Heliyon 9 (2023) e18004

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

A digital strategy for intraoperative acquisition of actual drill position and rapid assessment of bony preparation accuracy using an intraoral scanner

Tian Luo [a], Chenyang Xie [b], Jiacheng Wu [b], Jiakang Zhu [a], Haiyang Yu [a,*]

[a] *State Key Laboratory of Oral Disease, National Clinical Research Center for Oral Diseases, West China Hospital of Stomatology, Sichuan University, Chengdu, China*

[b] *Department of Dental Technology, West China Hospital of Stomatology, Sichuan University, Chengdu, China*

ARTICLE INFO

Keywords:
Intraoral scan
Scan body
Polyetheretherketone
Bony preparation accuracy
Implant surgery

ABSTRACT

A digital workflow to acquire actual position of the drill and assess bony preparation accuracy intraoperatively was described. Based on the widely used intraoral scanner, this digital workflow was a relatively practical and economical option for digital intraoperative measurement. As a result, it could help the clinician in accurate verification and immediate correction of the drill position and consequently facilitating the accurate implant placement in implant surgery.

1. Introduction

Surgical implementation of implant surgery mainly consists of flap elevation or tissue punch, bony preparation and implant insertion. In vivo and in vitro studies have been performed for exploring influence factors in accurate implant placement. The results of these studies have promoted improvements in selection of assisted surgery systems [1–3], selection of implant macro designs [4], selection of guide types [5], guide template design [6], selection of surgical protocols [7] and application of dedicated surgical instruments [8]. However, those articles only focused on the implant insertion accuracy without notice of bony preparation accuracy during the surgery.

The bony preparation with drills of increasing diameters before implant insertion is necessary whatever in immediate and delayed implant surgery. Deviations existed in this process may adversely affect the overall accuracy and consequently cause serious surgical and prosthetic complications [9]. Recently, several studies have investigated the bony preparation accuracy by different methods. A literature study on this topic measured deviations of drilled holes after matching the postoperative and preoperative cone beam computed tomography (CBCT) images [3]. Although this study focused on the osteotomy preparation accuracy, the methodologies for acquisition of drilled holes and deviation measurements described in their study were ex post facto, which could not get the immediate assessment and verification of the actual drill position during the surgery. As a result, the deviation of drill position could not be detected and corrected timely, resulting in deviations in subsequent implant insertion and the higher risk of surgical failure. Besides, these methods would expose the patient to addition radiation exposure in a short time. Additionally, a dedicated physical measuring probe with spring-loaded half-shells that were split by an expanding pin with a precision-lapped taper was introduced in another study on accuracy of implant site preparation [10]. However, it could only be used to measure the diameter of drilled holes instead of actual

* Corresponding author.
E-mail address: YHYmechanics@163.com (H. Yu).

https://doi.org/10.1016/j.heliyon.2023.e18004
Received 3 December 2022; Received in revised form 2 July 2023; Accepted 5 July 2023
Available online 7 July 2023
2405-8440/© 2023 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

horizontal, vertical, and axial position of the drill. With the advancement of digital dentistry, application of dynamic computer-assisted implant surgery (CAIS) system can visualize the actual drill position and deviations to the virtual plan on the screen by tracing fiducial tags mounted on patient's teeth and the handpiece. However, the dedicated equipment such as specialized software for intraoperative real-time navigation, as well as optical tracking systems for tracking fiducial tags, and preoperative preparations such as registration of the handpiece and calibration of the implant drill are indispensable, increasing operation time and cost. Moreover, the bony preparation accuracy of the dynamic system is still lack of sufficient evidence, and there's a learning period for the clinician to operate the dynamic system proficiently [11].

With the characteristic of non-reflective, the polyetheretherketone (PEEK) has been used for digital optical impression without powder spray [12]. And a recent study indicated that the scan body of PEEK had the better results on both linear and angular accuracy than that of titanium and peek-titanium [13]. As a result, it is possible that the scan body fabricated by PEEK could be used intraoral during the implant surgery. Therefore, the present article describes a digital strategy for intraoperative acquisition of actual drill position and accuracy assessment. With the use of intraoral scanner and individual scan body during the surgery, this technique can help the clinician identify and correct deviations occurring in bony preparation and improve preparation accuracy.

