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RESEARCH AND EDUCATION

Accuracy of pin-supported surgical guides for complete arch implant placement: A comparison with conventional mucosa-supported guides

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ABSTRACT

Statement of problem. While static computer-assisted implant surgery (sCAIS) has improved implant placement accuracy in edentulous arches, mucosa-supported sCAIS guides present limitations, including a lack of direct visualization and irrigation. A novel design for pin-supported sCAIS guides has been developed to address these issues, but its accuracy compared with that of mucosa-supported sCAIS guides remains unclear.

Purpose. The purpose of this in vitro study was to compare the accuracy of implant placement achieved with pin-supported and mucosa-supported sCAIS guides using standardized edentulous maxillary models.

Material and methods. Twenty-four identical edentulous maxillary models were divided into 2 groups (n=12). The mucosa-supported group underwent fully guided implant placement using mucosa-supported sCAIS guides with a flapless protocol. The pin-supported group used a 2-guide pin-supported sCAIS protocol with flap elevation, with 6 implants being planned and placed per model. After implant placement, scan bodies were attached, and the models were scanned. Deviations between planned and actual implant positions were measured using the Blender software program and custom Python scripts. A linear mixed model was used to compare mean deviations between groups (α=.05, with Bonferroni correction for multiple comparisons).

Results. The pin-supported group demonstrated statistically higher deviations across most parameters, including coronal global (0.89 ±0.36 mm versus 0.72 ±0.305 mm), apical global (1.22 ±0.47 mm versus 0.97 ±0.43 mm), coronal horizontal (0.63 ±0.36 mm versus 0.48 ±0.23 mm), apical horizontal (1.01 ±0.51 mm versus 0.77 ±0.44 mm), and angular deviations (2.84 ±1.33 degrees versus 2.03 ±1.03 degrees), compared with the mucosa-supported group (P<.05). Depth deviation showed no significant difference (P>.05). All mean deviations remained within clinically acceptable limits (<2 mm and <5 degrees).

Conclusions. In this in vitro study, pin-supported sCAIS guides showed statistically greater deviations than mucosa-supported sCAIS guides across most parameters. However, the mean differences were small, approximately 0.15 to 0.25 mm in linear deviation and 0.8 degree in angular deviation. These differences remained within generally accepted sCAIS accuracy thresholds. Further studies are warranted to validate these findings in clinical settings, assess applicability across patient variations, and evaluate long-term treatment outcomes. (J Prosthet Dent 2026;135:808.e1-e7)

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Clinical Implications

Both mucosa-supported and pin-supported sCAIS guides demonstrated accuracy within generally accepted thresholds in this in vitro model. The selection of guide type should be based on the clinical scenario, surgeon experience, and factors such as the need for visibility, irrigation access, or flap elevation.

Over the past 2 decades, the integration of computed tomography (CT) and 3-dimensional (3D) printing technologies has significantly advanced computer-assisted implant surgery (CAIS) in the field of dentistry.[1–3] These technologies enable clinicians to meticulously plan implant placement following a prosthetically driven approach, aiming for optimal functional, esthetic, and hygienic outcomes.[4–6] The resulting preoperative digital planning data can be integrated into a digital workflow and converted into a stereolithographic (SLA) file for the fabrication of a surgical template which guides implant positioning and angulation during surgery. This technique, commonly referred to as static computer-aided implant surgery (sCAIS), has gained widespread acceptance in clinical practice.[5,7]

Initially, sCAIS in completely edentulous arches was performed using a bone-supported SLA guide placed on the alveolar crest after flap elevation.[8–12] Further advances in technology have led to the development of mucosa-supported guides featuring fixation pins, enabling flapless surgeries to be performed with greater support and stability.[13,14] This flapless approach shortens surgical time and reduces postoperative discomfort. Therefore, implant surgery may become more straightforward for both the patient and the clinician.[15] Currently, the mucosa-supported guide design has become the most prevalent choice for sCAIS guide design in edentulous arches.[6,16] However, the flapless approach using mucosa-supported sCAIS guides presents inherent limitations, including the lack of direct visualization of the surgical site and the potential for restricted saline irrigation during osteotomy preparation. As a result, the precision of implant placement may be compromised, and the risk of osseous overheating increased compared with techniques that allow direct irrigation.[17,18]

