RAABE Clemens (Orcid ID: 0000-0003-2659-3505)

Influence of Drilling Sequence and Guide-hole Design on the Accuracy of static Computer-Assisted Implant Surgery in Extraction Sockets and Healed Sites - An In Vitro Investigation

Running title: Influence of drilling sequence on implant placement accuracy

Clemens RAABE, Fabrice Alain DULLA, Burak YILMAZ, Vivianne CHAPPUIS, Samir ABOU-AYASH

Clemens Raabe, Dr. med. dent., MAS clemens.raabe@unibe.ch

Senior Lecturer, Department of Oral Surgery & Stomatology; School of Dental Medicine, University of Bern, Switzerland.

Fabrice Alain Dulla, Dr. med. dent. fabrice.dulla@unibe.ch

Resident, Department of Oral Surgery & Stomatology; School of Dental Medicine, University of Bern, Switzerland.

Burak Yilmaz, Prof. Dr. med. dent. burak.yilmaz@unibe.ch

Faculty member, Department of Reconstructive Dentistry and Gerodontology; School of Dental Medicine, University of Bern, Switzerland

Department of Restorative, Preventive and Pediatric Dentistry, School of Dental Medicine, University of Bern, Bern, Switzerland

Division of Restorative and Prosthetic Dentistry, The Ohio State University College of Dentistry, Columbus, OH, USA

Vivianne Chappuis, Prof. Dr. med. dent. vivianne.chappuis@unibe.ch

Chair, Department of Oral Surgery & Stomatology; School of Dental Medicine, University of Bern, Switzerland

Samir Abou-Ayash, PD Dr. med. dent. samir.abou-ayash@unibe.ch

Deputy Department Chair, Department of Reconstructive Dentistry and Gerodontology; School of Dental Medicine, University of Bern, Switzerland

Conflict of Interest

The authors declare that they have no conflict of interest.

Correspondence Address

Dr. med. dent. Clemens Raabe, MAS, Department of Oral Surgery & Stomatology; University of Bern, Freiburgstrasse 7, CH-3010 Bern, Switzerland. E-mail: clemens.raabe@unibe.ch

Tel +41 31 632 25 57 | Fax +41 31 632 25 03

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1111/clr.14042

Acknowledgments

The authors would like to thank Mr. Lukas Martig for the statistical support.

Authors' Contributions

Clemens Raabe, Fabrice A. Dulla, and Samir Abou-Ayash contributed to the study's conception and design. Data acquisition, analyses, and interpretation were performed by Clemens Raabe and Fabrice A. Dulla with contributions from all authors. The first draft was written by Clemens Raabe and Samir Abou-Ayash, and all authors commented on previous versions of the manuscript. All authors approved the final manuscript.

ORCID

Clemens Raabe ORCID 0000-0003-2659-3505

Vivianne Chappuis ORCID 0000-0003-1227-7587

Conflict of Interest Statement

Clemens Raabe declares that he has no conflict of interest.

Fabrice A. Dulla declares that he has no conflict of interest.

Burak Yilmaz declares that he has no conflict of interest.

Vivianne Chappuis declares that she has no conflict of interest.

Samir Abou-Ayash declares that he has no conflict of interest.

Funding

This study was funded by the Fund for Dental Research of the Swiss Dental Association.

Data availability statement

All data for the conducted study is available.

Ethics approval statement

This *in vitro* study was exempt from approval by the committee of the state of Bern, Switzerland.

Abstract

Objectives:

To evaluate the effect of drilling sequence, guide-hole design, and alveolar ridge morphology on the accuracy of implant placement via static Computer-Assisted Implant Surgery (sCAIS).

Materials and Methods:

Standardized maxillary bone models including single tooth gaps with fresh extraction sockets or healed alveolar ridge morphologies were evaluated in this study. Implants were placed using different drilling sequences (i.e., complete (CDS) or minimum (MDS), and guide-hole designs (i.e., manufacturer's sleeve (MS) or sleeveless (SL) guide-hole designs). The time for implant placement via sCAIS procedures was also recorded. The angular, crestal, and apical three-dimensional deviations between planned and final implant positions were digitally obtained. Statistical analyses were conducted by a non-parametric three-way ANOVA (α=0.05).

Results:

Based on a sample size analysis, a total of 72 implants were included in this study. Significantly higher implant position accuracy was found at healed sites compared to extraction sockets, and in SL compared to MS guide-hole design in angular, crestal, and apical 3D deviations, $p \leq 0.048$). A tendency for higher accuracy was observed for the CDS compared to the MDS, although the effect was not statistically significant ($p=0.09$). The MDS required significantly shorter preparation times compared with CDS ($p<0.0001$).

Conclusion:

Implant placement via sCAIS resulted in higher accuracy in healed sites than extraction sockets, when using SL compared to MS guides, and tended to be more accurate when using CDS compared to MDS. Therefore, even though surgery time was shorter with MDS, its use should be limited to strictly selected cases.

<u>MeSH term keywords:</u>
Surgery, Computer-Assisted; Dental implants, Single-Tooth; Surgery, Image-Guided; tooth extraction, alveolar ridge.

<u>Word count:</u>
249

1. Introduction

Implant dentistry offers attractive treatment options with favorable long-term outcomes in the rehabilitation of partially and completely edentulous patients (Buser et al., 2012; Chappuis et al., 2018). However, implant success and survival may be compromised by various factors, including the three-dimensional implant position. An ideal implant position is restoration-driven and respects the local anatomy (Buser et al., 2004). However, pre-operative planning and intra-operative realization of the correct three-dimensional implant position can be challenging, especially in cases with deficient alveolar bone volume, proximity of critical anatomic structures, or complex prosthetic rehabilitation. The malposition of implants may result in an increased risk for esthetic, technical, mechanical, and biological complications.

To support the clinician in challenging situations, static Computer-Assisted Implant Surgery (sCAIS) enables comprehensive virtual treatment planning and guided implant placement. If performed properly, sCAIS may result in greater accuracy of implant positioning than freehanded procedures (Tahmaseb et al., 2018). Nonetheless, sCAIS is a technique-sensitive procedure with numerous variables that could affect the ideal transfer of a pre-planned implant position to the actual clinical situation. Some of these factors have been related to bone quality and quantity, the morphology of the alveolar ridge, free drilling distance, surgical guide support, guide-hole design, and implant system (Adams et al., 2022; Chen, Li, et al., 2022; Chen, Liu, et al., 2022; El Kholy, Ebenezer, et al., 2019; El Kholy, Janner, et al., 2019; El Kholy, Lazarin, et al., 2019; Laederach et al., 2017; Li et al., 2022; Putra et al., 2020; Sittikornpaiboon et al., 2021; Tallarico et al., 2019).

