Mendonça Gustavo (Orcid ID: 0000-0003-2290-4046)
Wang Hom-Lay (Orcid ID: 0000-0003-4238-1799)

Open-sleeve templates for computer-assisted implant surgery at healed or extraction sockets: An in vitro comparison to closed-sleeve guided system and free-hand approach

Authors: Junying Li, DDS, MS, PHD[1], Priscila Ceolin Meneghetti DDS, MSC[1,3], Matthew Galli DDS[2], Gustavo Mendonca, DDS, MS, PhD[1], Zhaozhao Chen, DDS, MS, PHD[2], Hom-Lay Wang, DDS, MS, PhD[2]

Authors' affiliations:

[1]Department of Biologic and Materials Sciences, Division of Prosthodontics, School of Dentistry, University of Michigan, Ann Arbor, MI, USA

[2]Department of Periodontics and Oral Medicine, School of Dentistry, University of Michigan, Ann Arbor, MI, USA

[3]Department of Restorative Dentistry, Pontifical University Catholic of Rio Grande do Sul, Porto Alegre, Brazil

Running title: Accuracy of open-sleeve guided implant system

Word count: 2,966 words

Tables and figures: 6 figures and 2 tables

Number of references: 25

Conflict of interest: The authors do not have any financial interests, either directly or indirectly, in the products or information listed in the paper.

Corresponding author:

Dr. Hom-Lay Wang, Professor and director, Department of Periodontics and Oral Medicine, University of Michigan School of Dentistry, 1011 North University Avenue, Ann Arbor, MI 48109-1078, USA. TEL: +734 763 3383; FAX: +734 936 0374; E-mail address: homlay@umich.edu

Key words: dental implants, computer-assisted implant dentistry, stereolithography, immediate implant placement

Author's contribution:

JYL: Conceptualization, investigation, Software, Visualization, Writing – original draft, Writing – review & editing

PCM: investigation, Writing – review & editing

MG: investigation, Writing – review & editing

GM: Funding acquisition, Project administration, Resources, Writing – review & editing

ZZC: Data curation, Visualization, Writing – review & editing

HLW: Conceptualization, Funding acquisition, Supervision, Writing – review & editing

Data Availability Statement: Data available on request from the authors

Acknowledgement: We thanks Qin Chuang Precision Technology Co., Ltd for providing the implants fixtures and open-sleeve guide system.

ABSTRACT

Objective: A buccal opening guide provides better view and better irrigation. The aim of this study was to investigate the accuracy of this open-sleeve system.

Material and Methods: Thirty duplicated maxillary models, each with 6 extraction sockets and 4 healed sites, were used. Based on the same digital plan, three modalities, sCAIS with open-sleeves, closed-sleeves, and free-hand approach, were used to place implants. The global, horizontal, depth, and angular deviations between the virtual and actual implant positions were measured.

Results: Both sCAIS groups exhibited better accuracy than the free-hand group in two clinical scenarios. At healed sites, the closed-sleeve group showed a significantly fewer error than the open-sleeve group in global apical (0.68 ± 0.33 vs. 0.96 ± 0.49 mm), horizontal coronal (0.28±0.15 vs. 0.44±0.25 mm), horizontal apical (0.64±0.32 vs. 0.94±0.48 mm), and angular deviations (1.83 ± 0.95 vs. 2.86 ± 1.46°). For extraction sockets, the open-sleeve group exhibited fewer deviations than the closed-sleeve group in terms of global (coronal: 0.77 ± 0.29 vs. 0.91 ±0.22 mm; apical: 1.08 ± 0.49 vs. 1.37 ±0.52 mm), and horizontal (coronal: 0.60±0.24 vs. 0.86±0.20 mm; apical: 0.95±0.50 vs. 1.32±0.51mm) deviations. However, the closed-sleeve group was more accurate in the depth control (0.26 ± 0.20 vs. 0.40 ± 0.31 mm).

Conclusion: In this in vitro investigation, open-sleeve sCAIS proved better accuracy than free-hand surgery for both delayed and immediate implant placement. Compared with a closed-sleeve

sCAIS system, open-sleeve have the potential of providing better outcomes in extraction sockets but not in healed sites.

1. INTRODUCTION

Recently, computer-assisted implant surgery (CAIS) has become a common approach in daily practice(Z Chen, Li, Lin, & Wang, 2020). With this technology, implant placement can be planned virtually in a prosthetically-driven three-dimensional (3D) position based on the future prosthetic design (Arısan, Karabuda, & Özdemir, 2010; Ersoy, Turkyilmaz, Ozan, & McGlumphy, 2008). During static CAIS (sCAIS), the most implemented approach involves fabricating templates by either 3D printing or milling with circular metal tubes (Joda, Derksen, Wittneben, & Kuehl, 2018). During implant surgery, the direction and depth of drills are restricted by the metal tubes (also called sleeves); thus, the implant can be placed following pre-surgical virtual planning. The CAIS also allows for a minimally invasive implant surgery without flap reflection (Malo, de Araujo Nobre, & Lopes, 2007; Terzioğlu, Akkaya, & Ozan, 2009), as well as immediate loading of a prefabricated computer-aided design/computer aided manufacturing (CAD/CAM) prosthesis (Lewis et al., 2015; Li et al., 2020).

The accuracy of CAIS has been extensively researched in recent years and shown to be influenced by various factors, such as the quality of cone beam computed tomogram (CBCT) images and model/intraoral scanning (Lin et al., 2013; Muallah et al., 2017), superimposition of images (Cristache & Gurbanescu, 2017), the fabrication method and process of surgical templates (Bencharit et al., 2018; Deeb et al., 2017; Kühl, Payer, Zitzmann, Lambrecht, & Filippi, 2015), guide fixation and support (Raico Gallardo et al., 2017), and the intrinsic error of guided surgical kits (Cassetta, Di Mambro, Giansanti, Stefanelli, & Cavallini, 2013), amongst other variables (Cushen & Turkyilmaz, 2013; Kholy et al., 2019; Kholy, Janner, Schimmel, & Buser, 2019; Li et al., 2019). Though deviations cannot be eliminated, in general, sCAIS provides significantly better accuracy than a free-hand approach for both delayed and immediate implant placement (Zhaozhao Chen et al., 2018; Siqueira et al., 2020).

However, regular sCAIS templates possess several limitations (Moon, Lee, Kim, & Son, 2016). One of the major challenges is that the circular metal tube blocks the view of the surgical site, making it difficult for the surgeon to observe the bone during drilling. At the same time, saline irrigation is also hampered, which can be associated with a higher chance of bone overheating compared to direct irrigation (Frösch, Mukaddam, Filippi, Zitzmann, & Kühl, 2019). Moreover, implant drills must be inserted from the coronal opening of the guide sleeve thus increasing the need for inter-arch space and making it difficult to apply in the posterior regions.

To overcome these problems, sCAIS systems with an "open-sleeve" design have been proposed. Compared to conventional systems with "closed-sleeve" designs (the drill-guiding tube is a full circle), open-sleeve systems have a 1/2 or 3/4 circle guide tube with a buccal opening. The buccal opening allows the surgeon to insert drills laterally instead of from a coronal direction which allows guided osteotomy preparation even in situations with limited inter-arch distance. Moreover, the open-sleeve design provides a better view of the surgical field and access for irrigation without limiting the direction or depth of drills during the osteotomy. However, the existence of a buccal opening on the guide sleeve may raise concerns about potentially compromised accuracy. To the best of the authors' knowledge, there is only one study investigating this question. Tallarico et al compared the accuracy of guides with open-sleeves (n=15) or closed-sleeves (n=104) and reported a trend for improved accuracy when the open-sleeve group was excluded (Tallarico, Kim, Cocchi, Martinolli, & Meloni, 2019). However, no statistical analysis was performed to determine the exact difference between the two groups. Hence, there is a need to systematically investigate the accuracy of a sCAIS system with an open-sleeve design.

The aims of this study were three-fold: 1) to compare the accuracy of open-sleeve sCAIS with a free-hand approach; 2) to compare the accuracy of open-sleeve sCAIS and closed-sleeve sCAIS; and 3) to investigate the difference in deviation of open-sleeve sCAIS between fresh-sockets and healed sites. The null hypothesis was that there would be no differences between these interventions.

2. MATERIALS AND METHODS

Thirty duplicated maxillary models (U-011; BoneModels S.L.U., Castellon, Spain) were used in the current study (Figure 1). They were check by the study group and no observable difference were noticed. The models had both cortical (D1 density) and cancellous (D3 density) artificial bone for realistic simulation of human bone density. Ten sites, including six sites mimicking extraction sockets (#6-11) and four mimicking healed sites (#3, 4, 13, 14), were selected from each model for implant placement. The #5,12 sites were excluded because their socket shape was much different from that of anterior maxilla sites.

