ACCURACY OF CONVENTIONAL VERSUS DIGITAL IMPRESSION TECHNIQUES IN CONSTRUCTION OF DIGITALLY PRINTED SURGICAL GUIDE (IN VITRO STUDY)

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ABSTRACT

INTRODUCTION: Currently, the basis of implant planning is medical imaging. One of the most important outcomes of computer-assisted surgery is the capacity to accurately insert implants in insufficient tissue. Drilling guides come in a range of sizes, ranging from first-drill simple guidance to full-navigated surgical guides that lead every drill in all three directions. An important step for implant effectiveness is the impression record. To date, the quality of optical impressions has been found by scientific literature to be scientifically satisfactory and comparable to that of conventional impressions.

OBJECTIVES: To assess the accuracy of conventional versus digital impression technique in constructing digitally printed surgical guide used for fully guided implant placement. In addition, to assess if there is a difference in the implants' positions between planned and post-operative location.

MATERIALS AND METHODS: Sixteen polyurethane mandibular models were initially scanned using CBCT. The scanned models were divided into 2 equal groups; Group I (study group, n=8): optical impression was used to scan the models and Group II (control group, n=8): conventional impression was used to duplicate the models. Surgical guide for both groups was 3D printed in acrylic resin in accordance with the planning program, followed by placement of eight implants per group. The pre- and post-operative CBCTs were then matched, and the difference between pre- and post-operative implant locations was calculated using the preparation software matching feature.

RESULTS: Optical impression performed by CEREC Primescan (AC, Sirona, Bensheim, Germany) is a more accurate intraoral scanner than the conventional impression process.

CONCLUSION: Intraoral scanner is more accurate than the conventional impression in constructing the surgical guide as well as in the implant positioning in relation to the pre-planned implant.

KEYWORDS: CAD/CAM, Digital Impression, Intraoral scanner, Implants, Surgical Guide, CBCT.

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INTRODUCTION

Implantology has a significant effect which allows dentists to improve their patients' quality of life. Implant-supported restorations became a popular treatment option for patients who are partly or entirely edentulous as fixed partial dentures require teeth preparation of the abutments causing irreversible removal of dental hard tissues which might cause weakening of the teeth or damage to the pulp-dentin complex, and removable dentures which are always accompanied by patient complaints regarding to denture instability and compromised esthetics (1).

The recent advances in implantology including guided surgery facilitated the development of an accurate three-dimensional (3D) implant positioning anatomically and prosthetically, through recording essential anatomic structures (such as nerves, arteries, and sinuses). Moreover, implants can be positioned in an optimum prosthetic-driven location, avoiding bone augmentation or sinus lifting operations (2-4). Furthermore, for a "prefabricated prosthesis," the final implant positioning can be so precise that an immediate loading routine can be planned (2-4).

Guided implant surgery is used for two purposes; precise planning aimed at improved placement of implants through a tomographic image and constructing a surgical guide for precise implant placement based on a predetermined location for an immediate prosthesis insertion (5, 6).

Diagnostic imaging is the core for guided surgery and implant planning. One of the key objectives of the surgical process is to correctly identify the fixture's location. Modern surgery is focused on advanced diagnostic technology that provides surgeons more detailed knowledge about the anatomy. This allows the surgeon to engage actively with a 3D reconstruction of the situation as well as a virtual surgery result to evaluate various surgical techniques prior to the actual procedure (3, 7, 8).

Consequently, the computer-generated treatment plan based on diagnostic imaging can be precisely applied through surgical guides. The primary goal of the surgical guide is to steer the implant drills and to permit proper position of implants in ideal position as pre-planned virtually. According to the amount of surgical restrictions offered by the surgical guide, the design of surgical guides may be non-limiting, partially limiting or completely limiting (9, 10). Completely limiting or fully guided design limits all the instruments used for the osteotomy in a buccolingual and mesiodistal plane. Moreover, the addition of drill stops limits the depth of the osteotomy (9, 10).

