conventional frameworks were fabricated using a conventional open tray impression technique.

Group 1 implant restorations were designed and fabricated after scanning the metal scan bodies (JD ScanBody, JDental, Italy) which were screwed to the 4 implants by hand tightening (Fig 1) . The model was scanned using all studied intra-oral optical scanners. All intra oral scanners were calibrated immediately prior to the initiation of the scans and performed by a single operator who had 5 years of experience in intraoral scanning. The scans were conducted according to the manufacturer's recommended scan strategy. This involved starting from the palatal surface and then rolling towards the occlusal surface of the area of the first molar on one side, which corresponds to the most distal implant. The scanning continued towards the first left molar on the opposite side, corresponding to the most mesial implant. Throughout the process, scanning was performed horizontally, with care taken to avoid rotating the intraoral scanner in the vertical direction. This technique was performed for Primescan, Trios 4 and Medit i700. While for CEREC Omnicam, wavy or S sweep motion on vestibular, occlusal and lingual surfaces of each scan-body was executed (Fig 2). The scanning was repeated 5 times for each scanner to generate 20 scans for the same resin cast. The resultant scans were exported as standard tessellation language (STL) files.

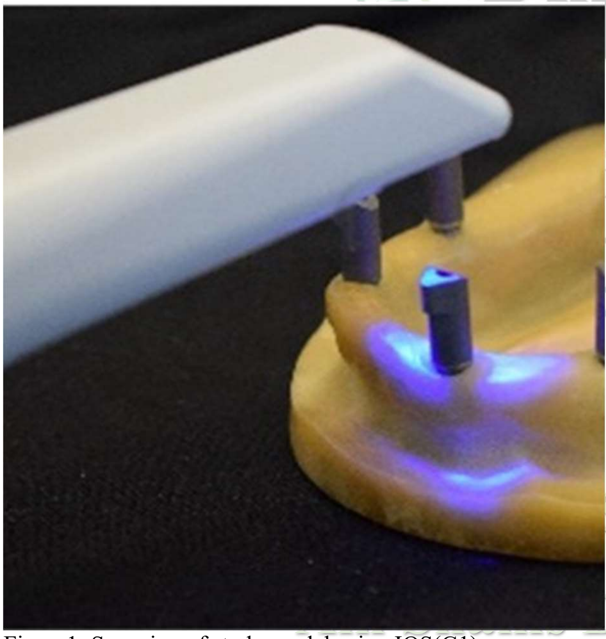

Figure1: Scanning of study model using IOS(G1)

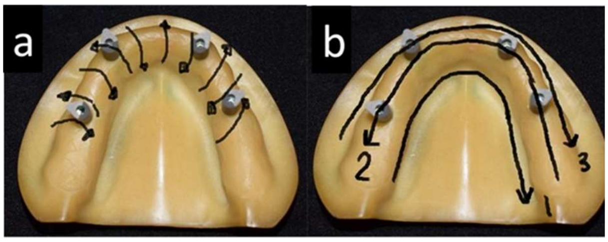

Figure 2: (a) Wavy scanning technique (b) Continuous scanning technique

Group 2 involved 5 zirconia oxide full arch restorations fabricated after attaching 4 open tray impression transfers (Impression coping open tray 4.0 H 3.0, JDEvolution Plus+) to the study model according to the manufacturer's instructions. All 4 implant transfers were connected using dental floss and splinted together using inlay pattern resin (Duralay, Reliance, USA) (fig 3). Inorder to reduce the polymerization shrinkage of the whole assembly, fully cured resin segments were sliced and reattached between adjacent implants. Five splinted open-tray conventional impressions were carried out using a customized self-cured acrylic resin tray and Poly vinyl siloxane putty and light consistencies (Zhermack Elite, Italy). After attaching the corresponding implant analogues, the implant impressions were poured into type 4 dental stone models and digitized using a desktop scanner (Medit T300, Medit, Korea) for the fabrication of 5 full arch restorations.