The model was scanned using a CBCT scanner (3D Accuitomo 170; J Morita, Kyoto, Japan) to obtain the DICOM images. The exposure setting was 5 mA and 90 kVp for 17.5 s. The field of view (FOV) was 140 x 100 mm, and the voxel size was set at 0.27 mm. Optical scans of the model were made using a desktop scanner (D2000; 3Shape, Copenhagen, Denmark) and were exported as standard tessellation language (STL) files.

Study models (N=30) were divided into three groups: 1) Group 1, open-sleeve guided implant placement; 2) Group 2, closed-sleeve guided implant placement; 3) Group 3, free-hand implant placement. There were 10 models and 100 implant sites (60 fresh socket sites, 40 healed sites) in each group.

2.1 Digital Planning

Digital planning was performed by an experienced dentist using the implant planning software Blue Sky Plan (version 4.70; Blue Sky Bio LLC, Grayslake, IL), a 3D design software program Blender (Blender v2.83; The Blender Foundation, Amsterdam, Netherlands), and a dental computer-assisted design (CAD) software Exocad (exocad GmbH, Darmstadt, Germany). An implant system (3.5 × 13 mm; S.I.N. Sistema de Implante Nacional S.A., Sao Paulo, Brazil) was used for all the study sites. To design a prosthetically-driven implant position, a digital wax-up was constructed using Exocad. The optical model scan, digital wax-up, and the DICOM file were imported into the implant planning software. For anterior sites, implant placement was planned at the cingulum position. For the posterior regions, the implants were placed in a central groove position. To ensure primary stability, the implant position at fresh socket sites was planned so that at least 4 mm of the implant apex was surrounded by bone.

2.2 Guide fabrication

Two groups of sCAIS templates (with open- or closed-sleeves) were generated from the same implant planning project. One is an open-sleeve surgical template from iEZ Guide System (Qin Chuang Precision Technology Co., Ltd, Pingtung, Taiwan). It has interchangeable zirconia sleeves with a buccal opening. Another is a closed-sleeve surgical template from S.I.N. Implant system (S.I.N. Sistema de Implante Nacional S.A., Sao Paulo, Brazil). In each group, two surgical templates (one for sites #3, 7, 9, 11, 13; another for sites #4, 6, 8, 10, 14) were designed to provide sufficient space for adjacent sleeves. The guides were designed to be inserted from occlusal direction, the top, palatal, and part of buccal of the alveolar ridge were chosen as the support resigns as showed in Figure 1. The surgical templates were fabricated using a 3D printer

(SprintRay Pro; SprintRay Inc., Los Angeles, CA) with surgical guide resin (Surgical guide resin v2; SprintRay Inc., Los Angeles, CA). For the free-hand group, a special set of templates was designed and printed using the model resin (Model v2; Formlabs, Somerville, MA). This template helps the surgeon to decide the implant position by taking reference from the adjacent teeth. All the templates were tried on the models to ensure full seating and were visually checked by comparing with the digital plan. All the guides showed good fit after slight adjustment.

2.3 Implant placement

A surgeon (JL) who has five years implant surgery experience carried out all the implant placement procedures. Implant bed preparations were performed according to the manufacturer's recommended sequence of surgical drills. In both open- and closed-sleeve groups, surgical templates were used for the guidance of drills. For the free-hand group, the surgeon was allowed to take reference from digital planning on a laptop. To control factors other than open-sleeve and closed-sleeve, implant fixtures in three groups were all inserted by free-hand. After implant placement, scan-bodies were attached and fixed, and digital scanning was performed using the desktop scanner to capture images of the model and implant positions.

2.4 Evaluation

The previous digital plan in Blue Sky Plan was exported as a STL file and imported into the open-source software Blender. Post-operative scans were imported and superimposed to the digital plan using an iterative closest point (ICP) algorithm Blender add-on. 3D deviations between virtually planned and actual implant positions at the crest and apex were assessed. A programing script (Supplementary file 1) was written using Python (version 3.8) to perform all the measurements within Blender automatically. Thus, measurement errors from human observation were eliminated. In general, the x, y, z coordinates of the implant crest and apex centers in the 3D space were obtained. Then, the following deviation (Figure 2) values were calculated from these coordinates using mathematic formulas:

1. Global deviations: 3D distance from the center of the crest (or apex) of the planned and placed implant.
2. Horizontal deviations: the global deviation decomposed in a part perpendicular to the long axis of the planned position.
3. Depth deviation: the global deviation decomposed in a part parallel to the long axis of the planned position.
4. Angular deviation: 3D angle between the centerlines of the placed and planned implant.

2.5 Statistical Analysis

For data description, means and standard deviations (SD) were presented. All the statistical analysis was conducted using the SPSS package (version 23.0, SPSS inc., Chicago, IL, USA) , GraphPad Prism software (version 9.0, GraphPad Software Inc., San Diego, CA, USA), and the RStudio (version 2021.09.0, RStudio, Boston, MA, USA). Data normality was checked by the Kolmogorov-Smirnov test, and equality of variance was assessed by Levene's Test. The mean accuracy of different approaches (open-sleeve guided, closed-sleeve guided, and free-hand), and different sites (extraction sockets and healed sockets) were compared using a linear mixed model taking repeated measures structure into account. All reported p-values were two-sided, and the level of significance was set at $\alpha = 0.05$.

3. RESULTS

3.1 Implant accuracy at healed sites

For this analysis, only implants placed at #3, 4, 13, 14 were compared among groups (Table 1, Figure 3). Forty implants were placed in each group (open-sleeve, closed-sleeve, and free-hand), totaling 120 implants. Our results showed there were significant differences among the three groups in all measurements except for depth deviation. Post-hoc analysis revealed that the open-sleeve group was significantly more accurate than the free-hand group in terms of global coronal (0.49 ± 0.24 mm vs. 0.71 ± 0.35 mm), global apical (0.96 ± 0.49 mm vs. 1.55 ± 0.56 mm), horizontal coronal (0.44 ± 0.25 mm vs. 0.68 ± 0.37 mm), horizontal apical (0.94 ± 0.48 mm vs. 1.40 ± 1.53 mm), and angular deviations (2.86 ± 1.46 ° vs. 4.80 ± 4.60 °) with the exception of depth deviation (0.44 ± 0.25 mm vs. 0.68 ± 0.37 mm, no difference). The closed-sleeve group also had a similar depth deviation to the free-hand group. When comparing the open-sleeve group with the closed-sleeve group, they both had similar depth deviation. However, the closed-sleeve group had a significantly lower error in global coronal, global apical, horizontal coronal, horizontal apical, and angular deviations.

3.2 Implant accuracy at fresh socket sites

Implants (n = 180) placed in anterior maxillary fresh sockets (#6-11) were included in this analysis (Table 1, Figure 4). The open-sleeve group (global coronal: 0.77 ± 0.29 mm; global apical: 1.08 ± 0.49 mm; horizontal coronal: 0.60 ± 0.24 mm; horizontal apical: 0.95 ± 0.50 mm; angular: 4.32 ± 2.57°) showed significantly higher accuracy than the free-hand group (global coronal: 1.21 ± 0.50 mm; global apical: 1.91 ± 0.86 mm; horizontal coronal: 1.07 ± 0.54 mm; horizontal apical: 1.81 ± 0.86 mm; angular: 6.55 ± 3.61°) in all measurements except depth deviation (open-sleeve: 0.40 ± 0.31 mm; free-hand 0.45 ± 0.27 mm). Moreover, the open-sleeve group was also more accurate than the closed-sleeve group (global coronal: 0.91 ±0.22 mm; global apical: 1.37 ±0.52 mm; horizontal coronal: 0.86 ±0.20 mm; horizontal apical: 1.32 ±0.51 mm) in terms of global and horizontal deviations. However, the closed-sleeve group was more accurate regarding depth control (0.26 ± 0.20 mm vs. 0.40 ± 0.31 mm) and exhibited similar angular deviation (3.20 ± 2.01 mm vs. 4.23 ± 2.57 mm) to the open-sleeve group.

3.3 Accuracy difference between immediate and delayed implant placement

In each group, 40 implants were placed at healed sites and 60 implants were placed in fresh sockets, totaling 300 implants in this study. The accuracy difference analysis between immediate and delayed implant placement within each group was shown in Table 2. Not surprisingly, the implants placed at fresh sockets had more deviations than those at healed sites. The results here should be interpreted cautiously because all the fresh sockets were at anterior region while all healed sites were posterior.

4. DISCUSSION

The present study investigated the accuracy of a sCAIS system with a buccal open sleeve design by comparing it with a closed sleeve sCAIS system and free-hand approach in a simulated situation. Our results demonstrated that open-sleeve sCAIS provided significantly better accuracy than a free-hand approach for both delayed and immediate implant placement. When comparing the open-sleeve and closed-sleeve sCAIS systems, data suggested that the closed-sleeve system was more accurate for delayed implant placement (healed sites), but the open-sleeve system exhibited greater accuracy for anterior maxillary extraction sockets.