To fabricate an accurate surgical guide an accurate intraoral structure is needed. Polyvinyl siloxane (PVS) is known to be the most popular conventional impression material with excellent dimensional stability and accuracy. But many factors may cause distortion of the material and impair precision. These factors may include temperature changes, the time between making an impression and pouring it, the disinfection procedures, and wettability of the gypsum (11). To overcome dimensional changes in impression material and dental stone and to remove physical casts performed by conventional impression, impression with intraoral scanner (IOS) was developed for dental practice to digitally record the intraoral outline by an intraoral 3D acquisition unit to obtain direct optical impression (12, 13).

Optical impressions have many benefits over conventional impressions: including, reduced patient anxiety and discomfort, decreased distortion of impression materials, save time for the dentist, and shorten the clinical procedures, mainly for complicated impressions (in oral Implantology if multiple implants are present and/or in patients with undercuts). Furthermore, it can detect excessively moving tissues in a passive state (Mucostatic impression) and eradicate the need for plaster models, which saves space and time while still allowing for easier contact with the dental technician. Additionally, it improves interaction with patients and offers improved 3D previsualization of tooth preparations (14). However, since edentulous sites are flat and devoid of features, scanning them with IOSs can be tedious and time-consuming (15).

Possible differences between the pre and the postoperative implant position must be taken into consideration since they may have a major effect on vital clinical outcomes (5). These positions are evaluated as angular and linear deviations between the preplanned virtual implant axis and the actual implant. Linear variations are evaluated in two areas which are in the cervical and apical region of the implant (16). Fully guided implant surgery has less variation in implant deviations compared to partially guided surgery especially in the distal and angular deviation, respectively. This suggests that clinician should pay more attention to angular deviation and distal displacement of implant fixtures while partially guided protocol is employed (17). The amount of the difference between the proposed and actual implant direction may be influenced by various factors, such as the construction accuracy of the guide, the surgical accuracy when using these guides, the study models' accuracy, the stereolithographic machine accuracy, and the measurement accuracy (18, 19).

Dental prostheses made from intraoral optical impressions have demonstrated excellent benefits in different ways over conventional impressions, according to a few published articles (20, 21). The current study aims to assess the accuracy of implant placement via a digitally printed surgical guide constructed from two different impression techniques (Intraoral scanning and polyvinyl siloxane impression material. The null hypothesis of this research is that there is no difference in the construction of surgical guide between conventional impression and digital impression (22-24).

MATERIAL AND METHODS

Sixteen polyurethane mandibular models in total, Kennedy class I modification 1 (Hann Ru Enterprisem China) were used for implant placement at lower right second premolar region. All models were initially scanned using CBCT (Scanora 3DX Soredex, Helsinki, Filand) figure (1-A). The obtained radiograph was then used for implant placement planning using Blueskybio software LLC, (Illinois, USA) figure (1-B).

The scanned models were distributed into 2 equal groups: Group I (study group, n=8): Optical impression using CEREC Primescan (AC, Sirona, Bensheim, Germany) was used to scan the models according to manufacturer's instructions figure (1-C). Group II (control group, n=8): Conventional impression using addition silicone impression material (Express, 3M ESPE, USA) and stainless-steel stock trays (GC trays, Leuven, Germany) were used to record the model in a single stage technique figure (1-E). Impression was then poured using Class IV extra hard dental stone (Zhermack, S.P.A, Rovigo, Italy) figure (1-F). Stone cast was then digitalized using dedicated in-lab optical scanner (InEos X5 In-lab, Sirona, Bensheim, Germany) figure (2-A).

Surgical guides were designed using (Blueskybio, USA) software figure (2-B). Initially virtual setting of the teeth to identify the tooth position (prosthetically driven) followed by planning of the implant position, the guide's sleeve was designed according to manufacturer's instructions (4.95mm in diameter, and 9mm offset). Subsequently the STL files were sent to the lab and guides were 3D printed (Formlabs printer, MA, USA) in acrylic resin (Dental LT clear resin, formlabs, MA, USA) figure (2-C) in accordance with the planning software instructions. The surgical guide extends anteriorly from the lower left central incisor till the lower right canine and posteriorly over the ridge till the retromolar pad. Guides were then finished and adjusted to fit the models precisely.