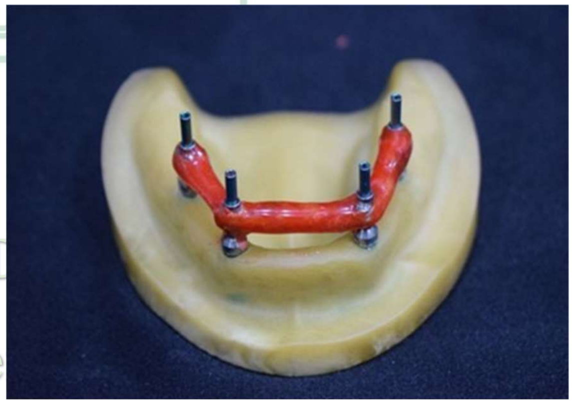

Figure 3: Duralay resin splint for open tray impression technique(G2)

The STL files were imported and designed on the bar module of a specialized design software, (DentalCAD 2.3 Matera, Exocad GmbH, Darmstadt, Germany). The designed bars were milled using 5-axis milling machine (Vhf 5s, Germany) from pre-sintered zirconia blancs(DD cubex-Dental Direkt zirconia). The final restoration were cemented to the metal sleeves of the corresponding multiunit abutments using self-adhesive resin cement (Ot Cem dual cure composite cement, Rhein 83, Italy) after sandblasting the metal sleeves and applying surface treatment to the zirconia bars.

The completed restorations from both groups underwent individual assessment for fit and passivity using the single screw test, following the methodology outlined by Sahin and Cehreli[27]. This technique involved initially screwing the most distal abutment of each framework and observing for any signs of lifting on the opposite side, which would indicate a lack of passivity. Detection of any gap was performed using a probe under suitable lighting conditions (fig4). If the framework remained stable without any lifting, the middle screw was then tightened, and this process continued sequentially for the remaining screws. This stepwise approach ensured thorough evaluation and adjustment of each screw to achieve optimal fit and passivity of the restoration.

Figure 4: Checking marginal gap distance using dental explorer

Following the recommended technique by Rutkunas et al[28] all screws were tightened over the multiunit abutment to ensure an active fit. Subsequently, each specimen was photographed using a USB Digital microscope equipped with a built-in camera (U500x Digital Microscope, Guangdong, China). The photographs were captured at maximum resolution (2272 × 1704 pixels) and transferred to an IBM compatible personal computer. The microscope maintained a fixed magnification of 40X during image acquisition, resulting in images with a resolution of 1280 × 1024 pixels each. For gap width measurement and evaluation, a digital image analysis system (Image J 1.43U, National Institute of Health, USA) was employed. In Image J, all dimensions and parameters are initially expressed in pixels. To convert these pixel measurements into real-world units, system calibration was performed. This calibration involved comparing a ruler with a scale generated by the Image J software. Images of the margins were taken for each specimen, and morphometric measurements were conducted at specific points—four equidistant landmarks along the circumference of each surface (fig 5). Each measurement point was assessed three times to ensure accuracy and reliability. The resulting data were then collected, tabulated, and subjected to subsequent statistical analysis.

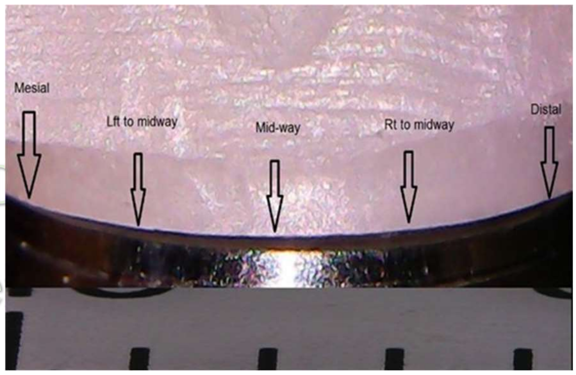

Figure 5: Digital image obtained from stereomicroscope with detection of measuring points

Statistical analysis

Statistical analysis was performed with SPSS 20®, Graph Pad Prism®, and Microsoft Excel 2016. All quantitative data were presented as minimum, maximum, mean, and standard deviation. Shapiro Wilk and Kolmogorov were used for normality exploration. One-Way ANOVA test to compare between all groups, followed by Tukey`s Post-Hoc test for multiple comparisons.

Results

In the current study, it was found that the significance level (P-value) exceeded 0.05, indicating that all the data followed a normal distribution (parametric data). This normal distribution is characterized by the familiar bell curve shape observed across all groups in the investigation. Generally speaking, all finished frameworks were considered passively seated over their corresponding implants in all groups using the one-screw test. The minimum, maximum, mean, and standard deviation of the 4 implants within each group were studied (table 1). Group 1A (Prime scan) and Group 1M (Medit i700) revealed an insignificant difference in the gap distance between the 4 implants as P=0.53 and P=0.67 respectively. However, the similar comparison revealed statistically significant gap distance in Group 1O (Cerec Omnicam) and Group 2 (conventional impression) at the right canine (39.37 ± 11.03), (57.75 ± 8.85) respectively, while at the left canine in Group 1T (3Shape Trios4) with a gap distance of (31.45 ± 5.77).