To the author's best knowledge, there was only one previous study compared an open-sleeve sCAIS with a closed-sleeve system (Tallarico et al., 2019). The article reported a trend of better accuracy for the closed-sleeve system. Nevertheless, that study had a very small sample size. Out of 119 placed implants, there were only 15 implant placement used open-sleeve guides. Moreover, no statistical analysis was performed to compare the two groups. In the current study, the open-sleeve system was slightly less accurate than the closed-sleeve system at healed sites. The buccal opening on the sleeve provides greater freedom of movement of the drills during osteotomy preparation, thus, there may be more deviation from the planned position if the osteotomy drills are not handled properly. Nevertheless, in the present study the difference between these two systems was quite small (accuracy mean difference: global coronal 0.13 mm, global apical 0.28 mm, angular 1.03 mm), and the open-sleeve system was still much more accurate than the free-hand approach. Considering its advantages of better visibility, irrigation, and less need for inter-arch distance, the open-sleeve sCAIS can be a good alternative to the closed-sleeve sCAIS system.

Previous studies have investigated the accuracy of closed-sleeve sCAIS systems at extraction sockets and healed sites. In an in vitro study using bone model, Kholy et al. reported that implant placement at extraction sockets demonstrated 50% higher mean apical and crestal 3D deviation (1.74 ± 0.25 mm and 0.95 ± 0.04 mm, respectively) compared to implants placed at healed sites (0.92 ± 0.1 mm and 0.6 ± 0.05 mm, respectively) (Kholy, Lazarin, et al., 2019). Furthermore, implants placed at immediate sites exhibited almost a two-fold increase in mean angular deviation (6.4 ± 1.2°) compared with implants placed at healed sites (3.2 ± 0.4°). These observations are similar to the present results. Nevertheless, due to an uneven anatomical distribution of the healed (all posterior sites) vs. extraction socket (all anterior) sites in the present study, the results comparing healed versus extraction socket sites should be interpreted cautiously.

It was observed that in anterior immediate implant locations, the open-sleeve system performed better than closed-sleeve sCAIS. The hypothesis explaining this maybe that the open-sleeve system allowed the surgeon to control the drills better. To place an implant at a cingulum position accurately in an anterior maxillary fresh socket, the drills must penetrate the palatal wall of the socket without shifting buccally. However, the angle between the drill inserting direction and the bony wall is usually small, which may cause a tendency for the drill to slide against the palatal wall, causing a buccal shift (Figure 5). For the closed-sleeve sCAIS, since the drill is fully restricted by the metal sleeve, there is limited visibility and space for the surgeon to correct the drill shift. When an open-sleeve guide is used, the surgeon could initially manipulate the drill to decrease sliding resistance from the palatal wall so the bone can be penetrated more easily; then, the correct drill position could be attained alongside the sleeve according to the pre-planned implant position.

A novel workflow for measuring implant deviation was developed during this study. Unlike previous studies where deviation measurements were done by humans, this workflow allowed us to directly obtain the x, y, z 3D space coordinates from the scans using a Python script, and all measurements were calculated by a computer. This eliminated human measurement errors and increased the validity of the study. Moreover, it allowed visualization of the implant deviation as shown in Figure 6. The coronal and apical central positions of each implant were displayed as points. The planned implant positions were marked as red, while the placed positions associated with the open-sleeve, closed-sleeve, and free-hand groups were marked as yellow, blue, and white, respectively. Points at apical positions generally exhibited more deviation than coronal points, and fresh sockets were associated with more deviation than healed sites. What was interesting is that immediate implant placement had a different pattern of deviation from delayed placement. The deviations at healed sites mostly surrounded the planned position circumferentially. However, the deviations at fresh sockets were distributed mostly in a buccal-lingual direction.

The results of the present study should be interpreted with caution duo to an in vitro design. In the actual clinical situation, the limited visual access, interference of anatomy structures, as well as limited mouth opening may affect the accuracy. In addition, there were two sCAIS system used in the current study. To control the factors other than sleeve design, the same digital plant, drills, implant fixtures, fixture inserting protocol (no fully-guided implant insertion) were used in all three groups. Future clinical trials are needed to validate the accuracy of open-sleeve systems, especially when compared to fully-guided sCAIS, and the influent of the difference buccal opening design .

CONCLUSION

This in vitro study demonstrated that open-sleeve sCAIS provided significantly better accuracy than free-hand implant surgery for both simulated healed site and extraction socket. When comparing an open-sleeve sCAIS system with a closed-sleeve sCAIS system, accuracy depended on the surgical approach. A closed-sleeve system was more accurate for delayed implant placement (healed sites), but an open-sleeve was more precise for anterior maxillary extraction sockets.

REFERENCE

Arısan, V., Karabuda, C. Z., & Özdemir, T. (2010). Implant surgery using bone-and mucosa-supported stereolithographic guides in totally edentulous jaws: Surgical and post-operative outcomes of computer-aided vs. Standard techniques. Clinical Oral Implants Research, 21, 980–988.

Bencharit, S., Staffen, A., Yeung, M., Whitley, D. 3rd, Laskin, D. M., & Deeb, G. R. (2018). In Vivo Tooth-Supported Implant Surgical Guides Fabricated With Desktop Stereolithographic Printers: Fully Guided Surgery Is More Accurate Than Partially Guided Surgery. Journal of Oral and Maxillofacial Surgery : Official Journal of the American Association of Oral and Maxillofacial Surgeons, 76, 1431–1439. doi: 10.1016/j.joms.2018.02.010

Cassetta, M., Di Mambro, A., Giansanti, M., Stefanelli, L., & Cavallini, C. (2013). The intrinsic error of a stereolithographic surgical template in implant guided surgery. International Journal of Oral and Maxillofacial Surgery, 42, 264–275.

Chen, Z, Li, J., Lin, C., & Wang, H. (2020). Trend of scientific production on digital implant dentistry (1990-2019): A bibliometric study. Stoma Edu J, 7, 123–130.

Chen, Z.,, Li, J., Sinjab, K., Mendonca, G., Yu, H., & Wang, H.-L. (2018). Accuracy of flapless immediate implant placement in anterior maxilla using computer-assisted versus freehand surgery: A cadaver study. Clinical Oral Implants Research, 29, 1186–1194. doi: 10.1111/clr.13382

Cristache, C. M., & Gurbanescu, S. (2017). Accuracy Evaluation of a Stereolithographic Surgical Template for Dental Implant Insertion Using 3D Superimposition Protocol. International Journal of Dentistry, 2017, 4292081. doi: 10.1155/2017/4292081

Cushen, S. E., & Turkyilmaz, I. (2013). Impact of operator experience on the accuracy of implant placement with stereolithographic surgical templates: An in vitro study. The Journal of Prosthetic Dentistry, 109, 248–254.

Deeb, G. R., Allen, R. K., Hall, V. P., Whitley, D. 3rd, Laskin, D. M., & Bencharit, S. (2017). How Accurate Are Implant Surgical Guides Produced With Desktop Stereolithographic. Journal of Oral and Maxillofacial Surgery : Official Journal of the American Association of Oral and Maxillofacial Surgeons, 75, 2559.e1-2559.e8. doi: 10.1016/j.joms.2017.08.001

Ersoy, A. E., Turkyilmaz, I., Ozan, O., & McGlumphy, E. A. (2008). Reliability of implant placement with stereolithographic surgical guides generated from computed tomography: Clinical data from 94 implants. Journal of Periodontology, 79, 1339–1345. doi: 10.1902/jop.2008.080059

Frösch, L., Mukaddam, K., Filippi, A., Zitzmann, N. U., & Kühl, S. (2019). Comparison of heat generation between guided and conventional implant surgery for single and sequential drilling protocols-An in vitro study. Clinical Oral Implants Research, 30, 121–130. doi: 10.1111/clr.13398

Joda, T., Derksen, W., Wittneben, J. G., & Kuehl, S. (2018). Static computer-aided implant surgery (s-CAIS) analysing patient-reported outcome measures (PROMs), economics and surgical complications: A systematic review. Clinical Oral Implants Research, 29 Suppl 16, 359–373. doi: 10.1111/clr.13136

Kholy, K. E., Janner, S. F. M., Schimmel, M., & Buser, D. (2019). The influence of guided sleeve height, drilling distance, and drilling key length on the accuracy of static

Computer-Assisted Implant Surgery. Clinical Implant Dentistry and Related Research, 21, 101–107. doi: 10.1111/cid.12705

Kholy, K. E., Lazarin, R., Janner, S. F. M., Faerber, K., Buser, R., & Buser, D. (2019). Influence of surgical guide support and implant site location on accuracy of static Computer - Assisted Implant Surgery. Clinical Oral Implants Research, 30, 1067-1075 doi: 10.1111/clr.13520

Kholy, K., Ebenezer, S., Wittneben, J.-G., Lazarin, R., Rousson, D., & Buser, D. (2019). Influence of implant macrodesign and insertion connection technology on the accuracy of static computer-assisted implant surgery. Clinical Implant Dentistry and Related Research, 21, 1073-1079. doi: 10.1111/cid.12836

Kühl, S., Payer, M., Zitzmann, N. U., Lambrecht, J. T., & Filippi, A. (2015). Technical Accuracy of Printed Surgical Templates for Guided Implant Surgery with the co Diagnosti X TM Software. Clinical implant dentistry and related research, 17, e177-e182.