As implant systems evolved, advancements in design and material facilitated new surgical components that might affect the accuracy of the final implant position via sCAIS. The optimization of cutting geometry and surface properties of surgical drills for the implant bed preparation reduced friction between the drill, bone chips, and the osteotomy walls (Heuzeroth et al., 2021). These factors enable more aggressive proceedings when enlarging the diameter of the osteotomy site by optional skipping of drills and thereby reducing operation time. In turn, aggressive enlargement increases friction that potentially causes overheating at the implant site (Heuzeroth et al., 2021). Furthermore, increased friction may have the potential to shift the drill during implant bed preparation to the zone of less resistance, especially in sites of the alveolar ridge with high bone density, impairing the accuracy of the final implant position (Chen, Liu, et al., 2022).

The displacement of instruments or implants is interrelated to the tolerances of components in an implant system (Laederach et al., 2017). A guide-related component is the manufacturer's sleeve, facilitating the correct position of surgical instruments in the surgical guide. However, omission of the manufacturer's sleeve and incorporation of the sleeve dimensions to the actual surgical guide (i.e., sleeveless guide) was found to reduce instrument tolerance resulting in a more precise implant placement via sCAIS procedures (Adams et al., 2022; Schneider et al., 2015). Nevertheless, another factor causing discrepancies from the pre-planned implant position is the morphology of the alveolar ridge, as more accurate final implant placements were found in healed sites than in extractions sockets (Chen, Li, et al., 2022; El Kholy, Lazarin, et al., 2019; Li et al., 2022).

To date, there is no or only limited information for the above-mentioned factors, which are under the control of the clinician and may affect the accuracy of the final implant position via sCAIS. Therefore, this study specifically aims to evaluate the effect of drilling sequence, guide-hole design, and alveolar ridge morphology on the accuracy of implant placement via sCAIS. The 0-hypotheses were that the drilling sequence ($H0_1$), guide hole design ($H0_2$), alveolar ridge morphology ($H0_3$), and interaction of these factors ($H0_4$) would not affect the accuracy of implant placement via sCAIS. Furthermore, the time efficiency of two different drilling sequences was analyzed.

2. Materials and Methods

This study was conducted on radiopaque duplicate acrylic models (BoneModels, Castellón de la Plana, Spain) mimicking human bone with D2 density (Misch, 2015) with six single-tooth gaps in FDI positions 16, 14, 25 (fully healed alveolar ridge) and 12, 21, 23 (extraction socket morphology with type I sagittal root position according to (Kan et al., 2011)) as displayed in Figure 1. The study models were digitized using a cone-beam computed tomography (field of view 8x5cm, 90kV, 1mA, 3D Accuitomo 170, J. Morita Corp, Osaka, Japan) and a laboratory scanner (3Shape E4, 3Shape Inc, Copenhagen, Denmark). An ideal digital tooth set-up (Zirkonzahn.Modellier, Zirkonzahn GmbH, Gais, Italy) was designed for all edentulous sites. The resulting files were imported to the implant planning software (coDiagnostiX, version 10.5, Dental Wings Inc, Montreal, Canada) and prosthetically oriented virtual implant planning was performed by the same investigator (CR) for all models, respecting at least 4 mm of apical engagement in extraction socket sites.

The study involved two different drilling sequences for BLX 4.0×12 mm RB implants (Straumann AG, Basel, Switzerland) according to the manufacturer's recommendation for D2 bone density and two guide-hole designs:

The drilling sequences were as follows and are shown in Figure 1.

- Complete drilling sequence (CDS) involving drills with gradually increasing diameter: 2.2 mm -> 2.8 mm -> 3.2 mm -> 3.5 mm -> 3.75 mm (the last drill was used only for the preparation of 6 mm apical from the implant osteotomy crest).
- Minimum drilling sequence (MDS) involving only pilot and final drills: 2.2 mm -> 3.5 mm and 3.75 mm (the last drill was used only for the preparation of 6 mm apical from the implant osteotomy crest).

The guide-hole designs were as follows and are displayed in Figure 1.

- Sites using the manufacturer's sleeve (MS)
- Sleeveless sites (SL) with the incorporation of the manufacturer sleeve's dimensions to the actual surgical guide using a guide-hole offset of +0.09 mm

To standardize the surgical guides, the guide-hole offset was determined independently for a precise fit and proper handling of drilling keys by three sCAIS experienced investigators (C.R, S.A.A, F.A.D) using a guide-hole calibration matrix with various offsets. The matrix was printed with the 3D printer that was subsequently used for guide fabrication. A statistical consultant assigned the study groups (MDS/CDS; MS/SL) to an alveolar ridge morphology site (healed ridge/extraction socket) in a rotational order across the models.

All other parameters including drilling key height (6 mm), the distance from implant shoulder to sleeve (6 mm), and the free drilling distance (18 mm) were equally standardized at all implant sites. The guide design included a material thickness of 3.5 mm, a guide-to-tooth offset of 0.15 mm, and fenestrations for intraoperative visual evaluation of the guide's fit. All guides were manufactured by the same dental technician by using a light-cured transparent resin for stereolithography (ProArt Print Splint, Ivoclar Vivadent AG, Schaan, Lichtenstein) in a 3D printer (PrograPrint PR5, Ivoclar Vivadent AG, Schaan, Lichtenstein).

For proper simulation of the patient's position, the models were mounted in phantom heads. All fully guided sCAIS procedures were performed according to the manufacturer's recommendations by one experienced and board-certified oral surgeon (C.R) using a surgical motor (ichiropro, Bien Air, Bienne, Switzerland). The time for each implant drilling procedure was recorded starting with the use of the first drill until the completion of the last step of implant osteotomy. After guided placement of the implants, scan bodies were tightened, and a post-operative scan was taken of each model using the laboratory scanner (3Shape E4, 3Shape Inc, Copenhagen, Denmark). Subsequently, the postoperative scans were imported to the implant planning software (coDiagnostiX, version 10.5, Dental Wings Inc, Montreal, Canada). Finally, the superimposition of corresponding pre-operative planning and postoperative scan facilitated the automatic measurement of angular deviations in degrees, 3D deviation at implant crest, and apex in mm (Figure 2) using computer algorithms of the software's treatment evaluation tool.

