Journal of Dental Sciences 19 (2024) S38—S43

Available online at www.sciencedirect.com

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journal homepage: www.e-jds.com

Original Article

Comparison of precision of implant placement between two different guided systems for static computer-assisted implant surgery: A simulation-based experimental study

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Received 27 June 2024; Final revision received 15 July 2024
Available online 25 July 2024

KEYWORDS
Computer-assisted implant surgery;
Dental implant;
Drilling system;
Guided surgery;
Precision

Abstract *Background/purpose:* Many designs of static computer-assisted implant surgery (sCAIS) are available for clinician to achieve proper implant position. However, there were not any studies that approached the design alone to evaluate whether sleeve-in-sleeve or sleeve-on-drill design provided most accuracy implant position. The purpose of this study was to investigate the precision of implant placement with sleeve-in-sleeve and sleeve-on-drill static computer assisted implant surgery (sCAIS) designs.
Materials and methods: Thirty-two models were fabricated simulating a patient with bilateral missing first premolar. Eight models (sixteen implants) were assigned in each group: Group A, B and C represented sleeve-in-sleeve design with 2, 4 and 6 mm sleeve height respectively. Group D represented integrated sleeve-on-drill design with 4 mm sleeve height. 3D deviation at implant platform, apex and angular deviation were measured. Data were analyzed using one way ANOVA ($P < 0.05$).
Results: The overall deviation at platform ranged from 0.40 $\pm$ 0.14 mm (group A) to 0.73 $\pm$ 1.54 mm (group C), at apex from 0.46 $\pm$ 0.16 mm (group A) to 1.07 $\pm$ 0.37 mm (group

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https://doi.org/10.1016/j.jds.2024.07.017

C) and the angular deviation ranged from 0.86 ± 0.89° (group A) to 3.40 ± 1.29° (group C). Group A and B showed significantly less deviation than groups C and D ($P < 0.05$). There was no statistically significant difference in all parameters measured between group A and B, as well as between group C and D ($P > 0.05$).

Conclusion: Sleeve-in-sleeve sCAIS demonstrated higher precision than sleeve-on-drill sCAIS.

Introduction

Titanium dental implants have been used for over fifty years and have documented predictably high long-term survival replacing missing teeth. The emerging treatment paradigms in implant dentistry are focused in increasing long-term successful clinical outcomes as well as improving patients' experience. Recent research has documented the importance of prosthetic design for achieving sustainable health of the peri-implant tissue,[1] while the introduction of digital workflow has empowered predictable immediacy[2] and further reduction of invasiveness. Consequently, a critical element of comprehensive digital treatment planning is currently emerging as a new norm in implant dentistry, where the design of the prosthesis and all components, as well as the position of the implant and its relation with the surrounding tissue is precisely determined before any intervention takes place. Thus, in the workflow of the contemporary, design-driven implant dentistry, the ability to place the implant in the exact planned position becomes an essential prerequisite for achieving the desired treatment outcomes and this is the role that computer assisted implant surgery (CAIS) aims to fulfill.

Static (sCAIS), dynamic (dCAIS) and robotic (rCAIS) are the three currently distinct technologies of CAIS, with the static being the most widespread and documented.[3] Static CAIS relies on the use of planning software, a prefabricated surgical guide and special drills in order to guide the osteotomy and achieve the implant placement in the planned position. Numerous clinical studies have demonstrated the effectiveness of sCAIS in increasing the precision of implant placement, both as compared to freehand surgery[4] but also other CAIS technologies.[5]

Apart from the surgical guide itself, each of the commercially available sCAIS systems utilizes a variety of components and designs to guide and control the drills during osteotomy. Two distinct concepts have emerged, namely systems which utilize a handheld "drill key" to fit the drills in the sleeve (often referred to as "sleeve-in-sleeve") and systems with a mount sleeve on drill or designs with integrated sleeve-on-drill.[6,7] Although there is indication that the design of such elements can influence both the achieved precision of implant placement,[6,8] as well as the ergonomics of surgery, there is little evidence to help identify the best designs. Previous in-vitro investigation has suggested superior precision of sCAIS utilizing a handheld "drill key" and the sleeve-in-sleeve concept, however this comparison was conducted between different implant systems, with several inherent design differences in addition to the handheld key. In addition, any value of the handheld key in increasing precision, must be weighed against possible ergonomic challenges added by the need to stabilize one more handheld instrument during the surgery. Recently, a sCAIS system was introduced with two different designs, one with and one without a handheld drill key, thus eliminating many confounding factors and allowing for a more direct comparison between the two design principles.