Lewis, R. C., Harris, B. T., Sarno, R., Morton, D., Llop, D. R., & Lin, W.-S. (2015). Maxillary and mandibular immediately loaded implant-supported interim complete fixed dental prostheses on immediately placed dental implants with a digital approach: A clinical report. The Journal of Prosthetic Dentistry, 114, 315–322. doi: 10.1016/j.prosdent.2015.03.021

Li, J., Chen, Z., Chan, H.-L., Sinjab, K., Yu, H., & Wang, H.-L. (2019). Does flap opening or not influence the accuracy of semi-guided implant placement in partially edentulous sites? Clinical Implant Dentistry and Related Research, 21, 1253-1261 doi: 10.1111/cid.12847

Li, J., Chen, Z., Dong, B., Wang, H.-L., Joda, T., & Yu, H. (2020). Registering Maxillomandibular Relation to Create a Virtual Patient Integrated with a Virtual

Articulator for Complex Implant Rehabilitation: A Clinical Report. Journal of Prosthodontics, 29, 553-557. doi: 10.1111/jopr.13204

Lin, H.-H., Chiang, W.-C., Lo, L.-J., Sheng-Pin Hsu, S., Wang, C.-H., & Wan, S.-Y. (2013). Artifact-resistant superimposition of digital dental models and cone-beam computed tomography images. Journal of Oral and Maxillofacial Surgery: Official Journal of the American Association of Oral and Maxillofacial Surgeons, 71, 1933–1947. doi: 10.1016/j.joms.2013.06.199

Malo, P., de Araujo Nobre, M., & Lopes, A. (2007). The use of computer-guided flapless implant surgery and four implants placed in immediate function to support a fixed denture: Preliminary results after a mean follow-up period of thirteen months. The Journal of Prosthetic Dentistry, 97, S26–S34.

Moon, S.-Y., Lee, K.-R., Kim, S.-G., & Son, M.-K. (2016). Clinical problems of computer-guided implant surgery. Maxillofacial Plastic and Reconstructive Surgery, 38, 1-6. doi: 10.1186/s40902-016-0063-3

Muallah, J., Wesemann, C., Nowak, R., Robben, J., Mah, J., Pospiech, P., & Bumann, A. (2017). Accuracy of full-arch scans using intraoral and extraoral scanners: An in vitro study using a new method of evaluation. International Journal of Computerized Dentistry, 20, 151–164.

Raico Gallardo, Y. N., da Silva-Olivio, I. R. T., Mukai, E., Morimoto, S., Sesma, N., & Cordaro, L. (2017). Accuracy comparison of guided surgery for dental implants according to the tissue of support: A systematic review and meta-analysis. Clinical Oral Implants Research, 28, 602–612. doi: 10.1111/clr.12841

Siqueira, R., Chen, Z., Galli, M., Saleh, I., Wang, H.-L., & Chan, H.-L. (2020). Does a fully digital workflow improve the accuracy of computer-assisted implant surgery in partially edentulous patients? A systematic review of clinical trials. Clinical Implant Dentistry and Related Research, 22, 660–671. doi: 10.1111/cid.12937

Tallarico, M., Kim, Y.-J., Cocchi, F., Martinolli, M., & Meloni, S. M. (2019). Accuracy of newly developed sleeve-designed templates for insertion of dental implants: A prospective multicenters clinical trial. Clinical Implant Dentistry and Related Research, 21, 108–113. doi: https://doi.org/10.1111/cid.12704

Terzioğlu, H., Akkaya, M., & Ozan, O. (2009). The use of a computerized tomography-based software program with a flapless surgical technique in implant dentistry: A case report. The International Journal of Oral & Maxillofacial Implants, 24, 137–142.

Tables and Figures Legend:

Table 1. Accuracy difference between open-sleeve, closed-sleeve and free-hand approaches.

Table 2. Accuracy difference between immediate and delayed implant placement.

Figure 1. Illustration of study design. Thirty duplicated models were assigned to three groups. Three approaches, including computer-assisted implant surgical guides with open sleeves, closed sleeves, or free-hand, were used to place implants in three groups. The postoperative scans of the models were superimposed on a pre-surgical plan to assess implant placement accuracy

Figure 2. Measurements of implant deviation

Figure 3. Deviations of implant placement at healed sites (teeth #3, 4, 13, 14). Open (open-sleeve group); Closed (closed-sleeve group); Hand (free-hand group).

Figure 4. Deviations of implant placement at immediate implant sites (teeth #6-11). Open (open-sleeve group); Closed (closed-sleeve group); Hand (free-hand group).

Figure 5. Closed-sleeve systems may limit surgeon's control on drills. When drills reach the palatal bone plate, a small angle between the drill and bony wall may cause the drill to slide buccally. While an open-sleeve system is used, the opening allows surgeons to manipulate the initial drill angulation to reduce resistance. This may help to reduce buccal shifting of the drill.

Figure 6. Visualization of implant deviations. (a) 300 placed implants were superimposed into a single image. Each point represents the center of an implant at the crest/apex. (b) Close view of crestal level of site #7. Different groups are marked with varied colors. (c) Deviations at the crestal level (occlusal view). (d) Deviations at the apex level (occlusal view).

Table 1. Accuracy difference between open-sleeve, closed-sleeve and free-hand approaches.

	Deviations (mean ± SD)											
	Open-sleeve (n=100)				**Closed-sleeve (n=100)**				**Free-hand (n=100)**			
All sites	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Global deviation at crest (mm)	0.66	0.30	0.07	1.40	0.69	0.34	0.08	1.49	1.01	0.51	0.13	2.51
Global deviation at apex (mm)	1.03	0.49	0.10	3.55	1.09	0.56	0.17	2.98	1.76	0.77	0.43	4.30
Horizontal deviation at crest (mm)	0.54	0.25	0.03	1.24	0.63	0.34	0.07	1.18	0.91	0.52	0.04	2.41
Horizontal deviation at apex (mm)	0.94	0.49	0.14	2.82	1.05	0.56	0.08	3.44	1.81	0.86	0.42	4.23
Depth (mm)	0.30	0.28	0.00	1.07	0.23	0.17	0.00	0.84	0.32	0.27	0.00	1.08
Angulation (°)	3.73	2.30	0.17	9.11	2.65	1.79	0.07	13.1	5.77	3.17	0.93	18.75
	Open-sleeve (n=60)				**Closed-sleeve (n=60)**				**Free-hand (n=60)**			
Fresh sockets	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Global deviation at crest (mm)	0.77	0.29	0.16	1.40	0.91	0.22	0.25	1.49	1.21	0.50	0.19	2.51
Global deviation at apex (mm)	1.08	0.49	0.22	2.98	1.37	0.52	0.58	3.55	1.91	0.86	0.44	4.30
Horizontal deviation at crest (mm)	0.60	0.24	0.15	1.11	0.86	0.20	0.24	1.24	1.07	0.54	0.04	2.41
Horizontal deviation at apex (mm)	0.95	0.50	0.14	2.82	1.32	0.51	0.54	3.44	1.81	0.86	0.42	4.23
Depth (mm)	0.40	0.31	0.00	1.07	0.26	0.17	0.01	0.84	0.45	0.27	0.02	1.18
Angulation (°)	4.32	2.57	0.17	9.11	3.20	2.01	0.95	13.10	6.55	3.61	0.93	18.75
	Open-sleeve (n=40)				**Closed-sleeve (n=40)**				**Free-hand (n=40)**			
Healed sites	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Global deviation at crest (mm)	0.49	0.24	0.07	1.23	0.36	0.18	0.08	0.86	0.71	0.35	0.13	1.47
Global deviation at apex (mm)	0.96	0.49	0.17	2.20	0.68	0.33	0.10	1.63	1.55	0.56	0.43	2.61
Horizontal deviation at crest (mm)	0.44	0.25	0.07	1.18	0.28	0.15	0.03	0.57	0.68	0.37	0.08	1.47
Horizontal deviation at apex (mm)	0.94	0.48	0.15	2.18	0.64	0.32	0.08	1.40	1.53	0.57	0.41	2.61
Depth (mm)	0.15	0.14	0.00	0.71	0.19	0.15	0.00	0.80	0.13	0.11	0.00	0.52
Angulation (°)	2.86	1.46	0.28	7.03	1.83	0.95	0.07	4.80	4.60	1.86	0.97	8.06

SD: standard deviation; Min: minimum; Max: maximum.