2.1 Statistical analysis

A sample size analysis was conducted to find the minimum required number of models to detect significant differences between factors in drilling sequence (MDS/CDS), alveolar ridge morphology (healed/socket), and guide-hole design (MS/SL) in at least 80% of cases which resulted in a total 72 implants in a fully-crossed design, that is nine per factor combination ($2^3 = 8$ combinations in total). For sample size analysis, all three factors were assessed simultaneously by using a three-way non-parametric ART-ANOVA (Higgins, 2004). All collected data were summarized by using descriptive statistics and presented in box plots and tables. A non-parametric three-way ANOVA (Higgins, 2004) was executed for each of the primary and secondary outcomes, considering *p*-values < 0.05 statistically significant. The three-way ANOVA always assessed the factors “drilling sequence (MDS, CDS)”, “guide-hole design (MS, SL)”, and “alveolar ridge morphology (healed, socket)” including two-way and three-way interactions. In case of significance, post-hoc tests for “drilling sequence” were calculated. All analyses were performed with the statistics software R, version 4.0.4 (R Core Team, 2020).

3. Results

A total number of 72 implants was finally evaluated in this study, of which 36 implants were placed utilizing the MDS (n=18 MS, n=18 SL), and 36 implants were placed utilizing the CDS (n=18 MS, n=18 SL) in sites with either extraction socket or healed alveolar ridge morphology.

Both the alveolar ridge morphology and guide-hole design had a statistically significant effect on 3D implant deviation in the angular, crestal and apical landmarks, but not the drilling sequence as shown in Table 1. No statistically significant interactions were found.

Regarding the drilling sequence, implants placed using the CDS showed a trend for less deviation than the MDS. However, the differences were not statistically significant, as displayed in Table 2 and Figure 3. The MDS required shorter implant osteotomy times (155.92s ± 34s) than the CDS (210s ± 50s) ($p<0.0001$). Considering guide-hole design, significantly smaller deviation values were obtained for implants placed using SL guides compared with MS guides, as displayed in Table 2 and Figure 3. Finally, concerning the alveolar ridge morphology, statistically significant smaller deviation values were observed for implants placed in healed ridge sites compared with the implants placed in extraction sockets as shown in Table 2 and Figure 3.

The measured values in mean and medians from each subgroup and descriptive statistics are displayed in Table 3.

4. Discussion

4.1 Principal findings

The current study aimed at evaluating the effect of the drilling sequence, guide-hole design, and morphology of the alveolar ridge on the accuracy of implant placement via sCAIS. Implants were placed more accurately relative to the planned position, when sCAIS was performed in clinical scenarios simulating healed ridges and when sleeveless surgical guides were used. Therefore, $H0_2$ and $H0_3$ were rejected. The drilling sequence and the interaction of the single factors did not influence implant placement accuracy. Consequently, $H0_1$ and $H0_4$ could not be rejected.

4.2 Agreements and disagreements with previous findings

Manufacturers of recent implant systems include redesigned surgical drills and may suggest patient-centered drilling sequences, offering the option to skip drills upon the surgeon's choice. The findings of this study demonstrated, that a reduced number of drills (MDS) results in decreased implant bed preparation time compared to CDS. Interestingly, the shorter duration of surgery has been reported to be beneficial for both the surgeon and the patient, especially in complex surgical procedures with multiple implant placements. Tan and colleagues found shorter surgery duration associated with less bleeding, swelling, pain, and bruising in patients who underwent periodontal or implant surgical procedures (Tan et al., 2014). Additionally, reduced operation time might be financially advantageous. However, the reduction of surgical drills may result in more aggressive enlargement of the osteotomies' diameter along with increased friction between the drill, bone chips, and the osteotomy walls.

Firstly, increased friction may cause the displacement of the drill during osteotomy. The results of this investigation demonstrated small angular (CDS 2.63 ± 1.86°, MDS 2.98 ± 1.55°) and 3D implant deviations (crest: CDS 0.49 ± 0.28 mm, MDS 0.56 ± 0.30 mm; apex: CDS 0.97 ± 0.63 mm, MDS 1.10 ± 0.55 mm) between applied drilling sequences, indicating a tendency for increased accuracy for the CDS. Marheineke and collaborators investigated applying stepwise drilling procedures to a single drill sequence by measuring diameters of implant osteotomies and observed fewer metric discrepancies for the single-drill sequence (Marheineke et al., 2018). However, no implant placement and subsequent implant deviation measurements were evaluated, and thereby, no conclusion on the accuracy of the final implant position with respect to a pre-operative implant planning position could be drawn. One of the major disadvantages of MDS is the reduction of checkpoints during implant bed preparation to evaluate and, if necessary, correct the orientation of the implant osteotomy. Therefore, we recommended that this procedure should only be considered, when an adequate alveolar bone volume is present with no proximity to critical anatomical structures, or when future prosthetic options could compensate for discrepancies from the ideal implant axis (i.e., angulated screw access channels).

Secondly, increased friction may lead to an increase in the temperature of the alveolar bone, causing osteocyte damage and bone resorption (Dolan et al., 2012; A. R. Eriksson & Albrektsson, 1983; Franssen et al., 2008; Heuzeroth et al., 2021; Yarmolenko et al., 2011). To avoid overheating of the alveolar bone during implant osteotomy, meticulous and standardized drilling sequences were established over decades (R. A. Eriksson & Adell, 1986). Most recently, Heuzeroth and colleagues investigated thermal exposure and its impact on osseointegration for various drill designs and drilling procedures (Heuzeroth et al., 2021). For standard drills, a minimum drilling sequence resulted in increased thermal exposure of implant osteotomies and fewer bone-to-implant-contacts (BIC). On the contrary, significantly lower maximum temperatures and higher BIC were noticed when using designoptimized drills with a minimum drilling sequence. Nevertheless, other factors could affect the temperature changes during implant bed osteotomy including bone density, cooling type, wear, rotational speed, and diameter of the drill, (Augustin et al., 2012; Heuzeroth et al., 2021; Karaca et al., 2011; Pandey & Panda, 2013; Tehemar, 1999).

A significant confounding factor was the guide-hole design, as SL guides provided significantly more accurate implant placement than MS guides. These findings agree with the reported outcomes of a previous randomized controlled trial (Tallarico et al., 2019). However, other studies concluded similar accuracy for both SL and MS groups (Adams et al., 2022; Oh et al., 2021) but higher precision when using SL guides (Adams et al., 2022). The disadvantage of MS guide-holes might be design-related, as minimal gap spaces cause instrument tolerance but are necessary to interface all components of the guided system. MS guides require three gaps (between guide – MS, MS – key, and key – drill), whilst SL guides only require two gaps (between guide – key and key – drill) as the sleeve's dimensions are incorporated into the guide itself and thereby reduce tolerances.