To address these limitations, a pin-supported sCAIS guide design has been proposed as a potential solution. This technique involves the fabrication of 2 distinct surgical guides. The first is a conventional mucosa-supported guide, intended solely for the placement of fixation pins. The second is a pin-supported guide, designed with sleeves for both fixation pins and implant osteotomies. During the surgical procedure, the first guide is positioned and secured using fixation pins. Upon confirming the complete seating of the pins and accurate guide placement, the pins and the initial guide are removed. Subsequently, an incision is made over the surgical site, and full-thickness flaps are elevated to expose the underlying bone. The second, pin-supported guide is then secured in the predetermined position using the same fixation pin holes prepared previously. This 2-guide protocol allows clinicians to proceed with guided implant placement under direct visualization and with effective saline irrigation, thereby improving surgical accuracy and intraoperative control (Fig. 1).

In clinical practice, pin-supported surgical guides have often been used as part of stackable guide systems designed for patients with a terminal dentition who require complete arch extraction and immediate implant placement or in patients requiring bone reduction guides or the integration of surgical guides with the delivery of an immediate interim prosthesis.[19] The success of guided implant surgery has been reported to hinge on the accurate transfer of the planned implant position from the surgical planning software program to the actual placement in the patient's mouth.[1,7,13] However, discrepancies between preoperative plans and postoperative implant positions are inevitable. Although an open-flap approach using a pin-supported guide allows direct visualization for the practitioner, the need to switch between surgical guides may raise concerns regarding compromised accuracy.

Despite the growing popularity and clinical application of pin-supported sCAIS guide design, scientific evidence evaluating their accuracy remains limited. The authors are unaware of prior studies that have investigated their impact on implant placement accuracy. Therefore, a systematic comparative investigation was warranted to assess the accuracy of implant placement using pin-supported versus mucosa-supported guides. The null hypothesis was that no statistically significant difference in implant placement accuracy would be

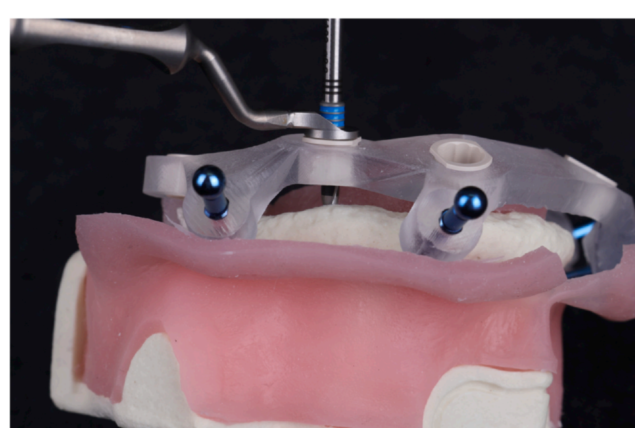

Figure 1. Pin-supported static computer-assisted implant surgical guide.