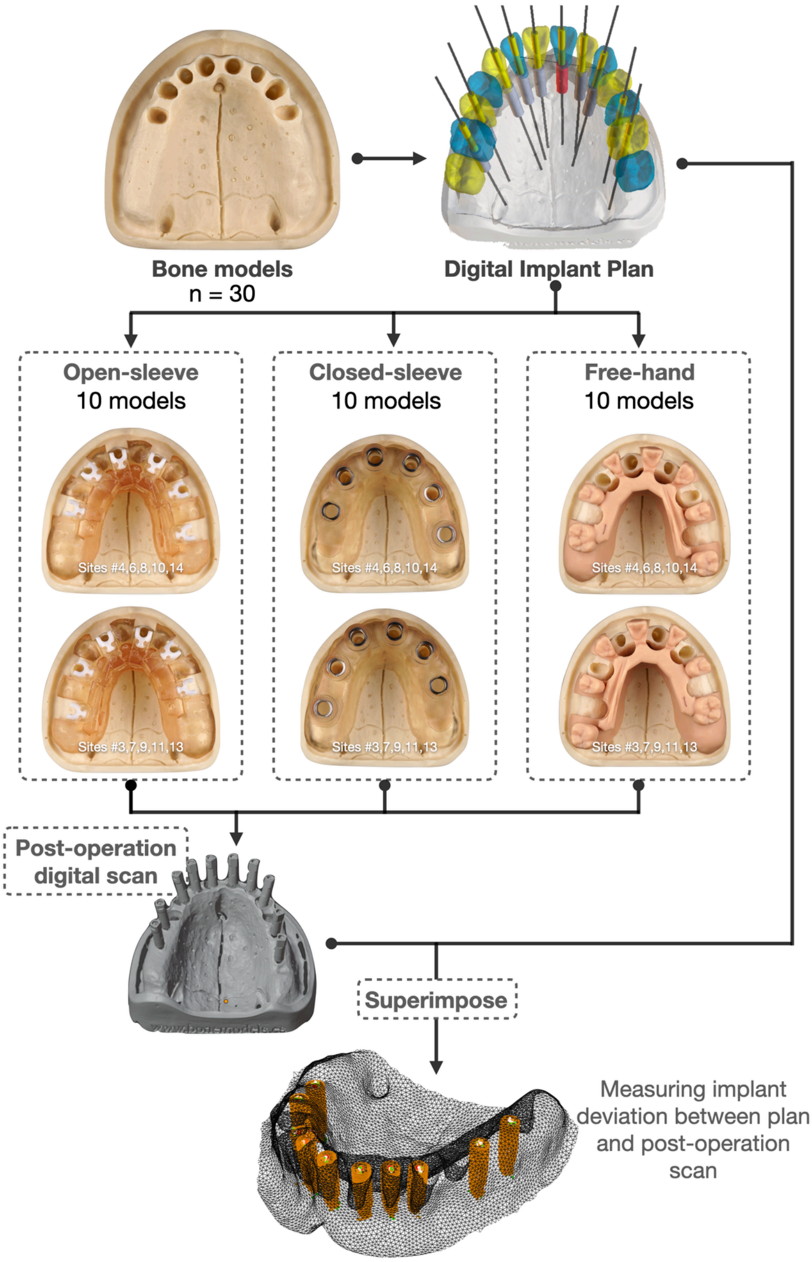
Table 2. Accuracy difference between immediate and delayed implant placement.

	Deviations (mean ± SD)			
Open-sleeve	**Fresh sockets (n=60)**	**Healed sites (n=40)**	**Difference (mean ± SEM)**	**P value**
Global deviation at crest (mm)	0.77 ± 0.29	0.49 ± 0.24	0.28 ± 0.66	<0.0001*
Global deviation at apex (mm)	1.08 ± 0.49	0.96 ± 0.49	0.11 ± 0.10	0.2469
Horizontal deviation at crest (mm)	0.60 ± 0.24	0.44 ± 0.25	0.16 ± 0.05	0.0011*
Horizontal deviation at apex (mm)	0.95 ± 0.50	0.94 ± 0.48	0.06 ± 0.09	0.9547
Depth (mm)	0.40 ± 0.31	0.15 ± 0.14	0.25 ± 0.05	<0.0001*
Angulation (°)	4.32 ± 2.57	2.86 ± 1.46	2.04 ± 0.38	0.0003*
Closed-sleeve	**Fresh sockets (n=60)**	**Healed sites (n=40)**	**Difference (mean ± SEM)**	**P value**
Global deviation at crest (mm)	0.91 ± 0.22	0.36 ± 0.18	0.55 ± 0.04	<0.0001*
Global deviation at apex (mm)	1.37 ± 0.52	0.68 ± 0.33	0.68 ± 0.09	<0.0001*
Horizontal deviation at crest (mm)	0.86 ± 0.20	0.28 ± 0.15	0.58 ± 0.04	<0.0001*

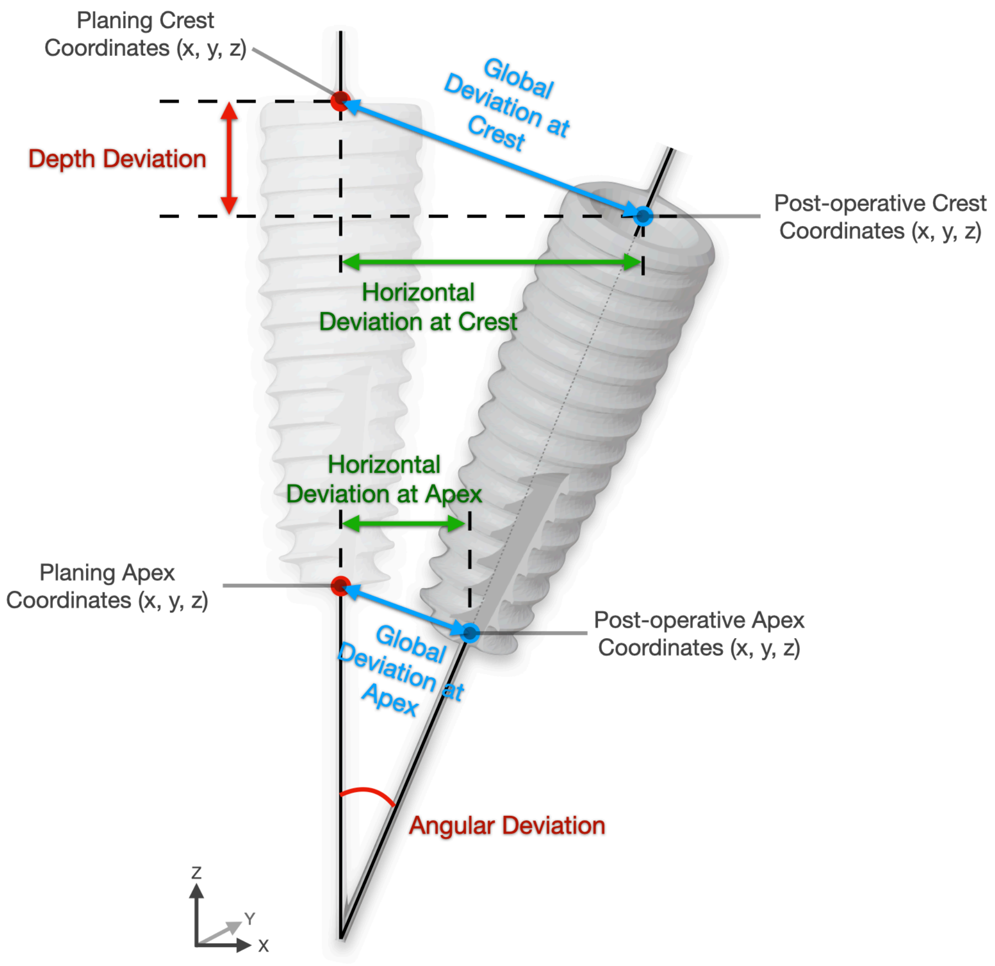
Horizontal deviation at apex (mm)	1.32±0.51	0.64±0.32	0.52±0.09	<0.0001*
Depth (mm)	0.26±0.17	0.19±0.15	0.07±0.03	0.5792
Angulation (°)	3.20±2.01	1.83±0.95	1.60±0.28	<0.0001*
Free-hand	**Fresh sockets (n=60)**	**Healed sites (n=40)**	**Difference (mean±SEM)**	**P value**
Global deviation at crest (mm)	1.21±0.50	0.71±0.35	0.50±0.09	<0.0001*
Global deviation at apex (mm)	1.91±0.86	1.55±0.56	0.35±0.15	0.0207*
Horizontal deviation at crest (mm)	1.07±0.54	0.68±0.37	0.39±0.10	<0.0001*
Horizontal deviation at apex (mm)	1.81±0.86	1.53±0.57	0.28±0.16	0.0742
Depth (mm)	0.45±0.27	0.13±0.11	0.28±0.06	<0.0001*
Angulation (°)	6.55±3.61	4.60±1.86	1.94±0.62	0.0010*

SD: standard deviation; SEM: standard error of mean.