The aim of this study was to compare the precision of implant placement between a sleeve-in-sleeve and an integrated sleeve-on-drill sCAIS systems, based on a simulation experimental model, which allowed for the elimination of most confounding variables. A secondary aim of this study was to investigate the influence of the sleeve height (vertical distance of sleeve from bone) to precision of implant placement.

Materials and methods

Sample size calculation

The sample size was calculated based on the results of angular deviation reported by Sittikornpaiboon,[6] who reported mean angular deviations of 2.7, 2.5, 5.13, and 5.3 (SD 1.86) for the four groups tested, respectively. The calculation was performed by setting type-I error(α) = 0.05 and power = 0.95 to determine the number of implants needed for statistical significance. G*Power 3.1 software (Franz Faul, Christian-Albrechts-Universität Kiel, Kiel, Germany) was used for the analysis. The number of 10 implants in each group was calculated.

Model fabrication

Model fabrication technique was modified from the previous study of Yeung et al.[9] A patient with bilateral edentulous areas at the maxillary first premolar was utilized in this study. Intraoral scanning of the patient was conducted and the Standard Tessellation Language (STL) file was generated and imported into Meshmixer software version 3.5.474 (Autodesk Inc., San Francisco, CA, USA). At both edentulous areas, a hollow space with a cylindrical shape of 7 mm in diameter and 15 mm in length was designed to correspond to the implant placement site. After that, the final digital model file was imported into the Netfabb Premium 2020 software (Autodesk Inc.). A 3D printer (Straumann CARES P30+, Straumann AG, Basel, Switzerland) was used to print 32 models using a model resin material (P Pro Master Model

Gray, Straumann AG) with a layer thickness of 0.05 mm. The models were cured with UV after being rinsed with isopropyl alcohol. To simulate human cancellous bone of low-to-medium density at the implant insertion site, the hollow spaces at each edentulous site were filled with bovine bone taken from a cow's femur.

Implant planning procedures

To create a Digital Imaging and Communications in Medicine (DICOM) file, the model was scanned with a cone beam CT (CBCT) scanner (Xmind Trium, de Götzen S.r.l.-Acteon Group, Varese, Italy). The machine was set to 7 mA, 70 kV, 63 s of exposure duration, 0.15 $\times$ 0.15 $\times$ 0.15 mm voxel size, and 11 $\times$ 9 cm field of view. The model was then scanned to create an STL file using a desktop scanner (Cares 7 SERIES, Dentalwings, Montreal, Quebec, Canada). DICOM and STL files were imported and transposed in the Implant planning software (coDiagnostiX software version 9.7, Dental Wings GmbH, Chemnitz, Germany). A digital wax up with the proper crown shape and size for bilateral first premolars was created by means of a dental CADprogram (CARES Visual software, Straumann AG). Thereafter, one implant (4.1 $\times$ 8 mm bone level tapered implant -Straumann AG) was planned in the optimal position for both edentulous sites 14 and 24. Thereafter sCAIS was planned with 4 different guided surgery protocols utilizing 2 different sCAIS systems by Straumann AG as shown in Fig. 1 and Table 1:

A: sleeve-in-sleeve sCAIS, sleeve height 2 mm, position H2.

B: sleeve-in-sleeve sCAIS, sleeve height 4 mm, position H4.

C: sleeve-in-sleeve sCAIS, sleeve height 6 mm, position H6.

D: integrated sleeve-on-drill, sleeve height 4 mm, position H4.

Each group included 8 models/surgical guides and 16 implants.

All surgical guides covered FDI teeth #11, 12, 13, 15, 16, 21, 22, 23, 25, and 26 with four inspection windows. The space between the surgical guide and the tooth was set to 0.05 mm. All guides were manufactured using a 3D printer (Straumann CARES P30+, Straumann AG) and 2 mm thick medical grade surgical guide resin material (P Pro Surgical Guide, Straumann AG) at a layer thickness of 0.1 mm.