A total of sixteen implants (C-TECH, Bologna, Italy) (3.5 mm width and 9 mm length) figure (2-D); eight per each group, were inserted using the previously printed surgical guides. Drilling was performed using the manufacturer guided surgical kit (C-TECH, Bologna, Italy). Implants were consecutively inserted through the surgical guide's pre-planned drilling holes. During drilling for implant placement, the surgical guide was totally supported by the anterior teeth as well the contralateral central incisor near the cross-arch concept with the distal extension of the guide on the lower central incisor which resists any possible dislodgment during osteotomy preparation, also it was placed in a tripod manner supported by the lower right canine, lower right lateral and lower left central.

After implants have been placed for both groups, an additional CBCT was obtained. Virtual implants were super-imposed on their previously pre-planned images figure (2-E). Both pre- and post-operative CBCTs were then matched using the planning software matching function. Following that, the difference between pre- and post-operative implant locations was calculated. Radial deviation is defined as the projection of the post-operative implant axis in millimeters on a plane perpendicular to the pre-operative implant axis, calculated at the level of the implant shoulder (shoulder radial deviation) and apically (apical radial deviation). The angle formed by the pre- and post-operative implant axes is called angular deviation figure (2-F).

Data Management and Statistical Analysis

Data were fed to the computer and analyzed using IBM SPSS software package version 20.0. (Armonk, NY: IBM Corp). The Kolmogorov-Smirnov test was used to verify the normality of distribution Quantitative data were described using range (minimum and maximum), mean, standard deviation, median and interquartile range (IQR). Significance of the obtained results was judged at the 5% level using Paired t-test for normally distributed quantitative variables.

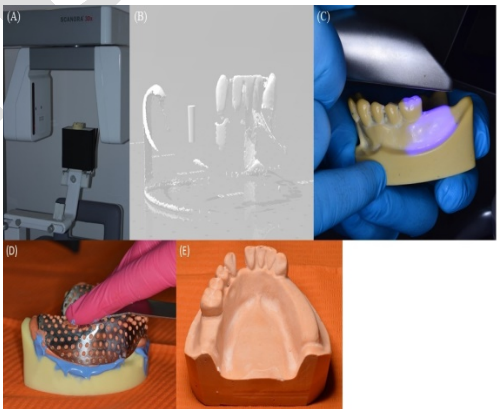

Figure (1): (A) shows cone beam computed tomography machine while scanning the model, (B) shows the preplanned implant position, (C) shows intraoral scanning of the model, (D) Conventional impression and stainless-steel stock trays were used to record the model in a single stage technique, (E) shows stone cast.

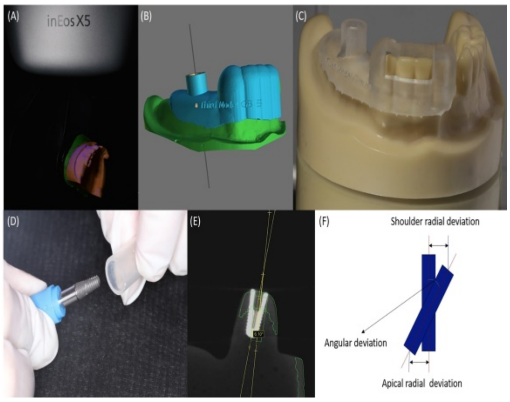

Figure (2): (A) shows In-lab optical scanner while scanning the model, (B) shows the designed surgical guide, (C) shows the printed surgical guide, (D) shows dummy dental implants (3.5 mm width and 9 mm length), (E) shows superimposition of the postoperative implant with the preoperative planned implant, (F) shows the measurement technique.