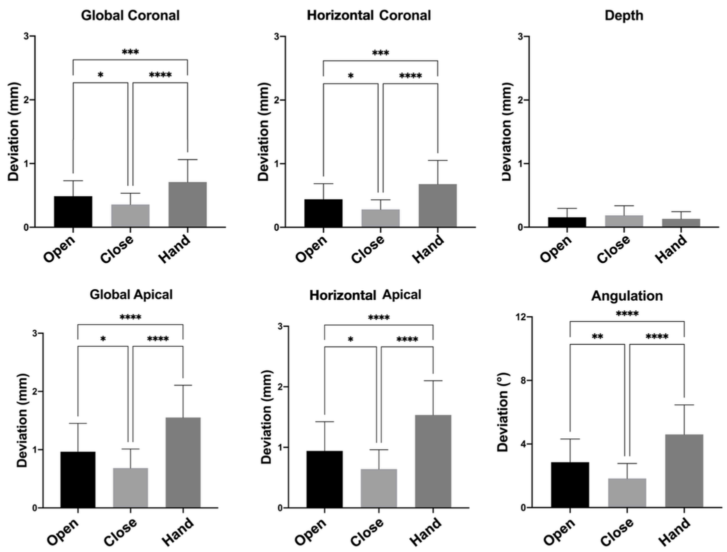
*Unpaired T-test was used to determine differences of implant's accuracy between fresh sockets and healed sites at a significant level of α<0.05.