2. Technical note

This study was approved by the West China School of Stomatology Ethics Committee Commission with number WCHSIRB-CT-2021-302. A 32-year-old patient planned for one mandibular implant with an implant-supported fixed prosthesis was recruited for this digital strategy technique. The entire treatment plan was clearly explained and discussed with the patient. And an informed consent was signed by the patient form authorizing for treatment and publication of this article.

1. Obtain the CBCT data set (J Morita; Kyoto, Japan) in digital imaging and communications in medicine (DICOM) format and intraoral scan data (Aoralscan, beta version; Shining 3D, Hangzhou, China) in standard tessellation language (STL) format. Design the virtual diagnostic waxing in dental CAD software (exocad Dental CAD; exocad, Darmstadt, Germany) (Fig. 1A).
2. Superimpose the waxing data to the CBCT data and perform the virtual implant planning based on the prosthesis in the dedicated software (BlueSky Plan 4; BlueSky Bio, IL, USA) (Fig. 1B). One mandibular implant (3.3 × 14mm, BLT; Institut Straumann AG, Basel, Switzerland) was planned virtually. Export STL files of the virtual plan.

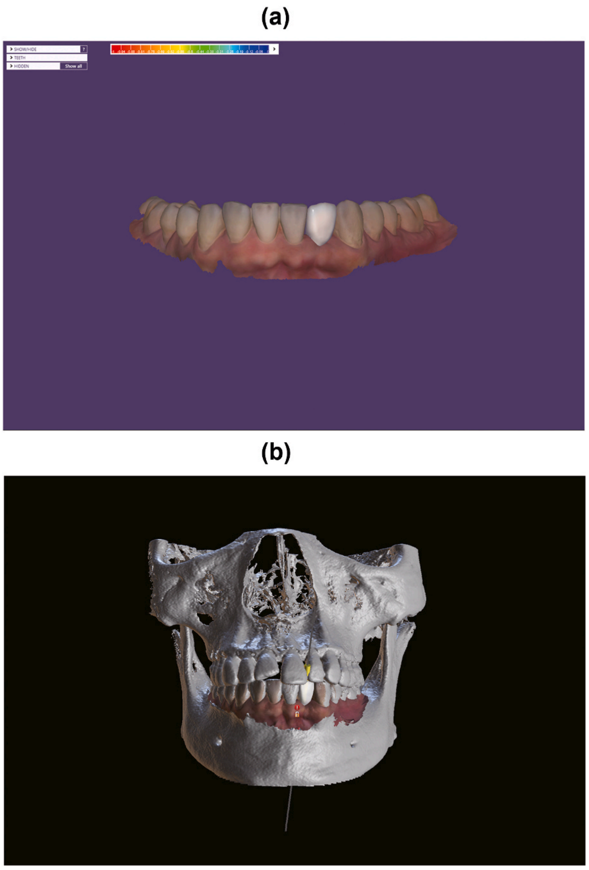


Fig. 1. (A) Virtual diagnostic waxing. (B) Virtual implant planning from the prosthetic standpoint.