Concerning the alveolar ridge morphology, the results of the recent study revealed that different morphologies of the ridge significantly influence the accuracy of the final implant position via sCAIS. Angular (healed sites 1.82 ± 0.81°, extraction sockets 3.79 ± 1.81°) and 3D implant deviations (crest: healed sites 0.31 ± 0.12 mm, extraction sockets 0.73 ± 0.26 mm; apex: healed sites 0.63 ± 0.25 mm, extraction sockets 1.44 ± 0.55 mm) were in favor of healed sites compared to fresh extraction sockets. These results are in line with the findings of previous studies, where the authors observed similar angular (healed sites 1.57 ± 0.83° up to 3.2 ± 0.4°, extraction sockets 2.36 ± 1.1° up to 6.4 ± 1.2°) and 3D implant deviations (crest: healed sites 0.39 ± 0.16 mm up to 1.09 ± 0.17 mm, extraction sockets 0.74 ± 0.15 mm up to 1.24 ± 0.26 mm; apex: healed sites 0.67 ± 0.31 mm up to 1.40 ± 0.30 mm, extraction sockets 1.19 ± 0.35 mm up to 1.74 ± 0.25 mm) when using sCAIS (Chen, Li, et al., 2022; El Kholy, Lazarin, et al., 2019; Li et al., 2022). Given these observations, clinicians must be aware of the challenging anatomical situation and expect more pronounced deviations when placing implants using sCAIS in fresh extraction sockets compared to implant placement in a fully healed ridge. Existing literature advises safety distances of 1 – 2 mm between implants and critical adjacent anatomic structures (Buser et al., 2004; Greenstein & Tarnow, 2006), which becomes questionable in the light of mean apical implant deviations (1.54 ± 0.55 mm) for sCAIS procedures in fresh extraction sockets. Based on the findings of the present study, a need for larger safety distances is indicated in this type of clinical scenario.

4.3 Limitations and recommendations for future research

First, this study only included one type of implant system with standardized implant diameter and length. Therefore, the findings of this study should be interpreted with caution when using other implant systems, as both surgical components and implant macro-design influence the accuracy of sCAIS (Schnutenhaus et al., 2022). Second, only the drilling sequence for one implant diameter in a scenario simulating D2 bone density was evaluated. Moreover, higher or lower discrepancies could be observed according to different bone densities. Third, the alveolar ridge morphologies were unevenly positioned in the model, as the extraction sockets were in the anterior and the healed sites in the posterior regions and related bias cannot be ruled out. Additionally, the morphology of the single rooted extraction socket was uncompromised, and care should be taken when transferring the results to extraction sockets with altered or multi-rooted morphology. Fourth, the interaction terms had small p-values but did not reach significance, which must be interpreted with caution, as the sample size calculation was conducted for the single factors but not the interaction terms. Finally, although this is an *in vitro* study and could be interpreted as a limitation, the study design facilitates effective investigation of individual factors by standardization of several variables. However, these variables could influence the outcomes observed in this study in daily practice. Therefore, the clinician is responsible to evaluate the 3D orientation of implant osteotomies and correct the position in a freehanded manner, when sCAIS procedures fail. To further improve the accuracy of implant placement via sCAIS, other potentially modulating factors involving different bone densities, drill designs, or ridge morphologies (Type II/Type III implant placement) need to be evaluated preclinically and validated in clinical studies.

5. Conclusion

Within the limitations of the study, we conclude that the accuracy of implant placement via sCAIS:

1) Tended to be higher when using complete drilling sequences than minimum drilling sequences. Even though surgery time was shorter with MDS, the use of minimum drilling sequences should be limited to strictly selected cases.
2) Was significantly affected by the morphology of the implant site, as higher accuracy was achieved in healed sites than in extraction sockets.
3) Was significantly affected by the guide-hole design, as higher accuracy was found for sleeveless guides compared to guides with the manufacturer's sleeve.

Therefore, these factors should be taken into consideration to optimize the accuracy of the final implant position via sCAIS.

References

Adams, C. R., Ammoun, R., Deeb, G. R., & Bencharit, S. (2022). Influence of metal guide sleeves on the accuracy and precision of dental implant placement using guided implant surgery: An in vitro study. *Journal of Prosthodontics*, *0*, 1–9. https://doi.org/10.1111/jopr.13503

Augustin, G., Zigman, T., Davila, S., Udilljak, T., Staroveski, T., Brezak, D., & Babic, S. (2012). Cortical bone drilling and thermal osteonecrosis. *Clinical Biomechanics*, *27*(4), 313–325. https://doi.org/10.1016/j.clinbiomech.2011.10.010

Buser, D., Janner, S. F. M., Wittneben, J.-G., Brägger, U., Ramseier, C. A., & Salvi, G. E. (2012). 10-year survival and success rates of 511 titanium implants with a sandblasted and acid-etched surface: A retrospective study in 303 partially edentulous patients. *Clinical Implant Dentistry and Related Research*, *14*(6), 839–851. https://doi.org/10.1111/j.1708-8208.2012.00456.x

Buser, D., Martin, W., & Belser, U. C. (2004). Optimizing esthetics for implant restorations in the anterior maxilla: anatomic and surgical considerations. *The International Journal of Oral & Maxillofacial Implants*, *19 Suppl*(January), 43–61. http://www.ncbi.nlm.nih.gov/pubmed/15635945

Chappuis, V., Rahman, L., Buser, R., Janner, S. F. M., Belser, U. C., & Buser, D. (2018). Effectiveness of contour augmentation with guided bone regeneration: 10-year results. *Journal of Dental Research*, *97*(3), 266–274. https://doi.org/10.1177/0022034517737755

Chen, Z., Li, J., Ceolin, P., Galli, M., Mendonça, G., & Wang, H. L. (2022). Does guided level (fully or partially) influence implant placement accuracy at post - extraction sockets and healed sites ? An in vitro study. *Clinical Oral Investigations*, *0123456789*. https://doi.org/10.1007/s00784-022-04512-y

Chen, Z., Liu, Y., Xie, X., & Deng, F. (2022). Influence of bone density on the accuracy of artificial intelligence–guided implant surgery: An in vitro study. *The Journal of Prosthetic Dentistry*, 1–8. https://doi.org/10.1016/j.prosdent.2021.07.019