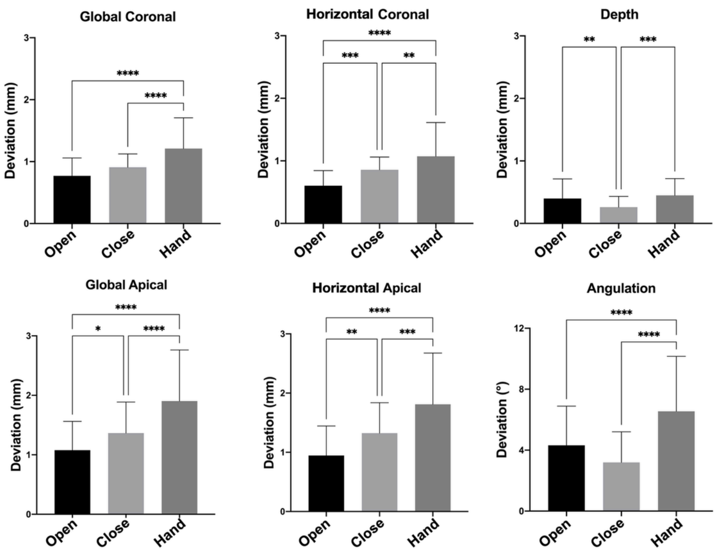
CLR_13957_Figure 1.tif



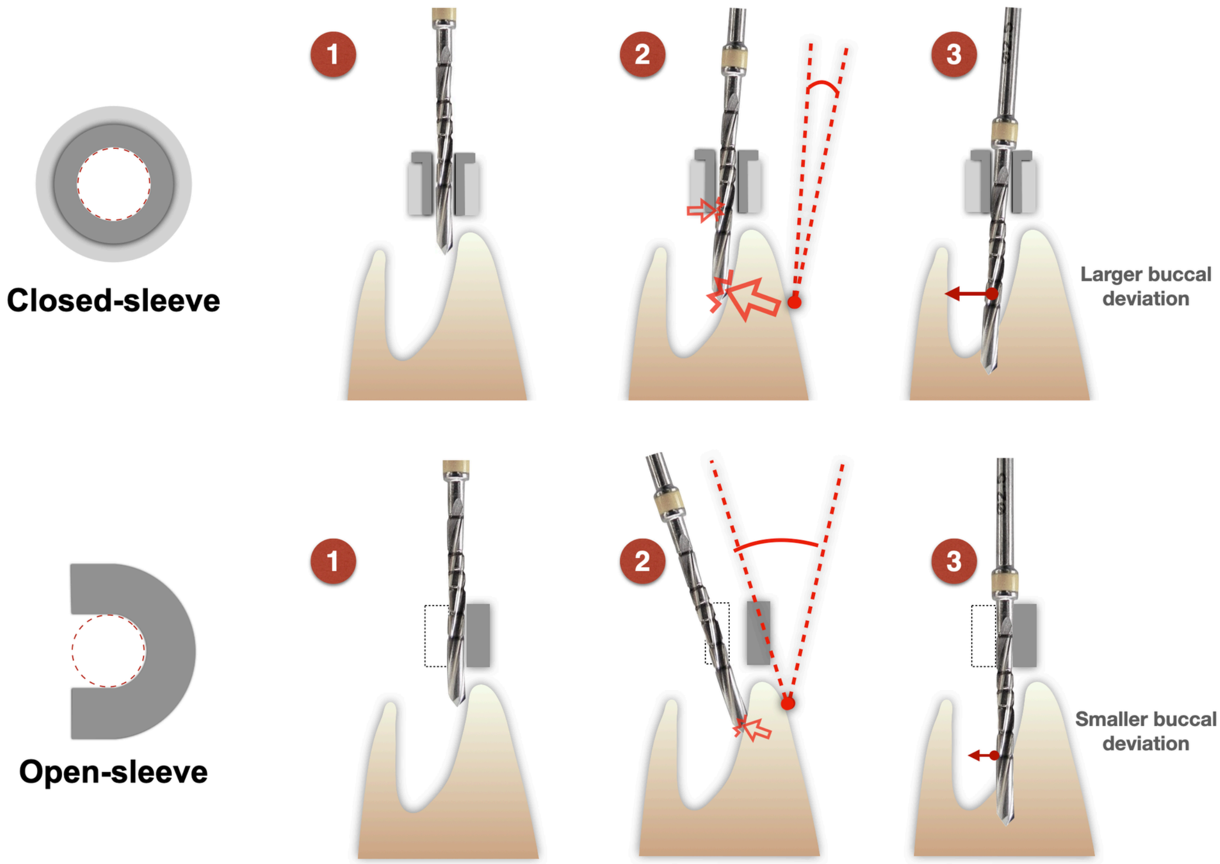
CLR_13957_Figure 2.tif



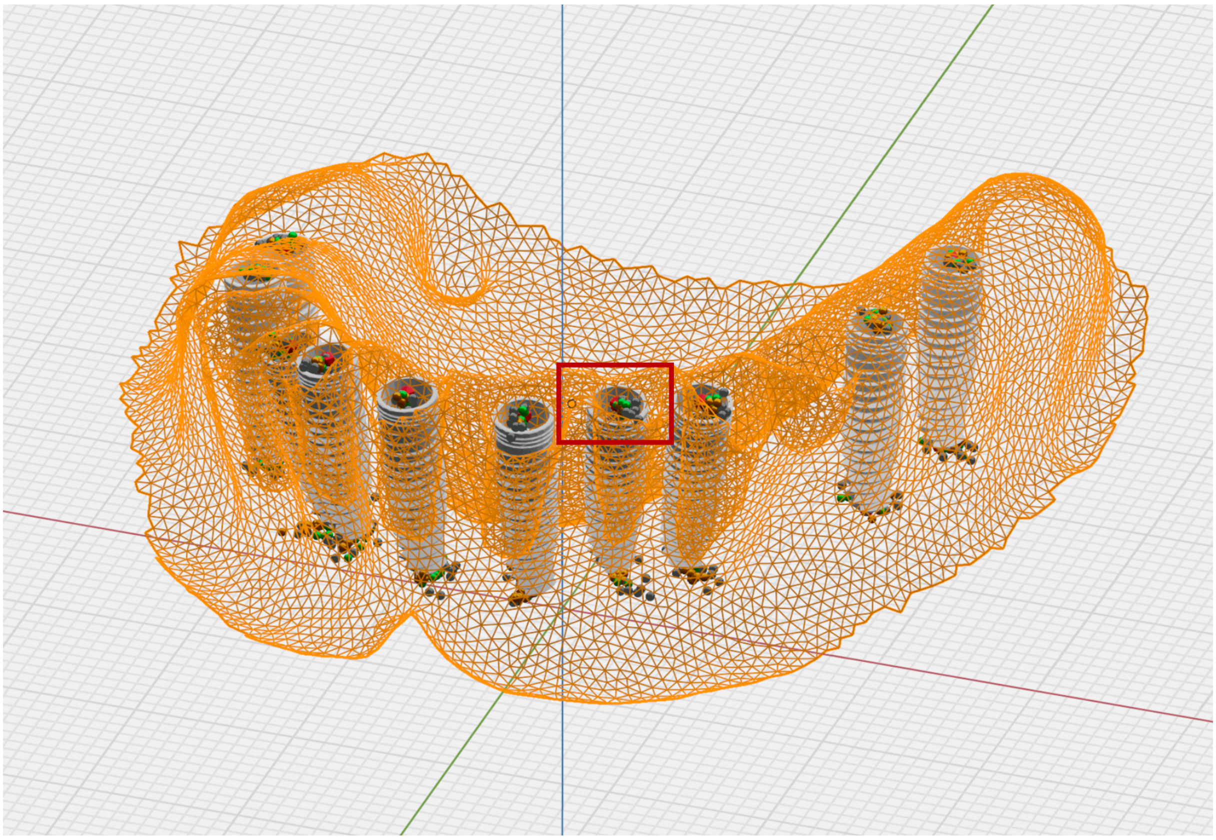
CLR_13957_Figure 3.tif



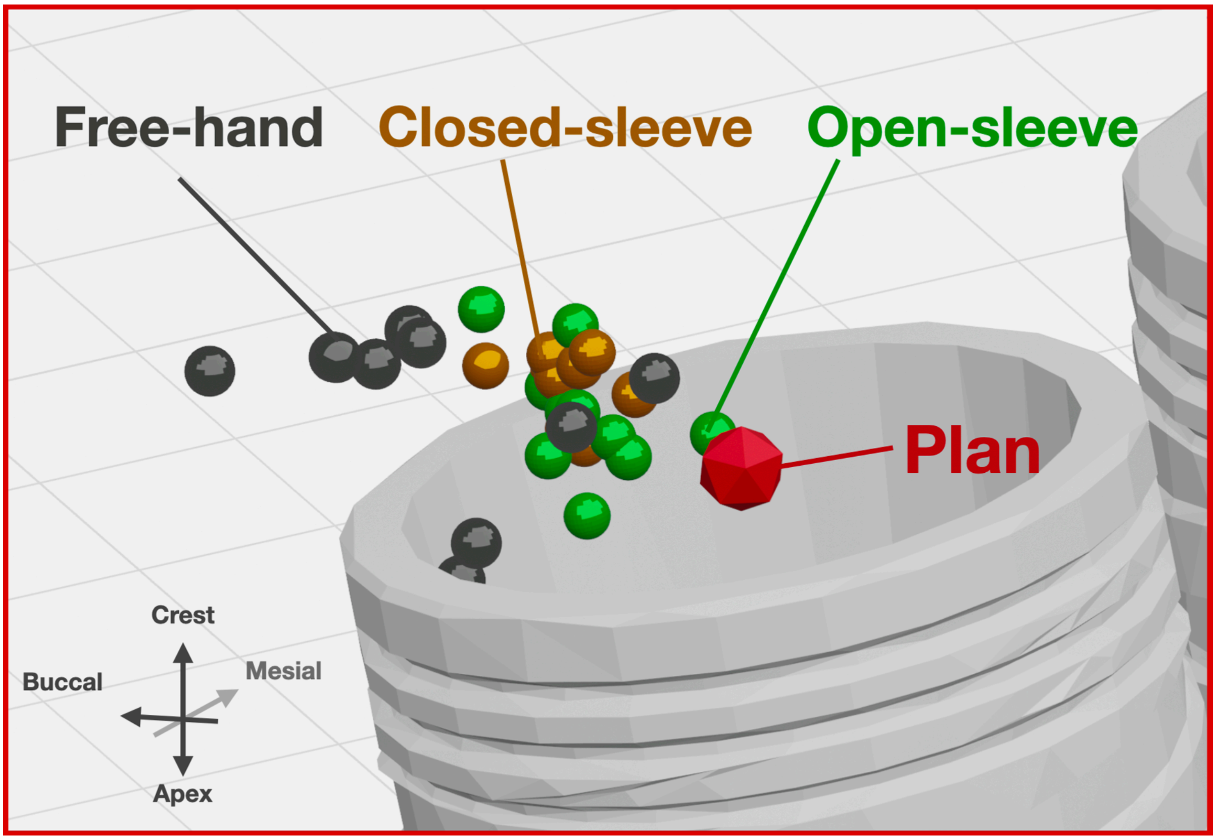
CLR_13957_Figure 4.tif



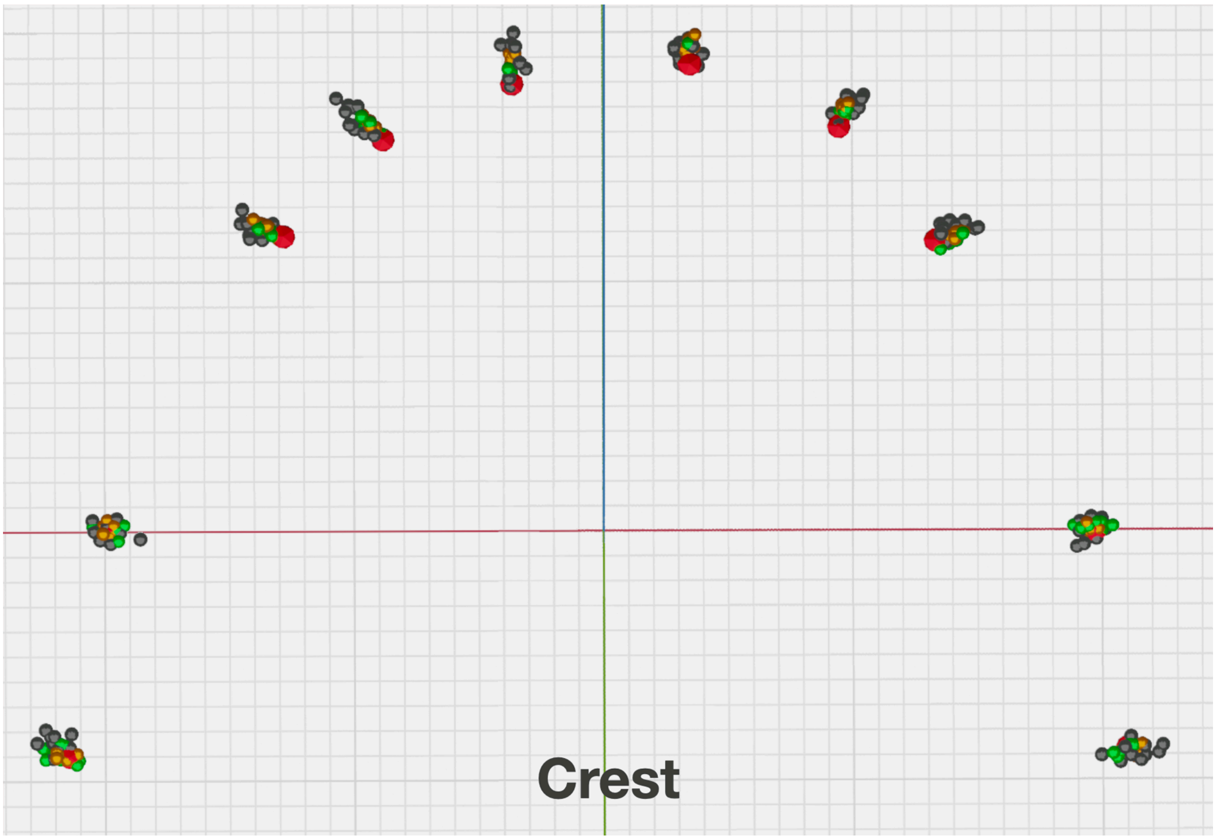
CLR_13957_Figure 5.tif



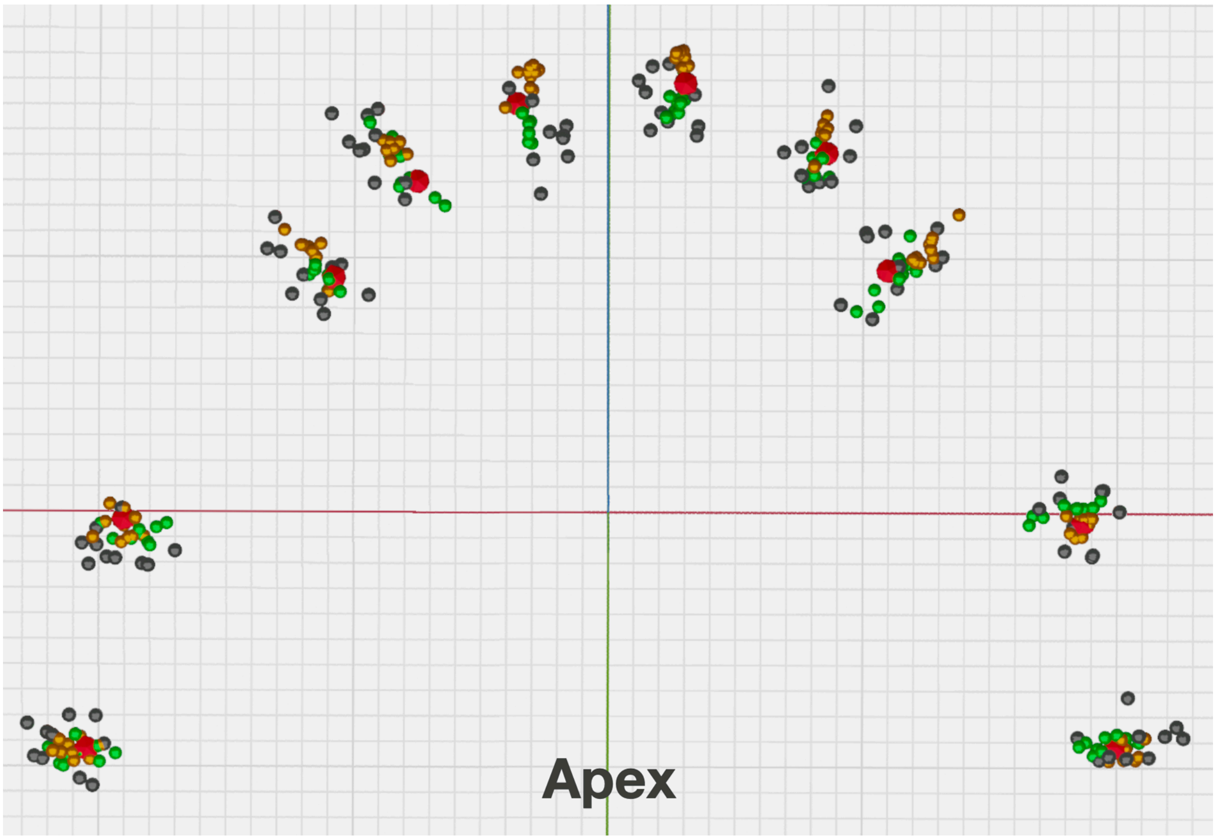
CLR_13957_Figure 6a.tif



CLR_13957_Figure 6b.tif



CLR_13957_Figure 6c.tif



CLR_13957_Figure 6d.tif

Table 1. Accuracy difference between open-sleeve, closed-sleeve and free-hand approaches.

	Deviations (mean ± SD)											
	Open-sleeve (n=100)				**Closed-sleeve (n=100)**				**Free-hand (n=100)**			
All sites	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Global deviation at crest (mm)	0.66	0.30	0.07	1.40	0.69	0.34	0.08	1.49	1.01	0.51	0.13	2.51
Global deviation at apex (mm)	1.03	0.49	0.10	3.55	1.09	0.56	0.17	2.98	1.76	0.77	0.43	4.30
Horizontal deviation at crest (mm)	0.54	0.25	0.03	1.24	0.63	0.34	0.07	1.18	0.91	0.52	0.04	2.41
Horizontal deviation at apex (mm)	0.94	0.49	0.14	2.82	1.05	0.56	0.08	3.44	1.81	0.86	0.42	4.23
Depth (mm)	0.30	0.28	0.00	1.07	0.23	0.17	0.00	0.84	0.32	0.27	0.00	1.08
Angulation (°)	3.73	2.30	0.17	9.11	2.65	1.79	0.07	13.1	5.77	3.17	0.93	18.75
	Open-sleeve (n=60)				**Closed-sleeve (n=60)**				**Free-hand (n=60)**			
Fresh sockets	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Global deviation at crest (mm)	0.77	0.29	0.16	1.40	0.91	0.22	0.25	1.49	1.21	0.50	0.19	2.51
Global deviation at apex (mm)	1.08	0.49	0.22	2.98	1.37	0.52	0.58	3.55	1.91	0.86	0.44	4.30
Horizontal deviation at crest (mm)	0.60	0.24	0.15	1.11	0.86	0.20	0.24	1.24	1.07	0.54	0.04	2.41
Horizontal deviation at apex (mm)	0.95	0.50	0.14	2.82	1.32	0.51	0.54	3.44	1.81	0.86	0.42	4.23
Depth (mm)	0.40	0.31	0.00	1.07	0.26	0.17	0.01	0.84	0.45	0.27	0.02	1.18
Angulation (°)	4.32	2.57	0.17	9.11	3.20	2.01	0.95	13.10	6.55	3.61	0.93	18.75
	Open-sleeve (n=40)				**Closed-sleeve (n=40)**				**Free-hand (n=40)**			
Healed sites	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Global deviation at crest (mm)	0.49	0.24	0.07	1.23	0.36	0.18	0.08	0.86	0.71	0.35	0.13	1.47