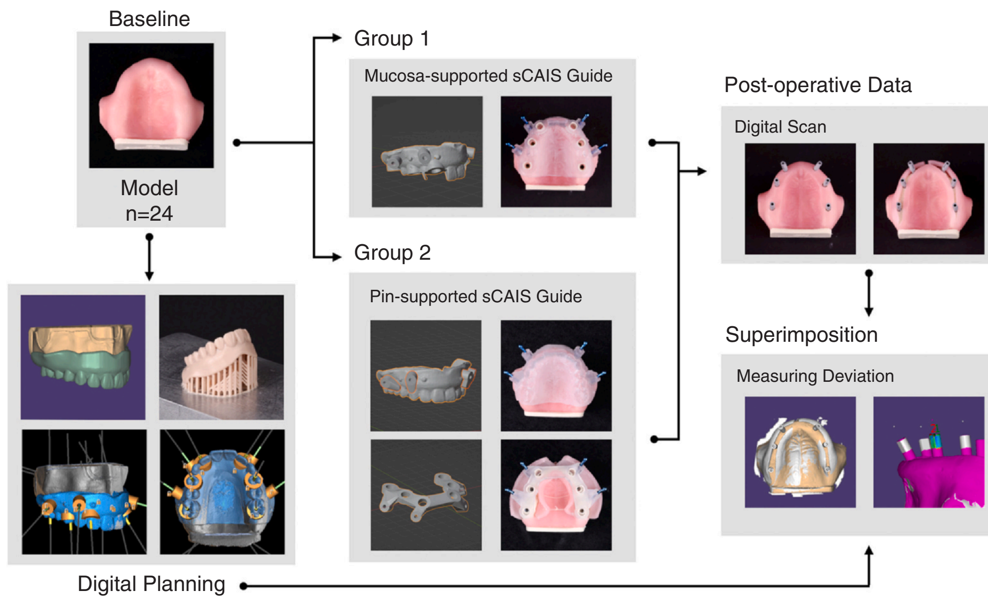

Figure 2. Study design.

found between pin-supported and mucosa-supported sCAIS protocols.

MATERIAL AND METHODS

The overall workflow is illustrated in Figure 2. The aims of the study were to compare the accuracy of implant placement achieved with pin-supported versus mucosa-supported sCAIS and to quantify the 3D deviation associated with pin-supported sCAIS.

Twenty-four identical edentulous maxillary models with simulated soft tissue (U-007A; BoneModels S.L.U.) were used in this study. Digital Imaging and Communications in Medicine (DICOM) image data of a model were acquired using a CBCT scanner (3D Accuitomo 170; J. Morita Mfg Corp). The scanning parameters were set at 5 mA and 90 kVp with an exposure time of 17.5 seconds. The field of view (FOV) was 140×100 mm, and the resulting voxel size was 0.27 mm. Additionally, an optical scan of the same model was performed using a desktop scanner (D2000; 3Shape A/S), and the surface data were exported as standard tessellation language (STL) files. These digital datasets were then used for the subsequent planning and fabrication of the surgical guides for all edentulous maxillary models used in the study. A total of 24 study models were included and divided equally into 2 groups: mucosa-supported group (fully guided implant placement using mucosa-supported sCAIS) and pin-supported group (fully guided implant placement using pin-supported sCAIS). Each group comprised 12 models, with a total of 72 implant sites planned within each group.

To simulate a clinically relevant, prosthetically driven, implant position, the maxillary virtual tooth arrangement was digitally constructed using the optical surface scan of the model in a dental computer-aided design (CAD) software program (exocad; exocad GmbH). A diagnostic denture was then printed (SprintRay Pro S; SprintRay Inc) with dental cast resin (Die and Model 2 resin; SprintRay Inc). To ensure optimal adaptation to the diagnostic cast, the printed denture was relined using a chairside hard denture reline material (Kooliner; GC America Inc). Six fiducial markers were placed on the relined denture, and the DICOM files of both the denture and the cast were subsequently obtained by following the dual-scan protocol.[12] The implant surgery was digitally planned by an experienced dentist (Y.C.) using an implant planning software program (Blue Sky Plan version 4.70; Blue Sky Bio LLC), a 3D design software program (Blender version 2.83; The Blender Foundation), and a dental CAD software program (exocad; exocad GmbH). Six dental implant sites, corresponding to the right and left first molar, first premolar, and canine regions of the edentulous maxillary arch, were planned to simulate treatment with a complete arch, implant-supported fixed dental prosthesis. All surgical sites were planned to receive implants from the same system (3.75 × 14 mm, BLX; Institut Straumann AG).

All sCAIS guides from both groups were generated from the same implant planning project and fabricated using a 3D printer (Straumann 30+; Institut Straumann AG) with the designated surgical guide resin (P Pro Surgical Guide; Institut Straumann AG). The sleeves for fixation pin placement and implant insertion for both groups were purchased from the same implant manufacturer (Straumann

T-sleeve; Institut Straumann AG). The fit of all sCAIS guides on the models was visually evaluated and verified to confirm congruence with the digital plan. Minor adjustments were made as necessary to achieve proper adaptation and fit with the model.