3. Measure the actual dimension of the drill using a digital vernier caliper with 0.01 mm resolution (Digimatic Caliper; Mitutoyo, Tokyo, Japan) and create a virtual drill analog with the consistent diameter and total length based on the planned implant position in reverse engineering software (Geomagic Wrap; 3D Systems, NC, USA) to represent the drill used intraoperatively (BLT pilot drill and twist drill; Institut Straumann AG) (Fig. 2A). Import the data of the virtual drill analog and dentition into the software of the intraoral scanner as the reference file.
4. Design a scan body with registration surfaces and an inspection window based on the virtual drill (Fig. 2B). Import the scan body connected with virtual drill analogs into the software of the intraoral scanner as the standard file. Fabricate the scan body with the chairside milling machine (AV-D5; Aidite, Hebei, China) and PEEK disc (BioPAEK; Sino-Dentex, Changchun, China).
5. Mark and delete the targeted area in the dentition of the reference file and lock the rest surface in the software (Fig. 3A).
6. Due to the use of endosteal implant with a depth of 1mm below the alveolar crest, the depth required for the pilot drill preparation was 15mm, which could be guided by the laser marking lines on the drills. Prepare the implant bed to preset depth with the pilot drill according to the manufacturer's recommendation. Disconnect the handpiece and the drill, then insert the scan body on the drill shank and confirm its good fit. Make its extended arms against adjacent teeth (Fig. 3 B, D). Replace with a shorter drill if necessary to reduce distance between the bottom of scan body and the mucosa.
7. Acquire the relative position of scan body and dentition using the same intraoral scanner with the scan range covering at least two teeth away from the drill (Fig. 3 C, E). Select and match the standard file to the scan data using best-fit algorithm and obtain the actual drill position in dentition (Fig. 4 A, B).
8. Visualize virtual drill analogs representing actual and planned drill position together in the same dentition. Assess the actual drill position qualitatively at first (Fig. 5 A–C). Then measure the global linear and angular deviation at the entry point and the apex using the "Analyze" function to assess the drilling accuracy. Measure the mesio-distal, bucco-lingual and apico-coronal deviations based on the created coordinate system if needed (Fig. 6 A, B).
9. Make targeted adjustments using the twist drill according to the analysis result. Repeat the operation from step 5 to step 8 for the twist drill to assess the definitive preparation accuracy. To maintain accurate alignment, intraoral scan and software should be performed by the same device and operator.

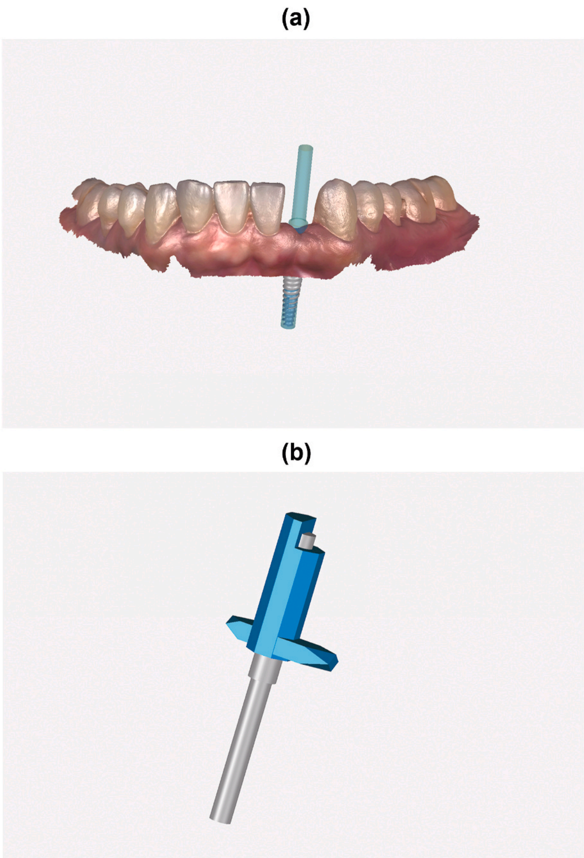


Fig. 2. (A)Virtually constructed drill analog according to the planned implant position and actual dimensions of the drill. (B) Virtual scan body designed based on the drill shank.