The comparison between G1 and G2 revealed a statistically significant difference in the overall gap distance favoring G1. Where G2 showed an overall gap distance of (42.63) followed by G1T (24.11), G1M (23.59), G1O (22.79), G1P (10.29). Studying the gap distance at each implant individually revealed the least gap distance at all implant sites in G1P followed by G1O except at right canine and the largest gap distance at all implant sites in G2. G1M showed the largest gap distance among IOS at right and left molar followed by G1T. While G1T showed the largest gap distance among all IOS at the left canine in followed by G1M.

Table 1: Mean and standard deviation of right and left molar and premolar gap distance (µm) in all groups and comparison between them.

Side	G1								G2 Impression		P value
	G1 P CEREC Primescan		G1 O Cerec Omnicam		G1 M Medit i700		G1 T 3 shape trios4				
	M	SD	M	SD	M	SD	M	SD	M	SD	
Left molar	9.33^{a}	2.14	16.12^{a}	5.61	21.63^{b}	5.16	20.08^{b}	2.89	38.71^{c}	7.81	0.0001*
Left canine	11.17^{a}	3.09	17.38^{a}	5.64	25.79^{b}	6.87	31.45^{b}	5.77	34.97^{b}	8.47	0.004*
Right canine	9.45^{a}	2.02	39.37^{b}	11.03	23.60^{a}	3.79	21.94^{a}	6.85	57.75^{c}	8.85	<0.0001*
Right molar	11.17^{a}	3.08	18.28^{a}	4.85	23.36^{a}	4.82	22.97^{a}	7.19	39.11^{b}	9.48	0.0003*
Overall	10.29^{a}	2.18	22.79^{b}	5.86	23.59^{b}	2.25	24.11^{b}	4.34	42.63^{c}	4.31	<0.0001*

M: mean, SD: standard deviation, Ns: non-significant as P>0.05. * Significant difference as P<0.05
Means with the same superscript letters were insignificantly different as P>0.05.

Discussion

The primary aim of this invitro study was to evaluate the fit accuracy of 4 intraoral scanners for the fabrication of full arch implant supported restorations. There is a wealth of evidence suggesting that while we can accurately capture and generate reliable digital models for dental restorations, our understanding of their accuracy across the wide array of commercially available devices remains limited. Some research indicates that intraoral scanners have the potential to replace traditional impressions for teeth and implant restorations. However, it remains uncertain whether digital scanners can universally replace conventional impressions in all clinical scenarios.[8]

The study's findings revealed that the initial hypothesis, which proposed no difference in the marginal gap distance between restorations made using four different intraoral scanners and conventional impression methods, was rejected. All tested restorations were considered clinically acceptable when subjected to one screw test representing a misfit less than 150um.[29] However, the full digitally fabricated restorations exhibited a significantly lower marginal gap distance compared to those of the conventional impression technique. These results align with the results of a recent systematic review and meta-analysis [10] which concluded that digital impressions using IOS present similar or better linear accuracy than conventional impression techniques. Kosago et al reported the highest 3D deviation values were found in the conventional splint open-tray impression technique when compared with other digital techniques.[17] Similar findings were reported in studies focusing on single implant restorations,[13,30] demonstrating superior precision with digital impressions. In contrast, Huang et al[31] and others[9,19] reported that conventional impressions, taken on abutment level, were superior compared to intra-oral scanning. Others suggested that digital impressions offer comparable levels of accuracy to conventional impressions.[11,18]

Discrepancies among different studies may stem from variations in experimental settings, impression techniques, data analysis methods, and intraoral scanner capabilities. Additionally, differences in scanner technology, including the number of cloud points, and variations in hardware and software algorithms, particularly the mesh algorithms that dictate surface precision, may influence overall accuracy. Although each scanner manufacturer provides specific scanning protocols for clinicians to follow, they typically do not specify the starting quadrant for full arch restorations. This lack of specification can lead to cumulative errors during scanning, especially if local errors occur. These errors can become more pronounced during the stitching process as the scanning progresses towards and along the curved sections of the arch.[3,22]