Dolan, E. B., Haugh, M. G., Tallon, D., Casey, C., & McNamara, L. M. (2012). Heat-shock-induced cellular responses to temperature elevations occurring during orthopaedic cutting. *Journal of the Royal Society Interface*, *9*(77), 3503–3513. https://doi.org/10.1098/rsif.2012.0520

El 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*(5), 1073–1079. https://doi.org/10.1111/cid.12836

El Kholy, K., 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*(1), 101–107. https://doi.org/10.1111/cid.12705

El Kholy, K., 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*(11), 1067–1075. https://doi.org/10.1111/clr.13520

Eriksson, A. R., & Albrektsson, T. (1983). Temperature threshold levels for heat-induced bone tissue injury: A vital-microscopic study in the rabbit. *The Journal of Prosthetic Dentistry*, *50*(1), 101–107. https://doi.org/https://doi.org/10.1016/0022-3913(83)90174-9

Eriksson, R. A., & Adell, R. (1986). Temperatures during drilling for the placement of implants using the osseointegration technique. *Journal of Oral and Maxillofacial Surgery*, *44*(1), 4–7. https://doi.org/https://doi.org/10.1016/0278-2391(86)90006-6

Franssen, B. B. G. M., Diest, P. J., Schuurman, A. H., & Kon, M. (2008). Drilling k-wires, what about the osteocytes? An experimental study in rabbits. *Archives of Orthopaedic and Trauma Surgery*, *128*(1), 83–87. https://doi.org/10.1007/s00402-007-0382-z

Greenstein, G., & Tarnow, D. (2006). The mental foramen and nerve: Clinical and anatomical factors related to dental implant placement: A literature review. *Journal of Periodontology*, *77*(12), 1933–1943. https://doi.org/10.1902/jop.2006.060197

Heuzeroth, R., Pippenger, B. E., Sandgren, R., Bellón, B., & Kühl, S. (2021). Thermal exposure of implant osteotomies and its impact on osseointegration—A preclinical in vivo study. *Clinical Oral Implants Research*, *32*(6), 672–683. https://doi.org/10.1111/clr.13729

Higgins, J. J. (2004). *An introduction to modern nonparametric statistics*. Brooks/Cole.

Kan, J. Y. K., Roe, P., Rungcharassaeng, K., Patel, R. D., Waki, T., Lozada, J. L., & Zimmerman, G. (2011). Classification of sagittal root position in relation to the anterior maxillary osseous housing for immediate implant placement: a cone beam computed tomography study. *The International Journal of Oral & Maxillofacial Implants*, *26*(4), 873–876. http://www.ncbi.nlm.nih.gov/pubmed/21841998

Karaca, F., Aksakal, B., & Kom, M. (2011). Influence of orthopaedic drilling parameters on temperature and histopathology of bovine tibia: An in vitro study. *Medical Engineering and Physics*, *33*(10), 1221–1227. https://doi.org/10.1016/j.medengphy.2011.05.013

Laederach, V., Mukaddam, K., Payer, M., Filippi, A., & Kühl, S. (2017). Deviations of different systems for guided implant surgery. *Clinical Oral Implants Research*, *28*(9), 1147–1151. https://doi.org/10.1111/clr.12930

Li, J., Meneghetti, P. C., Galli, M., Mendonca, G., Chen, Z., & Wang, H. L. (2022). 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. *Clinical Oral Implants Research*, *May 2021*, 1–11. https://doi.org/10.1111/clr.13957

Marheineke, N., Scherer, U., Rücker, M., von See, C., Rahlf, B., Gellrich, N. C., & Stoetzer, M. (2018). Evaluation of accuracy in implant site preparation performed in single- or multi-step drilling procedures. *Clinical Oral Investigations*, *22*(5), 2057–2067. https://doi.org/10.1007/s00784-017-2312-y

Misch, C. E. (2015). *Chapter 11 - Bone Density: A Key Determinant for Treatment Planning. Dental Implant Prosthetics (Second Edition)*. Mosby.

Oh, K. C., Shim, J. S., & Park, J. M. (2021). In vitro comparison between metal sleeve-free and metal sleeve-incorporated 3d-printed computer-assisted implant surgical guides. *Materials*, *14*(3), 1–10. https://doi.org/10.3390/ma14030615

Pandey, R. K., & Panda, S. S. (2013). Drilling of bone: A comprehensive review. In *Journal of Clinical Orthopaedics and Trauma* (Vol. 4, Issue 1, pp. 15–30). https://doi.org/10.1016/j.jcot.2013.01.002

Putra, R. H., Yoda, N., Iikubo, M., Kataoka, Y., Yamauchi, K., Koyama, S., Cooray, U., Astuti, E. R., Takahashi, T., & Sasaki, K. (2020). Influence of bone condition on implant placement accuracy with computer-guided surgery. *International Journal of Implant Dentistry*, *6*(1). https://doi.org/10.1186/s40729-020-00249-z

R Core Team, R. (2020). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing.

Schneider, D., Schober, F., Grohmann, P., Hammerle, C. H. F., & Jung, R. E. (2015). In-vitro evaluation of the tolerance of surgical instruments in templates for computer-assisted guided implantology produced by 3-D printing. *Clinical Oral Implants Research*, *26*(3), 320–325. https://doi.org/10.1111/clr.12327

Schnutenhaus, S., Edelmann, C., Wetzel, M., & Luthardt, R. G. (2022). Influence of the macrodesign of an implant and the sleeve system on the accuracy of template-guided implant placement: A prospective clinical study. *The Journal of Prosthetic Dentistry*. https://doi.org/10.1016/J.PROSDENT.2021.09.016

Sittikornpaiboon, P., Arunjaroensuk, S., Kaboosaya, B., Subbalekha, K., Mattheos, N., & Pimkhaokham, A. (2021). Comparison of the accuracy of implant placement using different drilling systems for static computer-assisted implant surgery: A simulation-based experimental study. *Clinical Implant Dentistry and Related Research*, cid.13032. https://doi.org/10.1111/cid.13032

Tahmaseb, A., Wu, V., Wismeijer, D., Coucke, W., & Evans, C. (2018). The accuracy of static computer-aided implant surgery: A systematic review and meta-analysis. *Clinical Oral Implants Research*, *29*(December 2017), 416–435. https://doi.org/10.1111/clr.13346

Tallarico, M., Martinolli, M., Kim, Y. J., Cocchi, F., Meloni, S. M., Alushi, A., & Xhanari, E. (2019). Accuracy of computer-assisted template-based implant placement using two different surgical templates designed with or without metallic sleeves: A randomized controlled trial. *Dentistry Journal*, *7*(2), 1–11. https://doi.org/10.3390/dj7020041

Tan, W. C., Krishnaswamy, G., Ong, M. M. A., & Lang, N. P. (2014). Patient-reported outcome measures after routine periodontal and implant surgical procedures. *Journal of Clinical Periodontology*, *41*(6), 618–624. https://doi.org/10.1111/jcpe.12248

Tehemar, S. H. (1999). Factors affecting heat generation during implant site preparation: a review of biologic observations and future considerations. *The International Journal of Oral & Maxillofacial Implants*, *14*(1), 127–136.