Surgical simulation protocol

The surgical guide's fit on the model was confirmed via the inspection window before the implant surgery. The surgery was performed with the models mounted on a phantom head in the supine position and the operator seated in the right rear position (11 o'clock) as shown in Fig. 2. Eligible models were randomly assigned to one of the four groups; sleeve-in-sleeve sCAIS (H2, H4, H6) and sleeve-on-drill sCAIS(H4) using block randomization method via an online random sampling generator (research randomizer, https://randomizer.org/). Concealment was archived by using sealed opaque envelopes. All guided surgeries for implant placement were performed by one experienced operator. The osteotomies were performed in accordance with the manufacturer's instructions and the implants were placed fully guided, using each system's guided adapter.

Outcome measurements

After implant placement, all models were scanned with CBCT using the same settings as previously described by an investigator blinded to the sCAIS mode used. The DICOM files were then imported into the coDiagnostiX software and segmented at 540–3500 H threshold. By using surface-based registration, the postoperative CBCT were superimposed onto the preoperative CBCT, which contains the virtual implant planned position. One operator conducted all measurements by means of the treatment evaluation module of the software, calculating the 3D deviation of the implant platform, apex, and angle between the planned and placed positions as shown in Fig. 3.

Statistical analysis

IBM SPSS Statistics software was used to collect and calculate measurement data (version 24 software SPSS Inc., Chicago, IL, USA). The mean difference between the virtually planned and actually placed implant in each model of 4 groups were compared. The Shapiro–Wilk test was used to determine the distribution of data.

One way ANOVA test was employed due to data's normal distribution. Statistical significance is defined as a *P*-value of less than 0.05.

Results

The mean deviations are shown in Table 2. Mean angular deviation for groups A-D were 0.86 $\pm$ 0.89, 1.13 $\pm$ 0.63, 3.4 $\pm$ 1.29, 2.76 $\pm$ 0.56° respectively. The platform deviation for groups A-D were 0.4 $\pm$ 0.14, 0.49 $\pm$ 0.26, 0.73 $\pm$ 1.54, 0.7 $\pm$ 0.2 mm respectively. The apex deviation for groups A-D were 0.46 $\pm$ 0.16, 0.57 $\pm$ 0.31, 1.07 $\pm$ 0.37, 0.84 $\pm$ 0.24 mm respectively.

Table 1 Parameters of each experimental group.

Group	Sleeve height (mm)	Sleeve position (mm)	handheld drill key	Free drilling distance
Group A	5	2	Drill key height 1 mm	10
Group B	5	4	Drill key height 3 mm	12
Group C	5	6	Drill key height 1 mm	14
Group D	5	4	none	12

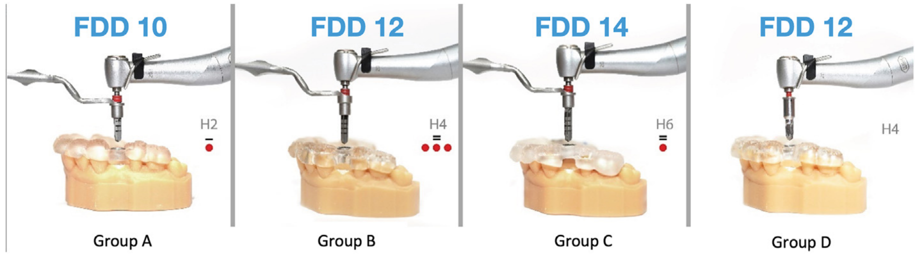

Figure 1 The configuration of each drilling system used with the final drill. Group A: sleeve-in-sleeve design with 2 mm sleeve height (H2), group B: sleeve-in-sleeve design with 4 mm sleeve height (H4), group C: sleeve-in-sleeve design with 6 mm sleeve height (H6), group D: integrated sleeve-on-drill design with 4 mm sleeve height (H4).

Figure 2 The surgery was simulated in phantom head.

One way ANOVA test demonstrated significant differences among the four groups of sCAIS in all parameters ($P < 0.001$). No statistically significant difference was shown in any measured parameter between groups A and B and also between groups C and D.

According to the angular, platform and apex deviation, group C and D showed the highest and second highest deviation and were significantly different to group A and B (Fig. 4).