RESULTS

The accuracy of digital impression versus conventional impression was evaluated by superimposing the post-operative implant to the pre-operative implant using Blueskybio LLC (Illinoise, USA) software, the following results were conducted. A significant difference in the mesiodistal angular deviation between both groups as it decreased by 57.6% for the digital impression compared to the control group (Table 1 Figure 3). On the other hand, there was there was no significant difference in the buccolingual angular deviation between both groups, however, it increased by 46.6% in the study group compared to the control group (Table 1 Figure 3). The angular deviation in general decreased by 1.9% in the study group compared to the control group but the differences were not significant (Table 1 Figure 3). The mesiodistal shoulder deviation in the study group decreased by 100% when compared to the control group, therefore the differences between both groups were statistically significant (Table 2 Figure 4). In addition, a significant difference was found in the buccolingual shoulder deviation in the study group as it decreased by 67.9% when compared to the control group (Table 2 Figure 4). The shoulder deviation in general decreased by 71.8% in the study group when compared to the control group and the differences between both groups were statistically significant (Table 2 Figure 4). Regarding the mesiodistal apical deviation there was statistically significant difference between both groups as it decreased by 65.8% in the study group when compared to the control group (Table 3 Figure 4). The buccolingual apical deviation in the study group decreased by 36.3% when compared to the control group. The apical deviation in general in the study group decreased by 44.3% when compared to the control group, therefore the differences between both groups were statistically significant (Table 3 Figure 4).

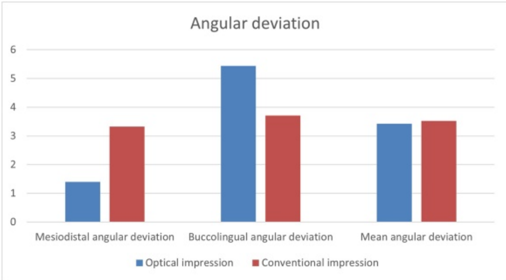

Figure (3): shows angular deviation (mesiodistal, buccolingual, and mean angular deviations).

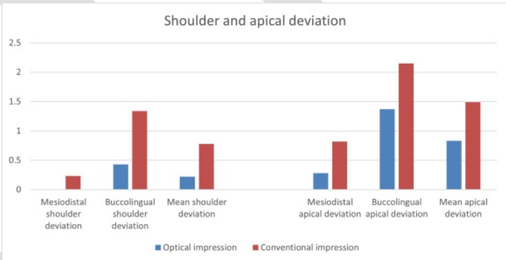

Figure (4): shows shoulder and apical deviation (mesiodistal, buccolingual, and mean shoulder/apical deviations).

Table 1: Comparison of mesio-distal, buccolingual, and mean angular deviation between the study and control group.

Angular deviation		Optical impression (Study group) (n=8)	Conventional impression (Control group) (n=8)
Mesiodistal angular deviation	Mean (SD)	1.40 (1.20)	3.33 (1.57)
	Median	1.21	3.81
	Min-Max	0 – 3.27	0.72 – 5.03
	P value	0.021*	
Buccolingual angular deviation	Mean (SD)	5.44 (1.96)	3.71 (2.51)
	Median	5.27	2.77
	Min-Max	3.43 – 9.61	0.99 – 6.95
	P value	0.248*	
Mean angular deviation	Mean (SD)	3.42 (1.09)	3.52 (1.78)
	Median	3.46	2.80
	Min-Max	1.96 – 5.18	1.29 – 5.75
	P value	0.834	

*Statistically significant difference at p value≤0.05

Table 2: Comparison of mesio-distal, buccolingual and mean shoulder deviation between the study and control group.

Shoulder deviation		Optical impression (Study group) (n=8)	Conventional impression (Control group) (n=8)
Mesiodistal shoulder deviation	Mean (SD)	0.00 (0.00)	0.23 (0.32)
	Median	0.00	0.00
	Min-Max	0.00 – 0.00	0.00 – 0.71
	P value	0.064	
Buccolingual shoulder deviation	Mean (SD)	0.43 (0.61)	1.34 (0.93)
	Median	0.12	1.38
	Min-Max	0.00 – 1.77	0.00 – 2.49
	P value	0.052	
Mean shoulder deviation	Mean (SD)	0.22 (0.30)	0.78 (0.44)
	Median	0.06	0.91
	Min-Max	0.00 – 0.89	0.00 – 1.25
	P value	0.031*	

*Statistically significant difference at p value≤0.05

Table 3: Comparison of mesiodistal, buccolingual, and mean apical deviation between the study and control group.