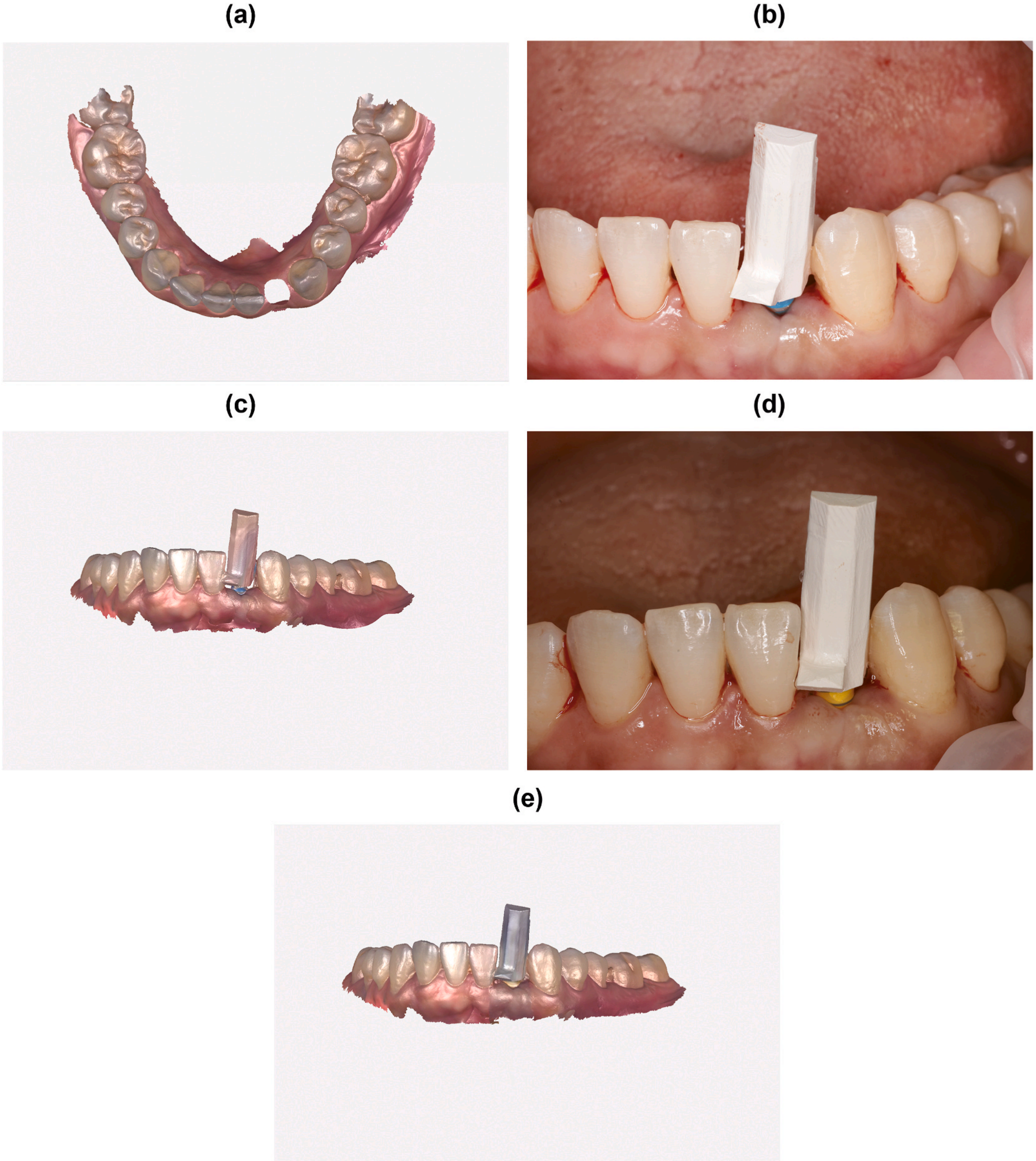


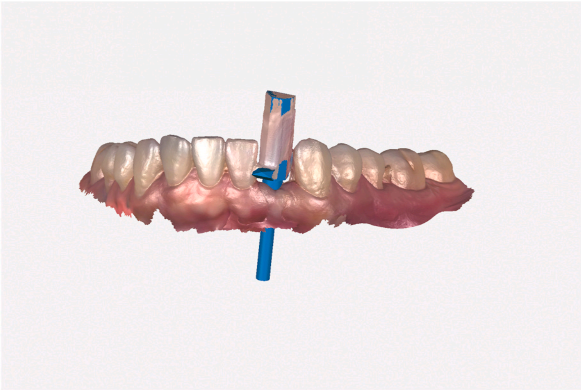
Fig. 3. (A) Trimmed scan data. (B) Scan body fitted on the bur shank of pilot drill. (C) Acquisition of the pilot drill position. (D) Scan body fitted on the bur shank of twist drill. (E) Acquisition of the twist drill position.

3. Discussion

In this technique, a PEEK scan body and the intraoral scanner were introduced during the bony preparation surgery to acquire and analyze the actual drill position. Compared with the previous protocol, the present technique provided a series of advantages: Based on the digital implant planning, the virtual position of future drill and scan body were available before bony preparation and implant placement. The best-fit algorithm used for matching the standard file to the scan data was automatic (Fig. 4 A, B). Subsequently, the quantitative accuracy analysis of each drilling, including angular and linear deviation could be measured during the surgery (Fig. 6 A, B). Therefore, the deviation of drill position could be detected and corrected timely during the bony preparation to avoid serious surgical and prosthetic complications. Furthermore, this technology protected patients from multiple irradiations in a short period of time.