All implants were placed by 1 experienced surgeon (Y.C.) following the manufacturer's instructions, and a primary stability of more than 35 Ncm was achieved. Different surgical procedure protocols were applied to different study groups. In the mucosa-supported group, the surgeon first positioned the mucosa-supported guide on the model to verify adaptation. Upon confirming stable seating, osteotomies for fixation pin were performed, followed by pin placement. Subsequently, all 6 implant osteotomies and placements were completed according to the manufacturer's protocol without flap elevation. In the pin-supported group, 2 surgical guides were used. The first guide was placed on the model to check adaptation, and, after confirming stable seating, fixation pin osteotomies and placement were performed. Once all pins were fully seated and the guide was in the planned position, the guide and pins were removed. A mid-crestal incision was then made across all surgical sites, and full-thickness flaps were elevated. The second surgical guide was subsequently secured using fixation pins in the previously prepared locations. With this second guide, the surgeon performed all 6 implant osteotomies and placements following the manufacturer's protocol.

Following implant placement, intraoral scan bodies were attached to all implants across all models and were digitally scanned using the desktop scanner to capture the 3D position of each implant. All resulting scan data were imported into the 3D design software program (Blender version 2.83; The Blender Foundation) for subsequent measurements. Postoperative scan data were then superimposed onto the original digital implant planning data, and deviations between the planned and actual implant positions were assessed using custom Python scripts. Accuracy was assessed in terms of trueness, defined as the mean deviation from the planned implant position. To precisely quantify these deviations, the following parameters were calculated based on the 3D coordinates derived from the planned and actual implant positions, as illustrated in Figure 3: global deviation, representing the 3D distance between the center of the crest or apex of the planned and placed implant, horizontal deviation, defined as the component of the global deviation perpendicular to the long axis of the planned implant position, depth deviation, representing the component of the global deviation parallel to the long axis of the planned implant position, and angular deviation, defined as the 3D angle between the centerlines of the placed and planned implant.

Descriptive statistics, including mean, standard deviation, maximum, and minimum, were determined. All statistical analyses were performed using statistical software programs (GraphPad Prism version 10.0; GraphPad Software Inc, RStudio version 2021.09; RStudio). Data normality was assessed using the Kolmogorov-Smirnov test. Given the presence of multiple measurements across related groups, the mean accuracy between different guide types and implant sites was compared using a linear mixed model. The fixed effect in the model was the sCAIS guide type, and the random effect was the diagnostic cast to account for intermodel variability. All reported *P* values were 2-sided (α=.05). Post hoc comparisons were adjusted for multiple testing using the Bonferroni correction method.

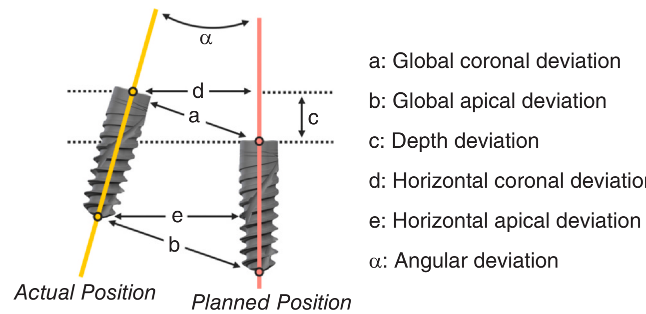

Figure 3. Measurement of deviations.

RESULTS

The Kolmogorov-Smirnov test revealed no statistically significant deviations from normality (P>.05) for all 6 deviation parameters within both study groups. This finding supported the application of parametric statistical testing for subsequent comparative analyses. Table 1 shows the descriptive statistics, including the mean, standard deviation, maximum, and minimum values for each of the 6 deviation parameters in the pin-supported and mucosa-supported sCAIS groups. These values provided an initial quantitative comparison of implant placement accuracy achieved with the 2 surgical guide approaches.