In the current study, it was observed that the middle-placed implants (i.e., in the canine regions) showed the highest marginal gap values in CEREC Omnicom and 3 shape trios 4 while Medit I700 showed the greatest deviation in the most posterior implants. Various authors reported that the accuracy of intraoral scans are influenced by the scanning sequence, Diker reported more errors with TRIOS in the molar region opposite to the starting point, while other scanners as Itero showed no difference.[32] Renne et al. observed that when scanning a maxillary full-arch implant-supported prosthesis, the first scanned scan body in the scanning path (i.e., the scan body in the molar area) shows a higher angular deviation than scan bodies on other implants, which aligns with the results of Medit I700 of the current study.[33] It is worth noting that some studies highlighted the effect of the scanning distance where longer scans showed less accurate results with digital impressions while no effect on conventional ones.[13,34]

The results of CEREC Primescan showed the lowest overall gap distance among the 4 studied IOS with a statistically significant difference. These results comes in agreement with Ivett et al., who compared the accuracy of 12 different intraoral scanners and found that the most accurate IOS was the CEREC Primescan.[35] Newer generations of intraoral scanners provides higher accuracy for full-arch scanning than the previous versions. The Cerec Primescan has an automatic lens that enables scanning of deep regions and inclined areas up to 30mm with various levels of scanning with the same high resolution, this allows simple and precise scanning of fully edentulous arches with few anatomical landmarks. [36]

The absence of significant difference in gap distance between CEREC Omnicom, TRIOS4, and Medit i700 in the current study aligns with Kurtulmus et al., who found no significant difference in accuracy between Medit and Cerec Omnicam. This can be explained by the fact that Medit and Omnicam employed the same scanning technique (active triangulation) and data-collecting strategy.[37] Studies[7,32,38] comparing different IOS reported that Primescan outperforms Trios 4 in terms of accuracy, which supports the findings of the current study. However, others demonstrate contradictory results, where Mangano et al [39] compared the trueness of 12 scanners in capturing 6 implant positions in maxillary full arches, according to the study results Medit i500 ranked the first followed by Trios 3, Primescan, and Virtuo Vivo. Additionally, Alpkılıç et al [40] compared five IOS devices (CS3600, Emerald S, Primescan, Trios 3, Trios 4) in a model featuring seven axial implants and found that Trios 4 exhibited the highest accuracy, followed by Trios 3 and Primescan. Revell et al. [7] found that when evaluating the trueness of 5 different intraoral scanners for complete-arch implant scanning, there was no significant difference between the Primescan and 3 shape Trios, while showed a higher deviation for the Medit i500. However it is worth noting that this was a vivo study and its results are liable to be affected by the oral environment. These discrepancies in rankings could stem from variations in the model used, materials employed, or specific brands of implants assessed in each study. Additionally, it has been demonstrated that differences in software versions within IOS, similar to variations in models, can impact the accuracy and precision of digital scans.[41]

Limitations of the current study include the fact that scan bodies were used for data acquisition and different marginal gap measurements obtained may not be related to the difference in scanning technologies but rather to implant abutment interface as a result of mesh errors in the structure of the multiunit virtual files supplied by manufacturing company. Additionally, very high marginal gap point discrepancies were observed with no pattern of repetition, which were believed to be related to the chipping of zirconia during milling procedures however, these readings were excluded using statistical package for social science.

Conclusions

Within the limitations of our in vitro study, it was concluded that:

1. Intraoral scanners can be used efficiently in cross-arch implant restoration impressions using scan bodies.
2. CEREC Primescan proved to be higher in precision than other tested intraoral scanners.
3. Digital implant-supported restorations workflow can replace conventional implant-supported workflow in daily practice.

Funding

This study was self-funded

Data Availability

The raw or processed data necessary to replicate the findings cannot be disclosed at this moment because they are part of an ongoing study.

Ethical approval

This study was approved by the Research Ethics Committee, Faculty of Dentistry, Cairo University (35-9-20).

Competing interests

The authors declare that they have no competing interests.

References

1. Papaspyridakos P, Chen CJ, Gallucci G, Doukoudakis A, Weber HP, Chronopoulos V. Accuracy of Implant Impressions for Partially and Completely Edentulous Patients: A Systematic Review. Int J Oral Maxillofac Implants. 2014;29(4):836–45.
2. Balkenhol M, Haunschild S, Erbe C, Wöstmann B. Influence of prolonged setting time on permanent deformation of elastomeric impression materials. J Prosthet Dent. 2010 May;103(5):288–94.
3. Fukazawa S, Odaira C, Kondo H. Investigation of accuracy and reproducibility of abutment position by intraoral scanners. J Prosthodont Res. 2017 Oct;61(4):450–9.
4. Menini M, Setti P, Pera F, Pera P, Pesce P. Accuracy of multi-unit implant impression: Traditional techniques versus a digital procedure. Clin Oral Investig. 2018 Apr;22(3):1253–62.
5. Gamal RM, El Said SM, Ibrahim RM. Clinical Study Comparing The Internal Adaptation And Marginal Fit Of All-Ceramic Zirconia Fixed Restorations Obtained From Conventional And Digital Intra oral Impression Techniques. (Randomized Controlled Clinical Trial). Ain Shams Dent J. 2020;20(4):60–9.
6. Rech-Ortega C, Fernández-Estevan L, Solá-Ruíz MF, Agustín-Panadero R, Labaig-Rueda C. Comparative in vitro study of the accuracy of impression techniques for dental implants: Direct