The accuracy of the intraoral digital impression was affected by characteristics of implant scan body as material, connection type, surface and software compatibility [12,14]. Lorenzo A et al. [13] reported that the implant scan body material significantly influenced the accuracy of the complete-arch digital impression, and PEEK showed the best results on both linear and angular measurements. The exclusive scan body fabricated by PEEK in present technique was conducive to direct digital optical impression without powder spray

(a)



(b)

Fig. 4. Align the standard file of scan body and drill analog to intraoral scan data. (A) Actual position of the pilot drill represented by the virtual drill analog. (B) Actual position of the twist drill represented by the virtual drill analog.

because of its non-reflective characteristic. The stability of scan body could also meet the requirements. Because the scan body was designed virtually based on the drill shank, and the shank end served as a physical stop, it was beneficial for accurate positioning of the scan body. And making the scan body against adjacent teeth not only maintain its stability but also facilitate images stitching during optical impression process. What's more, because the surface geometric characteristics of drill shanks in different surgical kit systems are the same, the scan body described in this technique is generic.

Software of the intraoral scanner was used to assess the drilling accuracy qualitatively and quantitatively. With automatic superimposition of the actual scan data and the reference file, it was convenient to facilitate intraoperative verification and immediate correction of the drill position. Therefore, there's no need to scan the whole dentition after each step of osteotomy preparation. The intraoperative scan with the range covering two teeth distal and mesial to the drill could be aligned to the reference file rapidly and automatically, reducing extra time for scanning. The qualitative analysis would indicate the inclination direction of the drill, while the quantitative analysis would point out deviation values in each direction. Based on the analysis result, the surgeon could make timely adjustments in further drilling process. Moreover, this technique can be used to verify the guided drilling accuracy using surgical templates. And it can be compared with accuracy of implant placement to explore their relationship in different protocols, which can provide a new perspective to modify template-guided surgical strategies.

The limitations of the present technique include that it can only be applied to a patient receiving digital scan and computer-assisted implant surgery. Besides, in the multiple implant caases, the digital implant impressions taken by intraoral scanners are not sufficiently accurate for clinical application [15], so this technique has been used in the case of single implant. Several studies had improved the scanning accuracy of multiple implant cases by modifying scan bodies with extensional structure [16], further research is needed to apply present technique to more cases of multiple implants. In conclusion, this described technique presented a digital workflow to acquire the actual drill position and assess the bony preparation accuracy using an intraoral scanner during the surgery.

Declarations

Author contribution statement

All authors listed have significantly contributed to the investigation, development and writing of this article.