The linear mixed model analysis revealed statistically significant differences between mucosa-supported and pin-supported sCAIS groups across most deviation parameters (Fig. 4). The pin-supported group demonstrated significantly greater coronal global deviation (mean: 0.167 mm; 95% CI: 0.043–0.291; $t(22)=2.807$; P=.01), apical global deviation (mean: 0.242 mm; 95% CI: 0.085–0.399; $t(22)=3.190$; P=.004), coronal horizontal deviation (mean: 0.144 mm; 95% CI: 0.007–0.28; $t(22)=2.182$; P=.04), and apical horizontal deviation (mean: 0.233 mm; 95% CI: 0.067–0.399; $t(22)=2.903$; P=.008) compared with the mucosa-supported group. The angle deviation was also significantly higher in the pin-supported group (mean: 0.813 degree; 95% CI: 0.343–1.282; t

Table 1. Deviation of implant of pin-supported and mucosa-supported sCAIS groups

	Pin-supported			Mucosa-supported			
	Mean ±SD	Max	Min	Mean ±SD	Max	Min	P^a
Coronal Global	0.90 ±0.36	1.78	0.17	0.72 ±0.30	1.48	0.11	.01*
Apical Global	1.22 ±0.47	2.15	0.23	0.97 ±0.43	2.45	0.24	.004*
Coronal Horizontal	0.63 ±0.36	1.62	0.05	0.48 ±0.23	1.28	0.07	.04*
Apical Horizontal	1.01 ±0.51	2.08	0.13	0.77 ±0.44	2.42	0.03	.008*
Angular	2.84 ±1.33	7.31	0.12	2.03 ±1.03	5.00	0.41	.001*
Depth	−0.20 ±0.60	1.39	−1.28	−0.34 ±0.46	1.10	−1.39	.207

* P<.05.
a Linear mixed model comparing the difference between 2 groups.

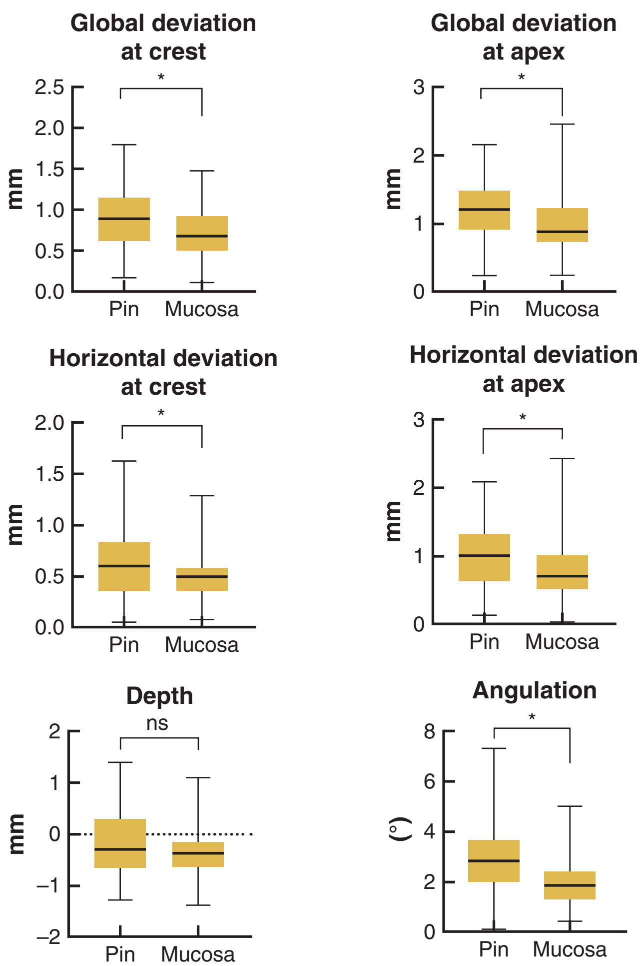

Figure 4. Box plot showing median and extreme values of deviation.

(22)=3.586; P=.001). In contrast, no statistically significant difference was observed in depth deviation between the 2 groups (mean: 0.145 mm; 95% CI: −0.086–0.375; t(22) =1.299; P=.207). The full outputs of the linear mixed model, including estimates, standard errors, t values, and P values for each parameter, are presented in Table 2.