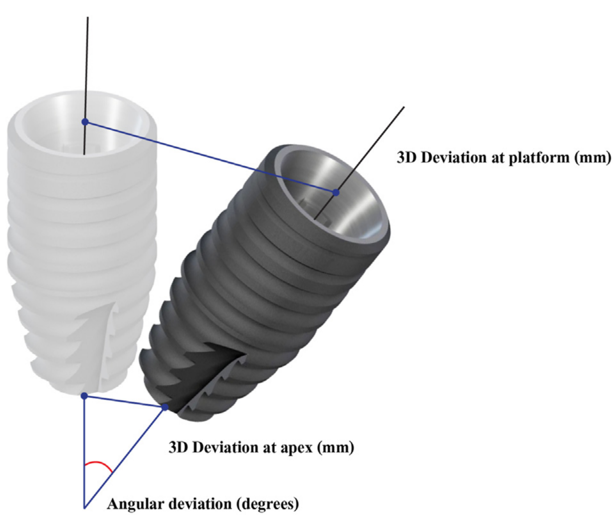

Figure 3 Measurements of the deviation between planned and placed implant position.

Discussion

In a strictly controlled simulation setting, this study intended to examine the possible influence of the sleeve and guide design of 2 widely available sCAIS configurations on the precision of implant placement. The study demonstrated that both systems performed well and within the currently expected benchmarks. Nevertheless, there were significant differences in precision among the 4 groups examined, indicating that the clinical outcomes may be considerably influenced by the design of the sCAIS, even withing the same implant system.

Three different sleeve heights of 2, 4 and 6 mm for the sleeve-in-sleeve sCAIS and one 4 mm sleeve height for the integrated sleeve-on-drill sCAIS were compared, as the latter only comes with one option for sleeve height (4 mm). The available specifications and manufacturer instructions for Straumann guided surgery stated that "mucosal thickness, type of surgical template (mucosa, bone or tooth-supported) and access for instrument irrigation" are the main factors to be considered by the clinician for determining the position of the sleeve.[10] The same document recommends to "always select the lowest T-sleeve position possible for maximum precision", without however any further mentioning of the potential implications of the selected sleeve position to accuracy or any other outcomes of the implant surgery. As the sleeve height might be a potential factor in the deviation observed,[11] this study format was selected to not only investigate the potential presence of such an influence, but also to assess its extent and potential clinical implications. The level of accuracy that is required for smooth execution of different restorative clinical procedures remains unknown and it is reasonable to assume that would depend on the complexity of the restorative protocol. For example, it is reasonable to anticipate that the tolerance for deviation in implant position would be higher in the case of a single crown than a full arch with immediate loading. Thus quantifying the level of accuracy that can be achieved with each different configuration of guided surgery can be meaningful, but the clinical relevance of these numbers in immediacy protocols will have to investigated with clinical studies in the future.

Many design features as well as site parameters can influence the outcome of sCAIS in terms of precision, thus

Table 2 The 3D deviation of implant in each group.

sCAIS	Sleeve-in-sleeve H2 (n = 16)	Sleeve-in-sleeve H4 (n = 16)	Sleeve-in-sleeve H6 (n = 16)	Integrated sleeve-on-drill H4 (n = 16)	Overall (n = 64)
Angular deviation (degree)					
Mean ± SD	0.86 ± 0.89	1.13 ± 0.63	3.4 ± 1.29	2.76 ± 0.56	2.04 ± 1.38
Median	0.8	1.1	3.75	2.75	1.9
Min-Max	0–2.8	0–2.6	1.6–5.8	1.9–4.0	0–5.8
Range	2.8	2.6	4.2	2.1	5.8
95%CI	0.39,1.33	0.79,1.46	2.71,4.09	2.46,3.05	1.69,2.38
Platform deviation (mm)					
Mean ± SD	0.4 ± 0.14	0.49 ± 0.26	0.73 ± 1.54	0.7 ± 0.2	0.58 ± 0.23
Median	0.38	0.43	0.72	0.69	0.58
Min-Max	0.11–0.73	0.12–0.96	0.44–0.99	0.35–1.0	0.11–1.0
Range	0.62	0.84	0.55	0.65	0.89
95%CI	0.33,0.48	0.35,0.62	0.65,0.82	0.59,0.8	0.52,0.64
Apex deviation (mm)					
Mean ± SD	0.46 ± 0.16	0.57 ± 0.31	1.07 ± 0.37	0.84 ± 0.24	0.74 ± 0.36
Median	0.42	0.51	1.13	0.82	0.64
Min-Max	0.19–0.76	0.07–1.15	0.46–1.57	0.43–1.26	0.07–1.57
Range	0.57	1.08	1.11	0.83	1.5
95%CI	0.38,0.54	0.40,0.74	0.87,1.26	0.72,0.97	0.64,0.83

sCAIS: static computer assisted implant surgery.