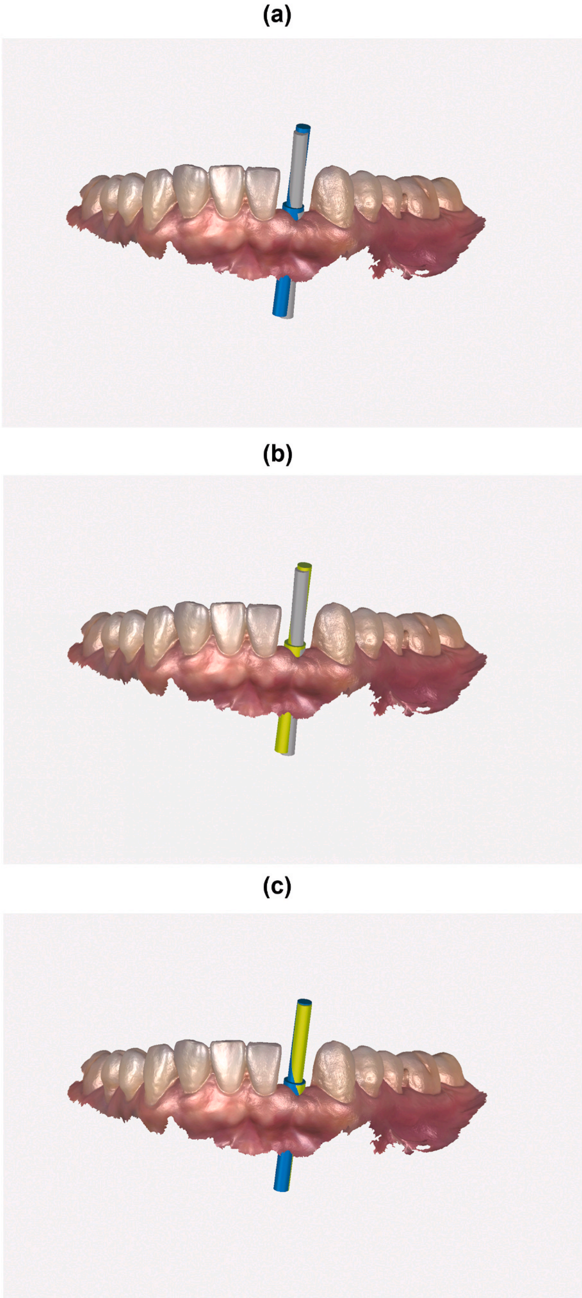


Fig. 5. Qualitative analysis of the deviation between actual drill position and planned drill position. (A) Pilot drill (blue) during the surgery locates labially, mesially and coronally to planned drill (gray). (B) Twist drill (yellow) during the surgery locates labially, mesially and coronally to planned drill (gray). (C) Twist drill (yellow) locates slightly lingually, distally and apically to pilot drill (blue). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Funding statement

This work was supported by the Sichuan University Horizontal Research Foundation [Grant Number: 21Z0019].

Additional information

No additional information is available for this paper.

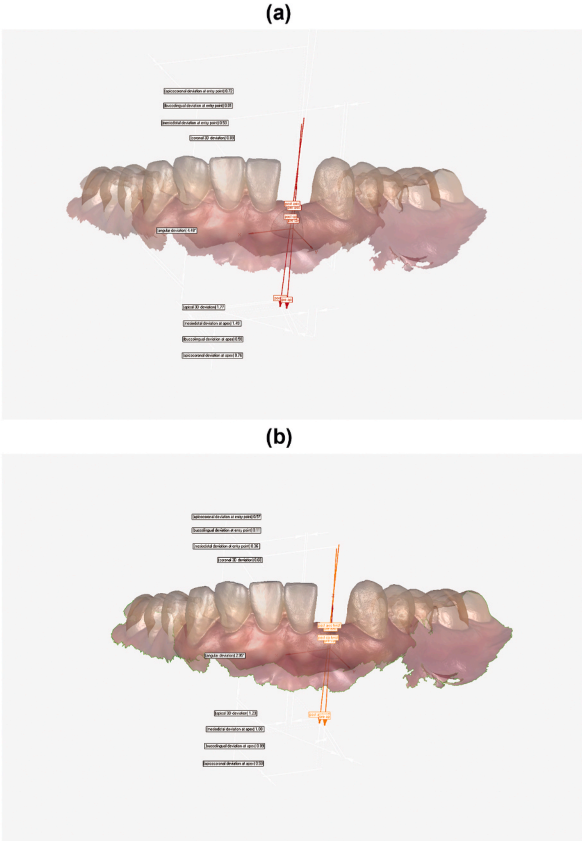


Fig. 6. Quantitative accuracy analysis of each drilling procedure. (A) Drilling accuracy assessment of the pilot drill indicates angular deviation of 4.48°, global linear deviation at the entry point of 0.89 mm and at the apex of 1.77 mm. (B) Drilling accuracy assessment of the twist drill indicates angular deviation of 2.95°, global linear deviation at the entry point of 0.68 mm and at the apex of 1.23 mm.

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.

Acknowledgements

The authors thank the patient whose case is documented here for his patience. Additionally, the authors would like to thank Sino-Dentex Co., Ltd and Aidite (Qinhuang DAO) Technology Co., Ltd for supporting this study with PEEK and milling machine, respectively.