Apical deviation		Optical impression (Study group) (n=8)	Conventional impression (Control group) (n=8)
Mesiodistal apical deviation	Mean (SD)	0.28 (0.31)	0.82 (0.22)
	Median	0.23	0.74
	Min-Max	0.00 – 0.69	0.63 – 1.26
	P value	0.003*	
Buccolingual apical deviation	Mean (SD)	1.37 (0.70)	2.15 (1.36)
	Median	1.24	2.20
	Min-Max	0.56 – 2.94	0.00 – 4.11
	P value	0.294	
Mean apical deviation	Mean (SD)	0.83 (0.32)	1.49 (0.42)
	Median	0.70	1.43
	Min-Max	0.52 – 1.47	0.63 – 2.42
	P value	0.036*	

DISCUSSION

Advances in CAD/CAM technology and digital IOSs have enabled a full digital framework for prosthetic rehabilitations that has eliminated the impression taking process as well as all conventional dental casts in the last few years. Several studies compared the accuracy of IOSs to conventional impressions, highlighting several limitations in intraoral conditions, especially in the retromolar region (4, 25). In the literature, there is no clear agreement on which scheme is more accurate: Some authors report improved results for the conventional system, while others report comparable or even better results for the digital system (25-29).

Computed tomography (CT) scanning is an important tool for implant patients, particularly where there are anatomical limitations, inadequate bone lengths, or insufficient bone density. As opposed to traditional radiographic methods, CT imaging improved the correlation between implant planning and actual implant placement (3). The implementation of CAM of anatomic models and surgical guides based on CAD images has allowed for detailed transition of planning information to implant placement. In terms of 3D determination of the patient's jaw structure and construction of both anatomical models and surgical guides, the combination of CAD and CAM techniques provides some advantages for implant planning and positioning (9).

The principle of direct surgical procedure result in deviations between the implant locations expected and clinically positioned. The total precision of the positioning of the implant is the amount of all mistakes occurring during the treatment process. While deviations that are likely to occur at each point are difficult to identify, it is necessary for dentists to learn to what degree the deviations occur between the virtually planned implant positions and the clinically positioned implant, to prevent anatomical hazards, as well as for final prosthetic reconstruction. Accuracy is also a major concern, especially when a prefabricated prosthesis is delivered immediately (19).

The models chosen for this study were a Kennedy’s class I modification 1. Tooth and implant supported removable partial denture (RPD) will be the economic treatment plan for this case. Implants would be positioned in lower second premolar and lower first molar for better stability and less financial recourses (30). Previous studies reported that the tooth supported surgical guides were more superior in accuracy while there is shortage in literature studying accuracy of optical impressions on free-end saddles (31).

Polyurethane foam resin models were selected for its structure and its close resemblance to natural bone that duplicates type II〜III hardness to simulate drilling in natural bone before implant placement. It has elastomeric properties as well as physical and mechanical properties similar to human bone (32).

For implant planning, Blueskybio software was the software of choice as it is one of the most popular programs as well as it is a free implant treatment planning software for download. It supported 3D image building facilities, precise and simpler superimposition than other applications, and simple angular measurements (33). The surgical guide was developed entirely by Blueskybio and exported directly as Standard tessellation language (STL) prototyping file.

For 3D printing of the surgical guide, Stereolithographic (SLA) technology was used for 3D printing in this study which is the most common technology used in dental field. With SLA printing, a laser must draw out each of these layers, and this was considered time consuming. Nevertheless, it gives good accuracy and smooth surfaces (7).

The surgical guide's main function is to direct the implant drilling process to ensure that the implant is properly positioned in accordance with the surgical treatment plan. For the precise transition of the plan to the operating site, customized conventional radiographic or computer image guided surgical guides have become the treatment of choice (6).

In the current study, it was found that the optical impression offered more accurate results compared to conventional impression. We found that the buccolingual angular deviation was higher for the IOS than the mesiodistal angular deviation. This may be due to intrinsic sources that arise from individual mistakes, such as problems regarding radiographic accuracy, file translation, CAD software, and mechanical component tolerance; and extrinsic sources, such as surgical guide fit, mucosal width at the surgical field, the site of the edentulous region, and the surgeon's experience. The buildup of individual mistakes generates the overall difference between pre-planned and postoperative conclusions(34).