DISCUSSION

Edentulism, or the loss of all teeth, has been described as the dental equivalent of mortality and considered as an oral handicap,[20,21] negatively impacting nutritional intake, self-esteem, quality of life, and increasing discomfort caused by pain and distress.[22–24] Despite a decreased prevalence over the last decade, edentulism remains a major disease worldwide, especially among the older population.[25] According to the most recent oral health surveillance report by the Centers for Disease Control and Prevention (CDC), nearly 1 in 5 adults aged 75 years or older were completely edentulous.[26] Given the growing acceptance for a fixed solution and the generally predictable outcomes of contemporary dental implants, clinicians and patients are increasingly opting for implants over conventional dentures as a preferred treatment option for rehabilitating edentulous arches. However, in edentulous arches, the lack of anatomic landmarks makes it challenging for the clinician to achieve optimal implant positioning using a nonguided approach, increasing the risk of suboptimal clinical outcomes.

sCAIS has significantly improved the precision of implant placement in completely edentulous patients.[6,7] Among the various guide types, the mucosa-supported guide with fixation pins and flapless surgical protocol has gained the most popularity. While this approach has become prevalent due to their minimally invasive nature, high accuracy and reduced surgical time, it has inherent limitations.[6,15,16,27,28] The lack of direct visualization and potential for compromised irrigation can introduce some inaccuracies and complications. This study proposed the pin-supported sCAIS guide to overcome those problems and further compared the accuracy of implant placement between the pin-supported and the mucosa-supported sCAIS in an in vitro setting using standardized edentulous maxillary casts.

While accuracy encompasses both trueness and precision, the present analysis focused on trueness because it best reflects the clinical relevance of how closely implant placement corresponds to the intended position. The results revealed statistically significant differences in placement accuracy, with the pin-supported guides exhibiting higher deviation across most parameters, including coronal and apical global deviation, horizontal deviation, and angular deviation. Consequently, the null hypothesis that no statistically significant difference in

Table 2. Linear mixed effects model for pin-supported sCAIS groups

Deviation	Coefficients	Estimate	Standard Error	*t*-value	*P*
Coronal Global	Intercept	0.729	0.042	17.240	<.001*
	Pin-supported sCAIS	0.168	0.459	2.807	.010*
Apical Global	Intercept	0.979	0.054	18.250	<.001*
	Pin-supported sCAIS	0.242	0.076	3.190	.004*
Coronal Horizontal	Intercept	0.486	0.047	10.442	<.001*
	Pin-supported sCAIS	0.144	0.066	2.182	.040*
Apical Horizontal	Intercept	0.778	0.057	13.705	<.001*
	Pin-supported sCAIS	0.233	0.080	2.903	.008*
Angular	Intercept	2.031	0.160	12.677	<.001*
	Pin-supported sCAIS	0.813	0.227	3.586	.002*
Depth	Intercept	−0.348	0.079	−4.427	<.001*
	Pin-supported sCAIS	0.145	0.111	1.300	.207

†Mucosa-supported sCAIS group is treated as the reference group.

* $P<.05$.

implant placement accuracy would be found between pin-supported and mucosa-supported sCAIS protocols was rejected.

Although the pin-supported guides were intended to improve outcomes through direct visualization and enhanced intraoperative control, the findings suggested that these advantages do not necessarily translate into improved accuracy. The slightly increased deviation observed in the pin-supported group may be attributed to the additional surgical steps required, such as switching between 2 guides, flap elevation, and repositioning of the second guide. However, the depth deviation was the only parameter without a statistically significant difference between the 2 groups, suggesting that vertical control was less affected by guide type and more influenced by other factors such as drill length calibration and stop depth within the guide sleeve system. The consistent performance across both groups in this dimension reinforced the general reliability of guided systems in maintaining depth control during osteotomy preparation and implant insertion.

While the concept of a pin-supported sCAIS guide is not entirely new, rigorous scientific evaluation has been lacking. Similar designs have been referenced in guided surgery manuals by implant manufacturers, presented in clinical reports, discussed at professional conferences, and shared informally through social media platforms. Despite their growing presence in practice, the accuracy of these guides has not been formally investigated or systematically compared with that of mucosa-supported systems. The authors are unaware of a previous study that directly evaluated and quantified the accuracy of implant placement using pin-supported versus mucosa-supported sCAIS protocols under controlled conditions.