Yarmolenko, P. S., Moon, E. J., Landon, C., Manzoor, A., Hochman, D. W., Viglianti, B. L., & Dewhirst, M. W. (2011). Thresholds for thermal damage to normal tissues: An update. In *International Journal of Hyperthermia* (Vol. 27, Issue 4, pp. 320–343). https://doi.org/10.3109/02656736.2010.534527

Tables

Factor	Angular deviation	3D deviation crest	3D deviation apex
Drilling sequence	*0.31*	*0.09*	*0.37*
Alveolar ridge morphology	*< 0.0001****	*< 0.0001****	*< 0.0001****
Guide-hole design	*0.03**	*0.048**	*0.02**
Drilling sequence: Alveolar ridge morphology	*0.86*	*0.38*	*0.69*
Alveolar ridge morphology: Guide-hole design	*0.28*	*0.92*	*0.28*
Drilling sequence: Guide-hole design	*0.39*	*0.69*	*0.44*
DS:ARM:GHD	*0.83*	*0.29*	*0.63*

Table 1

ANOVA results showing the p-values of the factors 1) drilling sequence, 2) alveolar ridge morphology, 3) guide-hole design, and their combination. DS: drilling sequence; ARM: alveolar ridge morphology; GHD: guide-hole design. **p*-values <0.05, ****p-values<0.001*.

Factor	Subgroup	n	Mean	SD	Min	Q1	Median	Q3	Max
Angular deviation (°)									
Drilling sequence	CDS	**36**	**2.63**	1.86	0.30	1.35	**2.00**	3.70	6.80
	MDS	**36**	**2.98**	1.55	0.60	1.70	**2.65**	4.00	6.40
Alveolar Ridge Morphology * **	healed ridge	**36**	**1.82**	0.81	0.30	1.20	**1.70**	2.23	4.00
	extraction socket	**36**	**3.79**	1.81	0.50	2.40	**3.95**	5.08	6.80
**Guide-hole design * **	MS	**36**	**2.90**	1.73	0.80	1.63	**2.40**	3.98	6.80
	SL	**36**	**2.34**	1.56	0.30	1.20	**1.85**	3.30	6.40
3D deviation crest (mm)									
Drilling sequence	CDS	**36**	**0.49**	0.28	0.06	0.28	**0.35**	0.69	1.25
	MDS	**36**	**0.56**	0.30	0.10	0.33	**0.51**	0.76	1.23
Alveolar Ridge Morphology * **	healed ridge	**36**	**0.31**	0.12	0.06	0.22	**0.31**	0.41	0.63
	extraction socket	**36**	**0.73**	0.26	0.24	0.60	**0.78**	0.87	1.25
**Guide-hole design * **	MS	**36**	**0.54**	0.29	0.17	0.34	**0.44**	0.78	1.25
	SL	**36**	**0.45**	0.26	0.06	0.28	**0.35**	0.62	1.07
3D deviation apex (mm)									
Drilling sequence	CDS	**36**	**0.97**	0.63	0.24	0.50	**0.75**	1.51	2.31
	MDS	**36**	**1.10**	0.55	0.20	0.73	**1.03**	1.46	2.22
Alveolar Ridge Morphology * **	healed ridge	**36**	**0.63**	0.25	0.20	0.44	**0.65**	0.78	1.19
	extraction socket	**36**	**1.44**	0.55	0.41	1.11	**1.50**	1.84	2.31
**Guide-hole design * **	MS	**36**	**1.07**	0.61	0.24	0.64	**0.89**	1.49	2.31
	SL	**36**	**0.86**	0.54	0.20	0.48	**0.72**	1.22	2.20

Table 2

Descriptive statistics of angular, crestal, and apical 3D implant deviation for the evaluation of the factors 1) drilling sequence, 2) alveolar ridge morphology, and 3) guide-hole design. MDS: Minimum drilling sequence; CDS: Complete drilling sequence. MS: Manufacturer's sleeve. SL: Sleeveless guide-hole design. SD: Standard deviation. *p-values <0.05, ***p-values<0.001.

Factor 1 Drilling sequence	Factor 2 Alveolar ridge morphology	Factor 3 Guide-hole	n	Mean	SD	Min	Q1	Median	Q3	Max
Angular deviation (°)										
MDS	**healed ridge**	MS	9	**2.12**	0.76	1.20	1.60	**1.70**	2.60	3.50
MDS	**healed ridge**	SL	9	**1.96**	1.03	0.60	1.10	**2.10**	2.20	4.0
MDS	**extraction socket**	MS	9	**4.20**	1.45	1.0	3.90	**4.10**	4.90	6.0
MDS	**extraction socket**	SL	9	**3.64**	1.62	1.40	2.40	**3.70**	4.90	6.40
CDS	**healed ridge**	MS	9	**1.84**	0.73	0.80	1.40	**2.0**	2.20	3.0
CDS	**healed ridge**	SL	9	**1.34**	0.56	0.30	1.10	**1.40**	1.60	2.30
CDS	**extraction socket**	MS	9	**4.24**	2.20	0.90	2.60	**5.30**	5.70	6.80
CDS	**extraction socket**	SL	9	**3.08**	1.92	0.50	1.40	**2.70**	4.40	6.20
3D deviation crest (mm)										
MDS	**healed ridge**	MS	9	**0.39**	0.15	0.17	0.22	**0.42**	0.46	0.63
MDS	**healed ridge**	SL	9	**0.29**	0.12	0.1	0.26	**0.31**	0.36	0.45
MDS	**extraction socket**	MS	9	**0.83**	0.25	0.52	0.67	**0.80**	0.95	1.23
MDS	**extraction socket**	SL	9	**0.73**	0.23	0.34	0.6	**0.75**	0.85	1.07
CDS	**healed ridge**	MS	9	**0.31**	0.07	0.19	0.26	**0.34**	0.35	0.42
CDS	**healed ridge**	SL	9	**0.27**	0.11	0.06	0.22	**0.28**	0.30	0.44
CDS	**extraction socket**	MS	9	**0.76**	0.27	0.27	0.62	**0.83**	0.85	1.25
CDS	**extraction socket**	SL	9	**0.60**	0.26	0.24	0.34	**0.62**	0.85	0.91
3D deviation apex (mm)										
MDS	**healed ridge**	MS	9	**0.76**	0.27	0.39	0.53	**0.75**	0.93	1.19
MDS	**healed ridge**	SL	9	**0.63**	0.31	0.20	0.36	**0.74**	0.78	1.10
MDS	**extraction socket**	MS	9	**1.62**	0.36	1.18	1.38	**1.52**	1.80	2.22
MDS	**extraction socket**	SL	9	**1.39**	0.48	0.69	1.06	**1.45**	1.67	2.20
CDS	**healed ridge**	MS	9	**0.63**	0.21	0.24	0.47	**0.69**	0.77	0.89
CDS	**healed ridge**	SL	9	**0.50**	0.17	0.29	0.37	**0.51**	0.56	0.84
CDS	**extraction socket**	MS	9	**1.58**	0.68	0.41	1.12	**1.91**	2.01	2.31
CDS	**extraction socket**	SL	9	**1.18**	0.61	0.46	0.62	**1.28**	1.60	2.18