When the surgical guide's sleeve restricts the drill's blade portion, a certain amount of gap is inevitable to enable the drill to rotate within the sleeve (35). Essentially, it is important to use the drill in a centric orientation and parallel to the internal wall of the sleeve to improve the positional harmony of the planned and placed implants (36). An unavoidable necessity in the surgical guide design which causes error in implant placement is the gap between the guide sleeve and the drill (34).

Kattadiyil MT *et al.* (37) conducted a clinical study to rate and compare complete removable dental prosthesis (CRDP) manufactured using digital prosthesis fabrication method compared to the conventional process. Each patient received two sets of maxillary and mandibular CRDP in two forms: a conventional set and a digital set. It was concluded that when compared to conventional prosthesis fabrication the digital procedure proved to be time-efficient and equally effective alternative.

In several studies conducted by Gjelvold B *et al.* (23), Kamimura E *et al.* (24), Ender A *et al.* (22) they compared digital impressions with conventional impressions and they all concluded that the conventional impression method was less accurate than the digital approach which was more efficient and convenient.

On the contrary, in the study by Malik J *et al.* (13), Using additional silicone impression material and an optical scanner, complete arch impressions of a model were recorded. They concluded that the conventional PVS impressions for full arch showed greater mean accuracy compared with the direct intraoral optical scanner.

Finally, Kiatkroekkrai P *et al.* (38), compared the precision of implant placement by using intraoral and extraoral model scans to produce surgical guides. The deviation between the planned and final implant locations was compared by a software. Surgical guides obtained from intraoral and extraoral scans resulted in implant positioning accuracy that was comparable between intraoral and extraoral scans.

According to some research the scanning procedure has an impact on the precision of the resulting impression (39). Due to the inherent error accumulation when screening greater sizes, this is particularly critical when placing implants. According to Gimenez *et al.* (40), operator skills have a major impact on the quality of digital impressions. As a result, both impressions were taken by a single dentist having profound professional experience in each of the checked programs.

Furthermore, the discrepancy between our results and the previously mentioned results could be attributed to the multiple dimensional changes of different impression materials used to compensate for the difference between the arch and the stock tray used in this study.

In terms of chemical composition, light reflection, natural tooth surface morphology, and mucosa resiliency, this study has many limitations. First, for patient emulation, the present analysis used a typodont, which is distinct from the oral cavity and normal tooth state of a real patient. Typodont polyurethane teeth eliminates the effect of saliva, temperature-related distortion, and water resorption. Furthermore, because only one conventional impression material and one digital impression device were used in this study, general conclusions should be drawn with caution. To validate the current study, further testing with various materials and systems would be needed.

CONCLUSION

When it comes to surgical guide fabrication and implant positioning, the intraoral optical impression technique is more precise than the conventional impression technique. IOSs have a distinct advantage in terms of work efficiency. Because of the accuracy of the intraoral digital impression technique, it may be widely used in dentistry, especially in patients who have free end saddles.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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REFERENCES