In the present study, the pin-supported guide group demonstrated a mean apical deviation of 1.22 mm and an angular deviation of 2.84 degrees, while the mucosa-supported guide group showed lower deviations of 0.98 mm and 2.03 degrees, respectively. Compared with values reported in previous in vitro studies, both guide types in this study exhibited better accuracy thab nonguided protocols. Kivovics et al[29] evaluated freehand implant placement using completely edentulous 3D printed casts and reported a mean apical deviation of 2.28 mm and an angular deviation of 5.85 degrees.

Despite the statistical differences observed between groups in the present study, these differences may not have been clinically relevant. All mean deviations observed in both groups remained within the commonly accepted thresholds for sCAIS, less than 2 mm for linear deviations and 5 degrees for angular deviations.[7,30] These findings suggested that while the pin-supported guides may demonstrate slightly lower accuracy than the mucosa-supported guides in a controlled in vitro setting, the magnitude of this difference is unlikely to be clinically significant.

The study design used a controlled in vitro model, which had both strengths and limitations. The use of identical edentulous maxillary casts allowed for standardization and minimized variability related to patient anatomy and bone quality. However, this cast did not fully replicate the complexities of a clinical setting. Factors such as soft tissue elasticity, patient movement, and surgical experience can influence implant placement accuracy in vivo.[1] Therefore, the findings of this study should be interpreted cautiously and further validated in clinical trials.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. The pin-supported guides demonstrated statistically higher deviations in most parameters, but these differences were generally within clinically acceptable limits.
2. The choice between guide types should be based on a comprehensive assessment of the clinical situation, considering factors such as the need for direct visualization, soft tissue conditions, and the clinician's experience.

3. Future research should focus on validating these findings in clinical studies, exploring techniques to enhance clinical applicability across patient variations and evaluating long-term treatment outcomes.