Global deviation at apex (mm)	0.96	0.49	0.17	2.20	0.68	0.33	0.10	1.63	1.55	0.56	0.43	2.61
Horizontal deviation at crest (mm)	0.44	0.25	0.07	1.18	0.28	0.15	0.03	0.57	0.68	0.37	0.08	1.47
Horizontal deviation at apex (mm)	0.94	0.48	0.15	2.18	0.64	0.32	0.08	1.40	1.53	0.57	0.41	2.61
Depth (mm)	0.15	0.14	0.00	0.71	0.19	0.15	0.00	0.80	0.13	0.11	0.00	0.52
Angulation (°)	2.86	1.46	0.28	7.03	1.83	0.95	0.07	4.80	4.60	1.86	0.97	8.06

SD: standard deviation; Min: minimum; Max: maximum.

Table 2. Accuracy difference between immediate and delayed implant placement.

	Deviations (mean ± SD)			
Open-sleeve	**Fresh sockets (n=60)**	**Healed sites (n=40)**	**Difference (mean±SEM)**	**P value**
Global deviation at crest (mm)	0.77±0.29	0.49±0.24	0.28±0.66	<0.0001*
Global deviation at apex (mm)	1.08±0.49	0.96±0.49	0.11±0.10	0.2469
Horizontal deviation at crest (mm)	0.60±0.24	0.44±0.25	0.16±0.05	0.0011*
Horizontal deviation at apex (mm)	0.95±0.50	0.94±0.48	0.06±0.09	0.9547
Depth (mm)	0.40±0.31	0.15±0.14	0.25±0.05	<0.0001*
Angulation (°)	4.32±2.57	2.86±1.46	2.04±0.38	0.0003*
Closed-sleeve	**Fresh sockets (n=60)**	**Healed sites (n=40)**	**Difference (mean±SEM)**	**P value**
Global deviation at crest (mm)	0.91±0.22	0.36±0.18	0.55±0.04	<0.0001*
Global deviation at apex (mm)	1.37±0.52	0.68±0.33	0.68±0.09	<0.0001*
Horizontal deviation at crest (mm)	0.86±0.20	0.28±0.15	0.58±0.04	<0.0001*
Horizontal deviation at apex (mm)	1.32±0.51	0.64±0.32	0.52±0.09	<0.0001*
Depth (mm)	0.26±0.17	0.19±0.15	0.07±0.03	0.5792
Angulation (°)	3.20±2.01	1.83±0.95	1.60±0.28	<0.0001*
Free-hand	**Fresh sockets (n=60)**	**Healed sites (n=40)**	**Difference (mean±SEM)**	**P value**
Global deviation at crest (mm)	1.21±0.50	0.71±0.35	0.50±0.09	<0.0001*
Global deviation at apex (mm)	1.91±0.86	1.55±0.56	0.35±0.15	0.0207*
Horizontal deviation at crest (mm)	1.07±0.54	0.68±0.37	0.39±0.10	<0.0001*
Horizontal deviation at apex (mm)	1.81±0.86	1.53±0.57	0.28±0.16	0.0742
Depth (mm)	0.45±0.27	0.13±0.11	0.28±0.06	<0.0001*
Angulation (°)	6.55±3.61	4.60±1.86	1.94±0.62	0.0010*

SD: standard deviation; SEM: standard error of mean.

*Unpaired T-test was used to determine differences of implant's accuracy between fresh sockets and healed sites at a significant level of α<0.05.