1. Luthardt R, Weber A, Rudolph H, Schone C, Quaas S, Walter M. Design and production of dental prosthetic restorations: basic research on dental CAD/CAM technology. Int J Comput Dent. 2002 Apr-Jul;5:165-76.
2. Laleman I, Bernard L, Vercruyssen M, Jacobs R, Bornstein MM, Quirynen M. Guided Implant Surgery in the Edentulous Maxilla: A Systematic Review. Int J Oral Maxillofac Implants. 2016;31 Suppl:s103-17.
3. Benavides E, Rios HF, Ganz SD, An C-H, Resnik R, Reardon GT, et al. Use of Cone Beam Computed Tomography in Implant Dentistry: The International Congress of Oral Implantologists Consensus Report. Implant Dentistry. 2012;21:78-86.
4. Schmidt A, Klussmann L, Wostmann B, Schlenz MA. Accuracy of Digital and Conventional Full-Arch Impressions in Patients: An Update. Journal of clinical medicine. 2020 Mar 4;9.
5. D'haese J, Van De Velde T, Komiyama A, Hultin M, De Bruyn H. Accuracy and Complications Using Computer-Designed Stereolithographic Surgical Guides for Oral Rehabilitation by Means of Dental Implants: A Review of the Literature. Clinical Implant Dentistry and Related Research. 2012;14:321-35.
6. Ramasamy M, Giri, Raja R, Subramonian, Karthik, Narendrakumar R. Implant surgical guides: From the past to the present. Journal of pharmacy & bioallied sciences. 2013 Jun;5:S98-S102.
7. Azari A, Nikzad S. The evolution of rapid prototyping in dentistry: a review. Rapid Prototyping Journal. 2009;15:216-25.
8. Meloni SM, De Riu G, Lolli FM, Pisano M, Deledda A, Frisardi G, et al. Computer-guided implant surgery: A critical review of treatment concepts. Journal of Oral and Maxillofacial Surgery, Medicine, and Pathology. 2014 2014/01/01/;26:1-6.
9. Beuer F, Schweiger J, Edelhoff D. Digital dentistry: an overview of recent developments for CAD/CAM generated restorations. Br Dent J. 2008 May 10;204:505-11.
10. D'Souza KM, Aras MA. Types of implant surgical guides in dentistry: a review. J Oral Implantol. 2012 Oct;38:643-52.
11. Nokar S, Moslehifard E, Bahman T, Bayanzadeh M, Nasirpouri F, Nokar A. Accuracy of implant placement using a CAD/CAM surgical guide: an in vitro study. International Journal of Oral & Maxillofacial Implants. 2011;26.
12. Ender A, Mehl A. In-vitro evaluation of the accuracy of conventional and digital methods of obtaining full-arch dental impressions. Quintessence Int. 2015 Jan;46:9-17.
13. Malik J, Rodriguez J, Weisbloom M, Petridis H. Comparison of Accuracy Between a Conventional and Two Digital Intraoral Impression Techniques. Int J Prosthodont. 2018 Mar/Apr;31:107-13.
14. Mangano F, Gandolfi A, Luongo G, Logozzo S. Intraoral scanners in dentistry: a review of the current literature. BMC Oral Health. 2017 Dec 12;17:149.
15. Patzelt SB, Vonau S, Stampf S, Att W. Assessing the feasibility and accuracy of digitizing edentulous jaws. J Am Dent Assoc. 2013 Aug;144:914-20.
16. Borisov R. Radiological templates and CAD/CAM surgical guides. A literature review. Journal of IMAB-Annual Proceeding (Scientific Papers). 2016;22:1285-95.
17. Bencharit S, Staffen A, Yeung M, Whitley D, 3rd, Laskin DM, Deeb GR. In Vivo Tooth-Supported Implant Surgical Guides Fabricated With Desktop Stereolithographic Printers: Fully Guided Surgery Is More Accurate Than Partially Guided Surgery. J Oral Maxillofac Surg. 2018 Jul;76:1431-9.
18. Pawar A, Mittal S, Singh RP, Bakshi R, Sehgal V. A step toward precision: a review on surgical guide templates for dental implants. Int J Sci Study. 2016;3:262-6.
19. Vercruyssen M, Laleman I, Jacobs R, Quirynen M. Computer-supported implant planning and guided surgery: a narrative review. Clin Oral Implants Res. 2015 Sep;26 Suppl 11:69-76.
20. Almeida e Silva JS, Erdelt K, Edelhoff D, Araujo E, Stimmelmayr M, Vieira LC, et al. Marginal and internal fit of four-unit zirconia fixed dental prostheses based on digital and conventional impression techniques. Clin Oral Investig. 2014;18:515-23.