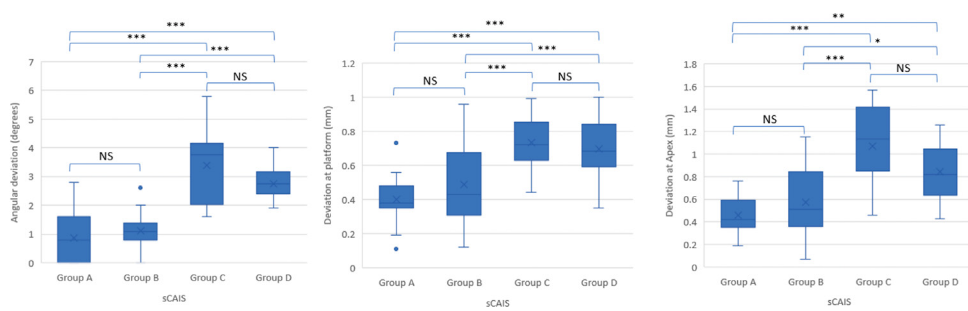

Figure 4 Box-and-whisker plot diagrams presenting the distribution of 3D deviation in each group. Median, Q1 (25th percentile), Q3 (75th percentile), minimum value, maximum value, and outliers of each group shown in diagrams. The statistically significant differences between groups were determined by One way ANOVA test under Posthoc's test with adjusted *P* values. Denoted as * for $P < 0.05$, ** for $P < 0.01$, *** for $P < 0.001$, and ns for not significant, respectively.

reducing the amount of potential confounding factors is very important in identifying the actual impact of the design features under study, in this case the sleeve/guide system used. Confounding factors which were not controlled in previous studies, implant macro design, osteotomy protocol, free drilling distance (FDD), sleeve height/diameter and sleeve length.[12] Kholy et al. reported that the precision of sCAIS is directly related to the free drilling distance apical to the guided sleeve and inversely related to the guided key height used above the sleeve.[11] As the same implant system was utilized in all groups in this study, much of these potential confounding factors were eliminated.

The dental implants placed using sleeve-in-sleeve sCAIS with sleeve height of 4 mm showed significantly less deviation compared to those placed using integrated sleeve-on-drill sCAIs with the same sleeve length, sleeve height, macrodesign of dental implant and FDD. This is in agreement with the study of Sittikornpaiboon et al.[6] which demonstrated that sleeve-in-sleeve design showed significantly less angular deviation than the integrated sleeve-on-drill design, although the groups compared were not of the same implant system.[6] At the same time, it was also shown that both systems can achieve precision within the current benchmarks.[3] As the actual level of precision required might differ in different clinical scenario, this implies that other factors such as e.g. ergonomics and ease of use might be as important as precision, when sCAIS system is considered in clinical practice.

Despite the different free drilling distance among groups A (10 mm), B (12 mm) and C (14 mm), the deviation between group A and B was no different, but collectively groups A and B achieved significantly less deviation that group C. This might suggest that the free drilling distance could be more important to influence deviation than the guiding channel from the drill key or the sleeve height alone, something that appears in agreement with Kholy et al.[11]

The results of this study should be seen under the light of the methodological limitations of a simulation study. Effort has been taken to standardize all parametres of influence other than the ones studied, yet the groups have been limited two commercially available drilling systems, which albeit from the same manufacturer might still present with minor design differences in componentry. The verification of the implant position and comparison to the planning was conducted by means of CBCT. Other methods have been proposed for the same purpose utilizing scan bodies and optical scanners, which however was reported to be less accurate when assessing implants placed deeper in the tissue.[13] At present, all methods reported for the assessment of implant position are reported to have their own inevitable errors and require careful interpretation in evaluation.[14] In the future, less invasive technologies could be utilized for this purpose, without the need of a post-surgery CBCT.

The study demonstrated that Implants placed with sleeve-in-sleeve sCAIS demonstrated higher precision than those of the same implant system placed with integrated sleeve-on-drill design. Nevertheless, both systems performed within the currently expected benchmarks of precision, suggesting that factors such as e.g. ergonomics and ease of use can be considered, when sCAIS system is selected in clinical practice.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

Acknowledgments

This research was supported by the 90th Anniversary of Chulalongkorn University Fund and N.M. is supported by the Second Century Fund (C2F), Chulalongkorn University.

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