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REVIEW

Depth distortion and angular deviation of a fully guided tooth-supported static surgical guide in a partially edentulous patient: A systematic review and meta-analysis

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Abstract

Purpose: This systematic review and meta-analysis aimed to evaluate the depth distortion and angular deviation of fully-guided tooth-supported static surgical guides (FTSG) in partially edentulous arches compared to partially guided surgical guides or freehand.

Material and Methods: This study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and was registered in the Open Science Framework (OSF). The formulated population, intervention, comparison, and outcome (PICO) question was: "In partially edentulous arches, what are the depth distortion and angular deviation of FTSG compared to partially guided surgical guides or freehand?" The search strategy involved four main electronic databases, and an additional manual search was completed in November 2023 by following an established search strategy. Initial inclusion was based on titles and abstracts, followed by a detailed review of selected studies, and clinical studies that evaluated the angular deviations or depth distortion in FTSG in partial arches, compared to partially guided surgical guides or freehand, were included. In FTSG, two surgical approaches were compared: open flap and flapless techniques, and two digital methods were assessed for surgical guide design with fiducial markers or dental surfaces. A qualitative analysis for clinical studies was used to assess the risk of bias. The certainty of the evidence was assessed according to the grading of recommendations, assessment, development, and evaluations (GRADE) system. In addition, a single-arm meta-analysis of proportion was performed to evaluate the angular deviation of freehand and FTSG.

Results: Ten studies, published between 2018 and 2023, met the eligibility criteria. Among them, 10 studies reported angular deviations ranging from -0.32° to 4.96° for FTSG. Regarding FTSG surgical approaches, seven studies examined the open flap technique for FTSG, reporting mean angular deviations ranging from 2.03° to 4.23°, and four studies evaluated flapless FTSG, reporting angular deviations ranging from -0.32° to 3.38°. Six studies assessed the freehand surgical approach, reporting angular deviations ranging from 1.40° to 7.36°. The mean depth distortion ranged between 0.19 mm to 2.05 mm for open flap FTSG, and between 0.15 mm to 0.45 mm for flapless FTSG. For partially guided surgical guides, two studies reported angular deviations ranging from 0.59° to 3.44°. Seven studies were eligible for meta-analysis, focusing on the FTSG in open flap technique, with high heterogeneity (I^2 (95%CI) = 92.3% (88.7%–96.4%)). In contrast, heterogeneity was low in studies comparing freehand versus FTSG in open flap techniques (I^2 (95%CI) = 21.3% (0.0%–67.8%)), favoring the FTSG surgical approach.

Conclusion: In partially edentulous arches, FTSG systems exhibited less angular deviation than freehand and partially guided surgical guides. Flapless surgical approaches were associated with reduced angular deviation and depth distortion, suggesting a potential preference for the FTSG method in these procedures.

KEYWORDS

accuracy, computer-aided design and computer-aided manufacturing, dental implants, digital workflow, guided implant surgery

Static guided implant surgery (sGIS), also known as static computer-assisted implant surgery (sCAIS), leverages advanced 3D imaging and computer-aided design and computer-aided manufacturing (CAD-CAM) software to create precise surgical guides.[1,2] These guides are critical for accurately transferring planned implant positions from a virtual environment on a computer directly to the surgical site,[3,4] enhancing the precision of implant placement, which can reduce surgical time and improve patient outcomes.[5] In the realm of a fully-guided tooth-supported static surgical guide (FTSG), the surgical guide ensures precise control over the direction and depth of implant placement.[6] In contrast, the partially guided surgical guide approach combines the use of drill guides for osteotomy with a freehand technique for implant placement.[7] Digital surgical guides fall into three categories: bone-supported, mucosa-supported, and tooth-supported templates.[3] Depending on their design, these can be either partially guided, assisting only in drilling, or fully guided, aiding in both drilling and implant placement.[8] Previous research indicates that fully guided tooth-supported static surgical guides result in significantly less variation in implant deviation compared to partially guided templates, particularly in terms of placement in the distal zone and angulation.[3,8] The transfer of digital information to actual clinical situations can be achieved through different surgical approaches, such as flapless with a small crestal incision or a punch after guide placement, and a full-thickness flap to position the guide directly onto the bone. Among these approaches, sGIS systems offer specialized drills that allow for depth control.[7–9]