21. Seelbach P, Brueckel C, Wostmann B. Accuracy of digital and conventional impression techniques and workflow. Clin Oral Investig. 2013 Sep;17:1759-64.
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;115:313-20.
23. Gjelvold B, Chrcanovic BR, Korduner EK, Collin-Bagewitz I, Kisch J. Intraoral Digital Impression Technique Compared to Conventional Impression Technique. A Randomized Clinical Trial. J Prosthodont. 2016 Jun;25:282-7.
24. Kamimura E, Tanaka S, Takaba M, Tachi K, Baba K. In vivo evaluation of inter-operator reproducibility of digital dental and conventional impression techniques. PLoS One. 2017;12:e0179188.
25. Malaguti G, Rossi R, Marziali B, Esposito A, Bruno G, Dariol C, et al. In vitro evaluation of prosthodontic impression on natural dentition: a comparison between traditional and digital techniques. Oral Implantol (Rome). 2017;9:21-7.
26. Mehl A, Ender A, Mormann W, Attin T. Accuracy testing of a new intraoral 3D camera. Int J Comput Dent. 2009;12:11-28.
27. Ender A, Mehl A. Accuracy of complete-arch dental impressions: a new method of measuring trueness and precision. J Prosthet Dent. 2013 Feb;109:121-8.
28. Di Fiore A, Meneghello R, Savio G, Sivolella S, Katsoulis J, Stellini E. In Vitro Implant Impression Accuracy Using a New Photopolymerizing SDR Splinting Material. Clinical Implant Dentistry and Related Research. 2015;17:e721-e9.
29. Syrek A, Reich G, Ranftl D, Klein C, Cerny B, Brodesser J. Clinical evaluation of all-ceramic crowns fabricated from intraoral digital impressions based on the principle of active wavefront sampling. J Dent. 2010 Jul;38:553-9.
30. Kuzmanovic DV, Payne AG, Purton DG. Distal implants to modify the Kennedy classification of a removable partial denture: a clinical report. J Prosthet Dent. 2004 Jul;92:8-11.
31. Geng W, Liu C, Su Y, Li J, Zhou Y. Accuracy of different types of computer-aided design/computer-aided manufacturing surgical guides for dental implant placement. Int J Clin Exp Med. 2015;8:8442-9.
32. Miyashiro M, Suedam V, Moretti Neto RT, Ferreira PM, Rubo JH. Validation of an experimental polyurethane model for biomechanical studies on implant supported prosthesis--tension tests. J Appl Oral Sci. 2011 May-Jun;19:244-8.
33. Talmazov G, Bencharit S, Waldrop TC, Ammoun R. Accuracy of Implant Placement Position Using Nondental Open-Source Software: An In Vitro Study. Journal of Prosthodontics. 2020;29:604-10.
34. Lee D-H, An S-Y, Hong M-H, Jeon K-B, Lee K-B. Accuracy of a direct drill-guiding system with minimal tolerance of surgical instruments used for implant surgery: a prospective clinical study. The journal of advanced prosthodontics. 2016;8:207.
35. Cassetta M, Di Mambro A, Giansanti M, Stefanelli LV, Cavallini C. The intrinsic error of a stereolithographic surgical template in implant guided surgery. Int J Oral Maxillofac Surg. 2013 Feb;42:264-75.
36. Lee JH, Park JM, Kim SM, Kim MJ, Lee JH, Kim MJ. An assessment of template-guided implant surgery in terms of accuracy and related factors. J Adv Prosthodont. 2013 Nov;5:440-7.
37. Kattadiyil MT, Jekki R, Goodacre CJ, Baba NZ. Comparison of treatment outcomes in digital and conventional complete removable dental prosthesis fabrications in a predoctoral setting. J Prosthet Dent. 2015 Dec;114:818-25.
38. Kiatkroekkrai P, Takolpuckdee C, Subbalekha K, Mattheos N, Pimkhaokham A. Accuracy of implant position when placed using static computer-assisted implant surgical guides manufactured with two different optical scanning techniques: a randomized clinical trial. Int J Oral Maxillofac Surg. 2020 Mar;49:377-83.
39. Ender A, Mehl A. Influence of scanning strategies on the accuracy of digital intraoral scanning systems. Int J Comput Dent. 2013;16:11-21.
40. Gimenez B, Ozcan M, Martinez-Rus F, Pradies G. Accuracy of a digital impression system based on active wavefront sampling technology for implants considering operator experience, implant angulation, and depth. Clin Implant Dent Relat Res. 2015 Jan;17 Suppl 1:e54-64.