References

[1] P. Yimarj, K. Subbalekha, K. Dhanesuan, K. Siriwatana, N. Mattheos, A. Pimkhaokham, Comparison of the accuracy of implant position for two-implants supported fixed dental prosthesis using static and dynamic computer-assisted implant surgery: a randomized controlled clinical trial, Clin. Implant Dent. Relat. Res. 22 (6) (2020) 672–678.
[2] C.A. Aydemir, V. Arısan, Accuracy of dental implant placement via dynamic navigation or the freehand method: a split-mouth randomized controlled clinical trial, Clin. Oral Implants Res. 31 (3) (2020) 255–263.
[3] C.K. Chen, D.Y. Yuh, R.Y. Huang, E. Fu, C.F. Tsai, C.Y. Chiang, Accuracy of implant placement with a navigation system, a laboratory guide, and freehand drilling, Int. J. Oral Maxillofac. Implants 33 (6) (2018) 1213–1218.
[4] K. El Kholy, S. Ebenezer, J.G. Wittneben, R. Lazarin, D. Rousson, D. Buser, Influence of implant macrodesign and insertion connection technology on the accuracy of static computer-assisted implant surgery, Clin. Implant Dent. Relat. Res. 21 (5) (2019) 1073–1079.
[5] F. Younes, J. Cosyn, T. De Bruyckere, R. Cleymaet, E. Bouckaert, A. Eghbali, A randomized controlled study on the accuracy of free-handed, pilot-drill guided and fully guided implant surgery in partially edentulous patients, J. Clin. Periodontol. 45 (6) (2018) 721–732.
[6] P. Kiatkroekkrai, C. Takolpuckdee, K. Subbalekha, N. Mattheos, A. Pimkhaokham, 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. 49 (3) (2020) 377–383.
[7] A. Behneke, M. Burwinkel, N. Behneke, Factors influencing transfer accuracy of cone beam CT-derived template-based implant placement, Clin. Oral Implants Res. 23 (4) (2012) 416–423.

[8] C. Monaco, A. Arena, L. Corsaletti, V. Santomauro, P. Venezia, R. Cavalcanti, et al., 2D/3D accuracies of implant position after guided surgery using different surgical protocols: a retrospective study, J. Prosthodont. Res. 64 (4) (2020) 424–430.
[9] E. Somogyi-Ganss, H.I. Holmes, A. Jokstad, Accuracy of a novel prototype dynamic computer-assisted surgery system, Clin. Oral Implants Res. 26 (8) (2015) 882–890.
[10] U. Scherer, M. Stoetzer, M. Ruecker, N.C. Gellrich, C. von See, Template-guided vs. non-guided drilling in site preparation of dental implants, Clin. Oral Invest. 19 (6) (2015) 1339–1346.
[11] D. Kaewsiri, S. Panmekiate, K. Subbalekha, N. Mattheos, A. Pimkhaokham, The accuracy of static vs. dynamic computer-assisted implant surgery in single tooth space: a randomized controlled trial, Clin. Oral Implants Res. 30 (6) (2019) 505–514.
[12] R.M. Mizumoto, B. Yilmaz, Intraoral scan bodies in implant dentistry: a systematic review, J. Prosthet. Dent 120 (3) (2018) 343–352.
[13] L. Arcuri, A. Pozzi, F. Lio, E. Rompen, W. Zechner, A. Nardi, Influence of implant scanbody material, position and operator on the accuracy of digital impression for complete-arch: a randomized in vitro trial, J. Prosthodont. Res. 64 (2) (2020) 128–136.
[14] F. Mangano, A. Gandolfi, G. Luongo, S. Logozzo, Intraoral scanners in dentistry: a review of the current literature, BMC Oral Health 17 (1) (2017) 149.
[15] Yi-Jie Zhang, Jun-Yu Shi, Shu-Jiao Qian, Shi-Chong Qiao, Hong-Chang Lai, Accuracy of full-arch digital implant impressions taken using intraoral scanners and related variables: a systematic review, Int. J. Oral Implant. 14 (2) (2021) 157–179.
[16] Ruoxuan Huang, Yuanxiang Liu, Baoxin Huang, Fengxing Zhou, Zhuofan Chen, Zhipeng Li, Improved accuracy of digital implant impressions with newly designed scan bodies: an in vivo evaluation in beagle dogs, BMC Oral Health 21 (1) (2021) 623.