Table 3

Descriptive statistics of angular, crestal, and apical 3D implant deviation for each combination of the factors 1) drilling sequence, 2) alveolar ridge morphology, and 3) guide-hole design. MDS: Minimum drilling sequence; CDS: Complete drilling sequence. MS: Manufacturer's sleeve. SL: Sleeveless guide-hole design. SD: Standard deviation.

Figures

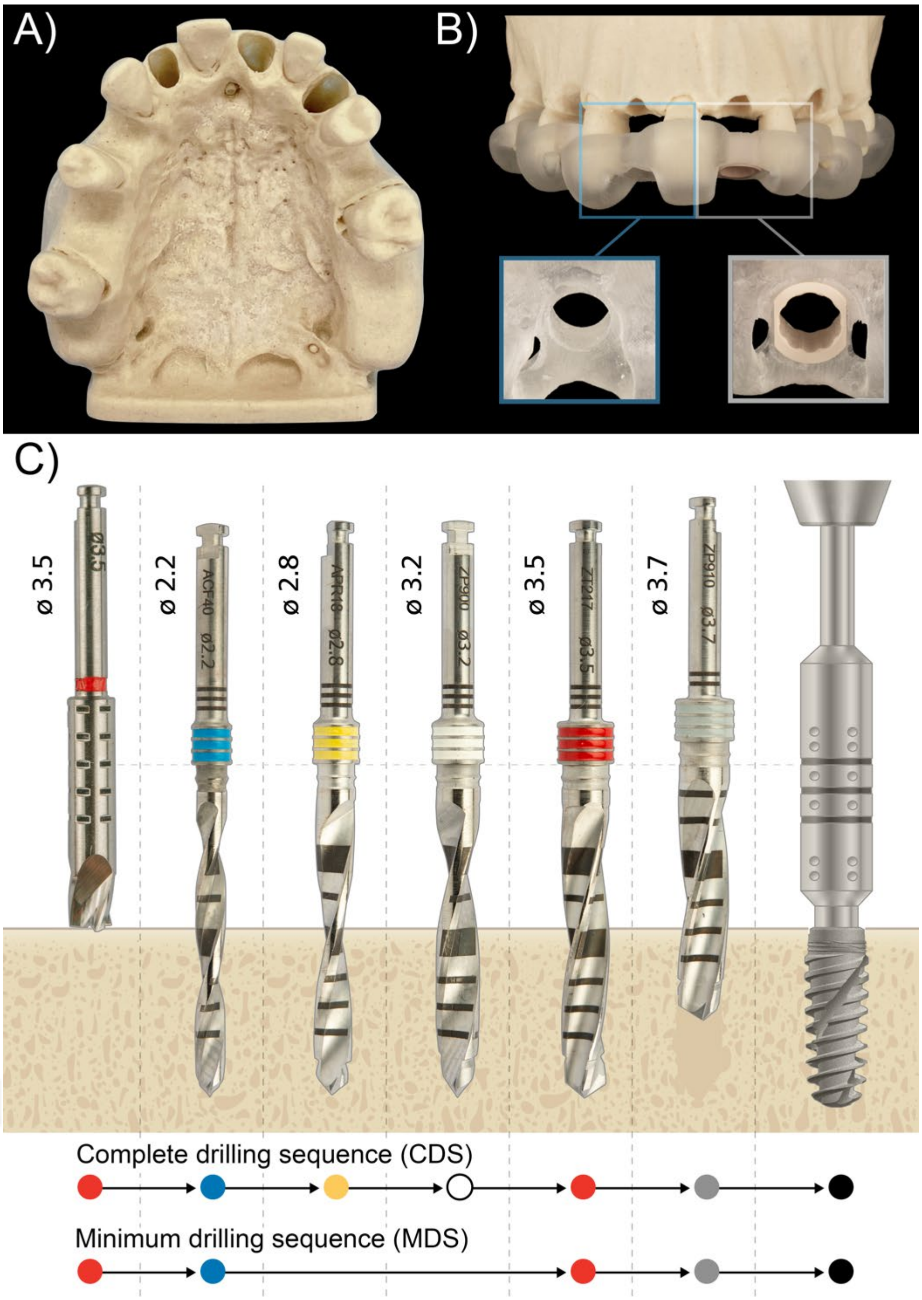

Figure 1

Representative model with different alveolar ridge morphologies (fresh extraction sockets and healed ridges, A) and surgical guide showing different guide-hole designs (blue: sleeveless and white: manufacturer's sleeve, B). Visual depiction of the methodology followed during the complete and minimum drilling sequences (C).