technique with an elastomeric impression material versus intraoral scanner. Medicina Oral Patologia Oral y Cirugia Bucal. 2019;24(1):89–95.
7. Revell G, Simon B, Mennito A, Evans ZP, Renne W, Ludlow M, et al. Evaluation of complete-arch implant scanning with 5 different intraoral scanners in terms of trueness and operator experience. J Prosthet Dent. 2022;128(4):632–8.
8. Bohner L, Gamba DD, Hanisch M, Marcio BS, Tortamano Neto P, Laganá DC, et al. Accuracy of digital technologies for the scanning of facial, skeletal, and intraoral tissues: A systematic review. J Prosthet Dent. 2019 Feb 1;121(2):246–51.
9. D'haese R, Vrombaut T, Roeykens H, Vandeweghe S. In Vitro Accuracy of Digital and Conventional Impressions for Full-Arch Implant-Supported Prostheses. J Clin Med. 2022;11(3).
10. Floriani F, Lopes GC, Cabrera A, Duarte W, Zoidis P, Oliveira D, et al. Linear Accuracy of Intraoral Scanners for Full-Arch Impressions of Implant-Supported Prostheses: A Systematic Review and Meta-Analysis. Eur J Dent. 2023;17(4):964–73.
11. Papaspyridakos P, Gallucci GO, Chen CJ, Hanssen S, Naert I, Vandenberghe B. Digital versus conventional implant impressions for edentulous patients: Accuracy outcomes. Clin Oral Implants Res. 2016 Apr;27(4):465–72.
12. Ender A, Mehl A. Influence of scanning strategies on the accuracy of digital intraoral scanning systems. Int J Comput Dent. 2013;16(1):11–21.
13. Tan M, Yee S, Wong K, Tan Y, Tan K. Comparison of Three-Dimensional Accuracy of Digital and Conventional Implant Impressions: Effect of Interimplant Distance in an Edentulous Arch. Int J Oral Maxillofac Implants. 2019;34(2):366–80.
14. Rutkunas V, Gedrimiene A, Akulauskas M, Fehmer V, Sailer I, Jegelevicius D. In vitro and in vivo accuracy of full-arch digital implant impressions. Clin Oral Implants Res. 2021 Dec;32(12):1444–54.
15. Güth JF, Edelhoff D, Schweiger J, Keul C. A new method for the evaluation of the accuracy of full-arch digital impressions in vitro. Clin Oral Investig. 2016 Sep;20(7):1487–94.
16. Keul C, Güth JF. Accuracy of full-arch digital impressions: an in vitro and in vivo comparison. Clin Oral Investig. 2020;24(2):735–45.
17. Kosago P, Ungurawasaporn C, Kukiattrakoon B. Comparison of the accuracy between conventional and various digital implant impressions for an implant-supported mandibular complete arch-fixed prosthesis: An in vitro study. J Prosthodont. 2023 Aug 1;32(7):616–24.
18. Nedelcu R, Olsson P, Nyström I, Rydén J, Thor A. Accuracy and precision of 3 intraoral scanners and accuracy of conventional impressions: A novel in vivo analysis method. J Dent. 2018;69:110–8.
19. Kim KR, Seo K young, Kim S. Conventional open-tray impression versus intraoral digital scan for implant-level complete-arch impression. Vol. 122, Journal of Prosthetic Dentistry. 2019;122(6):543–9.
20. Elifnur Güzelce Sultanoğlu BKE. Comparison of the Accuracy and Precision in Digital Scans for Implant-Supported Maxillary Hybrid Prosthesis: In Vitro Study. Research Square. 2023.
21. Albayrak B, Sukotjo C, Wee AG, Korkmaz İH, Bayındır F. Three-Dimensional Accuracy of Conventional Versus Digital Complete Arch Implant Impressions. J Prosthodont. 2021 Feb;30(2):163–70.
22. Ender A, Attin T, Mehl A. In vivo precision of conventional and digital methods of obtaining complete-arch dental impressions. J Prosthet Dent. 2016 Mar 1;115(3):313–20.
23. Maged ARM, Nawar NHH, Eid H, Shawky YM. Clinical Evaluation of the Effect of two Resilient Attachments Retaining Mandibular Over-Denture Supported by Implant and Natural Tooth on the Supporting Structures. Ain Shams Dent J. 2024;34(2):1–13.
24. Ismail J, Radi IAEW, Nassouhy NMH, ElKahsab MA. Effect of Smoking on Dental Implant Failure: A Systematic Review. Ain Shams Dent J. 2021;23(3):86–111.
25. Brandt J, Lauer HC, Peter T, Brandt S. Digital process for an implant-supported fixed dental prosthesis: A clinical report. J Prosthet Dent. 2015;114(4):469–73.
26.Treesh J, Liacouras P, Taft R, Brooks D, Raiciulescu S, Ellert D, et al. Complete-arch accuracy of intraoral scanners. J Prosthet Dent. 2018 Apr 1;120.
27. Sahin S, Çehreli MC. The Significance of Passive Framework Fit in Implant Prosthodontics: Current Status. Implant Dent. 2001;10(2):85–92.
28. Rutkunas V, Dirse J, Kules D, Simonaitis T. Misfit simulation on implant prostheses with different combinations of engaging and nonengaging titanium bases. Part 1: Stereomicroscopic assessment of the active and passive fit. J Prosthet Dent. 2023;129(4):589–96.
29. Wulfman C, Naveau A, Rignon-Bret C. Digital scanning for complete-arch implant-supported restorations: A systematic review. J Prosthet Dent. 2020 Aug 1;124(2):161–7.
30. Amin S, Weber HP, Finkelman M, El Rafie K, Kudara Y, Papaspyridakos P. Digital vs. conventional full-arch implant impressions: A comparative study. Clin Oral Implants Res. 2017;28(11):1360–7.
31. Huang R, Liu Y, Huang B, Zhang C, Chen Z, Li Z. Improved scanning accuracy with newly designed scan bodies: An in vitro study comparing digital versus conventional impression techniques for complete-arch implant rehabilitation. Clin Oral Implants Res. 2020;31(7):625–33.