REFERENCES

1. Zhou W, Liu Z, Song L, Kuo CL, Shafer D. Clinical factors affecting the accuracy of guided implant surgery—A systematic review and meta-analysis. *J Evid Based Dent Pract*. 2018;18:28–40.
2. Orentlicher G, Abboud M. Guided surgery for implant therapy. *Oral Maxillofac Surg Clin North Am*. 2011;23:239–256.
3. Li J, Meneghetti PC, Galli M, Mendonca G, Chen Z, Wang HL. 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. *Clin Oral Implants Res*. 2022;33:757–767.
4. Pyo SW, Lim YJ, Koo KT, Lee J. Methods used to assess the 3D accuracy of dental implant positions in computer-guided implant placement: a review. *J Clin Med*. 2019;8:54.
5. Li J, Chen Z, Chan HL, Sinjab K, Yu H, Wang HL. Does flap opening or not influence the accuracy of semi-guided implant placement in partially edentulous sites? *Clin Implant Dent Relat Res*. 2019;21:1253–1261.
6. Arısan V, Karabuda CZ, Özdemir T. Implant surgery using bone-and mucosa-supported stereolithographic guides in totally edentulous jaws: surgical and post-operative outcomes of computer-aided vs. standard techniques. *Clin Oral Implants Res*. 2010;21:980–988.
7. Tahmaseb A, Wu V, Wismeijer D, Coucke W, Evans C. The accuracy of static computer-aided implant surgery: A systematic review and meta-analysis. *Clin Oral Implants Res*. 2018;29:416–435.
8. Ganz SD. Use of stereolithographic models as diagnostic and restorative aids for predictable immediate loading of implants. *Pract Proced Aesthet Dent*. 2003;15:763–786.
9. Sarment DP, Al-Shammari K, Kazor CE. Stereolithographic surgical templates for placement of dental implants in complex cases. *Int J Periodontics Restorative Dent*. 2003;23:287–296.
10. Rosenfeld AL, Mandelaris GA, Tardieu PB. Prosthetically directed implant placement using computer software to ensure precise placement and predictable prosthetic outcomes. Part 1: diagnostics, imaging, and collaborative accountability. *Int J Periodontics Restorative Dent*. 2006;26:215–221.
11. Terzioğu H, Akkaya M, Ozan O. The use of a computerized tomography–based software program with a flapless surgical technique in implant dentistry: A case report. *Int J Oral Maxillofac Implants*. 2009;24:137–142.
12. Li J, Sommer C, Wang H-L, Lepidi L, Joda T, Mendonca G. Creating a virtual patient for completely edentulous computer-aided implant surgery: A dental technique. *J Prosthet Dent*. 2021;125:564–568.
13. Tardieu PB, Vrielinck L, Escolano E, Henne M, Tardieu A. Computer-assisted implant placement: scan template, simplant, surgiguide, and SAFE system. *Int J Periodontics Restorative Dent*. 2007;27:141–149.
14. Chen X, Yang Z, Wang Y, Fu G. Fixation pins increase the accuracy of implant surgery in free-end models: An in vitro study. *J Oral Maxillofac Surg*. 2023;81:593–601.
15. Becker W, Goldstein M, Becker BE, Sennerby L. Minimally invasive flapless implant surgery: A prospective multicenter study. *Clin Implant Dent Relat Res*. 2005;7:S21–S27.
16. Ochi M, Kanazawa M, Sato D, Kasugai S, Hirano S, Minakuchi S. Factors affecting accuracy of implant placement with mucosa-supported stereolithographic surgical guides in edentulous mandibles. *Comput Biol Med*. 2013;43:1653–1660.
17. Mishra SK, Chowdhary R. Heat generated by dental implant drills during osteotomy—A review: heat generated by dental implant drills. *J Indian Prosthodont Soc*. 2014;14:131–143.
18. Ramani S, Vijayalakshmi R, Kumari CBN, Mahendra J, Ambalavanan N. A short review on minimally invasive implants. *Bioinformation*. 2023;19:655–658.
19. Lin W-S. Complications related to digital technologies in treating edentulous patients with dental implants—Part II. Computer-guided surgery and prosthetic stages. *J Prosthet Dent*. 2023;129:817–818.
20. Weintraub JA, Burt BA. Oral health status in the United States: Tooth loss and edentulism. *J Dent Educ*. 1985;49:368–378.
21. Albrektsson T, Blomberg S, Brånemark A, Carlsson GE. Edentulousness—an oral handicap. Patient reactions to treatment with iawbone-anchored prostheses. *J Oral Rehabil*. 1987;14:503–511.
22. Nowjack-Raymer R, Sheiham A. Numbers of natural teeth, diet, and nutritional status in US adults. *J Dent Res*. 2007;86:1171–1175.
23. Jones JA, Orner MB, Spiro IIIA, Kressin NR. Tooth loss and dentures: Patients' perspectives. *Int Dent J*. 2003;53:327–334.
24. Emami E, de Souza RF, Kabawat M, Feine JS. The impact of edentulism on oral and general health. *Int J Dent*. 2013;2013:498305.
25. Douglass CW, Shih A, Ostry L. Will there be a need for complete dentures in the United States in 2020? *J Prosthet Dent*. 2002;87:5–8.
26. Prevention: Oral Health Surveillance Report: Dental Caries, Tooth Retention, and Edentulism, United States, 2017–March 2020. US Dept of Health and Human Services,; 2025.
27. Azevedo M, Correia F, Faria Almeida R. Accuracy of implant guided surgery in fully edentulous patients: Prediction vs. actual outcome—Systematic review. *J Clin Med*. 2024;13:5178.
28. Becker W, Goldstein M, Becker BE, Sennerby L, Kois D, Hujoel P. Minimally invasive flapless implant placement: Follow-up results from a multicenter study. *J Periodontol*. 2009;80:347–352.
29. Kivovics M, Takács A, Pénzes D, Németh O, Mijiritsky E. Accuracy of dental implant placement using augmented reality-based navigation, static computer assisted implant surgery, and the free-hand method: an in vitro study. *J Dent*. 2022;119:104070.
30. Shi Y, Wang J, Ma C, Shen J, Dong X, Lin D. A systematic review of the accuracy of digital surgical guides for dental implantation. *Int J Implant Dent*. 2023;9:38.

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