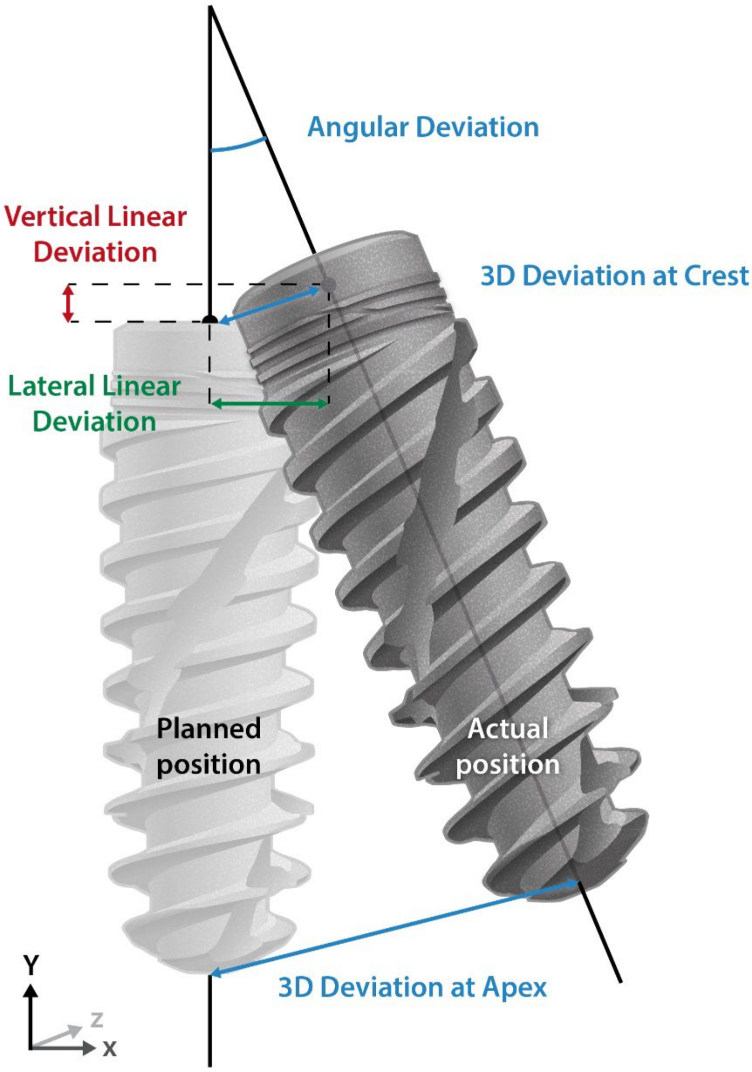

Figure 2

Deviation between pre-planned and post-surgical implant position and corresponding measurements.

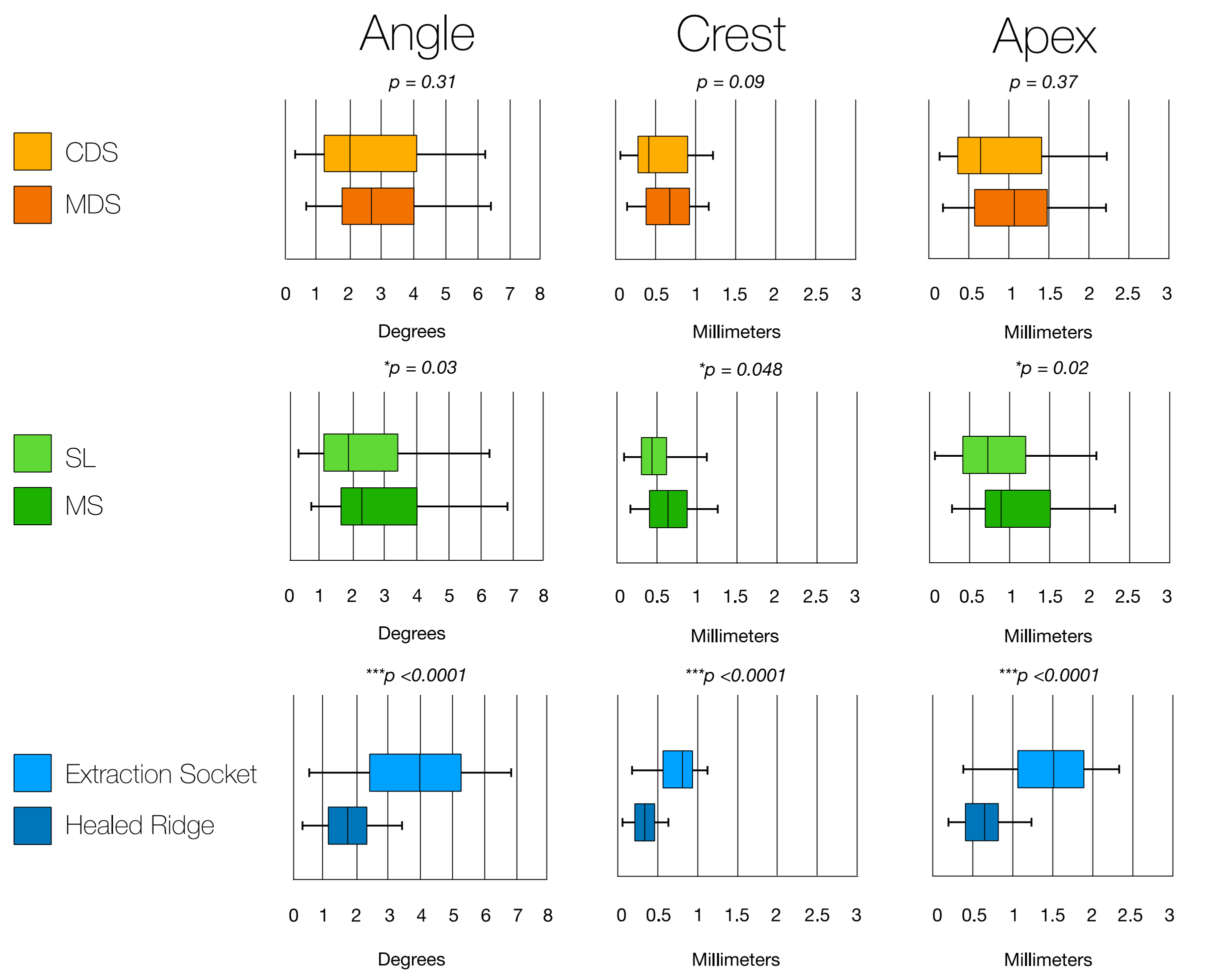

Figure 3

Box plots demonstrating the effect of the drilling sequence (orange colors), guide-hole design (green colors), and alveolar ridge morphology (blue colors) on the angular, crestal and apical 3D implant deviations. CDS: complete drilling sequence; MDS: minimum drilling sequence; MS: Manufacturer's sleeve; SL: Sleeveless.