32. Diker B, Tak Ö. Accuracy of six intraoral scanners for scanning complete-arch and 4-unit fixed partial dentures: An in vitro study. J Prosthet Dent. 2022;128(2):187–94.
33. Renne W, Ludlow M, Fryml J, Schurch Z, Mennito A, Kessler R, et al. Evaluation of the accuracy of 7 digital scanners: An in vitro analysis based on 3-dimensional comparisons. J Prosthet Dent. 2017;118(1):36–42.
34. Giménez B, Özcan M, Martínez-Rus F, Pradíes G. Accuracy of a Digital Impression System Based on Active Triangulation Technology With Blue Light for Implants: Effect of Clinically Relevant Parameters. Implant Dent. 2015;24(5).
35. Ivett DR, Judit DB, Péter DH, Bálint DV. Digital intraoral scanner devices- validation study based on common evaluation criteria. J Dent. 2022;121:103964.
36. Gurpinar B, Tak O. Effect of pulp chamber depth on the accuracy of endocrown scans made with different intraoral scanners versus an industrial scanner: An in vitro study. J Prosthet Dent. 2022;127(3):430–7.
37. Kurtulmus-Yilmaz S, Ozan O, Ozcelik TB, Yagiz A. Digital evaluation of the accuracy of impression techniques and materials in angulated implants. J Dent. 2014;42(12):1551–9.
38. Nulty AB. A comparison of full arch trueness and precision of nine intra-oral digital scanners and four lab digital scanners. Dent J. 2021 Jun;9(7).
39. Mangano FG, Admakin O, Bonacina M, Lerner H, Rutkunas V, Mangano C. Trueness of 12 intraoral scanners in the full-arch implant impression: A comparative in vitro study. BMC Oral Health . 2020;20(1):263.
40. İşsever D, Değer S. Trueness Evaluation of Latest Generation of Intraoral Scanners on Complete-Arch Implant Impressions. Int J Prosthodont. 2023 Sep;36(4):e1–12.
41. Schmalzl J, Róth I, Borbély J, Hermann P, Vecsei B. The impact of software updates on accuracy of intraoral scanners. BMC Oral Health. 2023 Apr;23(1):219.