Despite the potential benefits of digital surgical guides in enhancing implant placement accuracy, there is a risk of deviation, particularly concerning implant depth and angular deviation.[9] Several factors contribute to the accuracy of sCAIS, including the precision of data acquisition and integration, the types of surgical guide templates, surgeon experience, surgical approaches, and the guided systems employed.[2–5] However, numerous studies suggest that digital surgical guides can significantly enhance implant placement accuracy compared to freehand surgery, with increasing levels of guidance correlating with higher accuracy.[6–9] Additionally, the growing popularity of in-office 3D printing has influenced the fabrication of surgical templates for guided implant surgery, commonly created using photopolymerizing resin materials.[3,10] This method has gained favor due to its accessibility, cost-effectiveness, efficiency, and reduced waste.[10] However, it is crucial to be aware of certain limitations associated with photopolymerizing resins, such as discrepancies between different 3D printers and the influence of printing orientation on the parallelism of 3D printer features (distance, wall thickness, or inclination).[10–12]

Therefore, this systematic review and meta-analysis aimed to answer the following focused research question: "In partially edentulous arches, what are the depth distortion and angular deviation of FTSG compared to partially guided surgical guides or freehand?" The hypotheses are (1) there is no difference in depth distortion and angular deviation in fully-guided tooth-supported sCAIS compared to partially-guided surgical guides or freehand in an open flap and flapless surgical approach; (2) there is a difference in depth distortion and angular deviation in fully-guided tooth-supported sCAIS compared to partially-guided surgical guides or freehand in an open flap and flapless surgical approach

METHODS

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology criteria[13] and was registered in the Open Science Framework (OSF) under the DOI 10.17605/OSF.IO/X9DBK. The inclusion criteria were randomized controlled clinical trials (RCTs), and prospective clinical studies. Conversely, retrospective studies, reviews, expert opinions, in vitro studies, radiographic studies, and studies that did not compare digital and conventional methods of denture fabrication were excluded (Table 1). Only studies assessing the angular deviations or depth distortion in FTSG compared to partially guided surgical guides or freehand and published in English were considered eligible for inclusion in this systematic review.

The following population, intervention, comparison, and outcome (PICO) question was formulated to address the spe-

TABLE 1 PICO question and selection criteria.

Focused question (PICO)	**In partially edentulous arch, what is the depth distortion and angular deviation of fully-guided tooth-supported static surgical guide?**
Population	Partially edentulous arch.
Intervention or exposition	Fully-guided tooth-supported static surgical guide.
Comparison or control	Partially guided surgical guide and freehand implant surgery.
Outcome measure(s)	Depth distortion and angular deviations.
Types of studies included	Randomized clinical trials (RCTs); Prospective clinical studies; Case series with a minimum of 10 patients.
Types of studies excluded	Reviews; Expert opinions; In vitro studies; Studies that evaluated full-arch surgical guide; Dynamic guide; Only partially-guided.

cific aim of the study: "In partially edentulous arches, what are the depth distortion and angular deviation of FTSG compared to partially guided surgical guides or freehand?" The PICO acronym structured the focused question as follows: Population (P)—partially edentulous arch; Intervention (I)—FTSG; Comparison (C)—partially guided surgical guides or freehand; Outcome (O)—angular deviations and depth distortion.

The search strategy was developed in the PubMed (MEDLINE) database and adapted to other databases, including Scopus, Web of Science, and LILACS, and was completed in November 2023. A manual search on the internet and in the references within articles was also performed. The main search strategy was used as a reference and applied to the following databases: Scopus, Web of Science, and LILACS. The following keywords were used: "(partially edentulous OR tooth-supported OR dental implant OR static surgical guide OR fully-guided) AND (Data Accuracy OR Accuracy OR Dimensional measurement OR precision OR trueness OR reproducibility)" (Table 2).

All citations identified by both reviewers (FF and CJ) were loaded into the EndNote X9 software program (https://endnote.com) and duplicates were removed. Both independent reviewers participated in the article selection based on titles and abstract information using online software for systematic reviews (Rayyan, Qatar Computing Research Institute). Intra- and inter-reviewer agreement level was assessed. The Kappa score identified an acceptable level of agreement (>80%) between reviewers (Figure 1). In case of disagreement between the primary reviewers, a third reviewer (AC) was consulted, and disagreements were resolved through discussion and consensus.

The full texts of the potentially eligible studies were retrieved and evaluated independently by two reviewers followed by data extraction for primary outcomes. The data collected from the selected articles consisted of information about the author, year of study, study design, number of patients and implants, implant characteristics, and tooth-supported surgical guide information (Table 3). Details of the digital workflows in the included studies, including surgical approaches (open flap and flapless), angular distortion, deviation measurement, and depth distortion, CAD software were also extracted (Table 4).

The assessment of the risk of bias was performed with the ROB II tool used for randomized clinical trials (RCTs) and crossover trials.[14] Studies assessed with a low or moderate (some concerns) risk of bias were included in the study (Figure 2). A meta-analysis was performed using the software program Comprehensive Meta Analysis v. 2.2 (Biostat Inc.) using the random effects model.[13] The FTSG using an open flap technique (n) was referred to as the event rate (%) to represent the combined prevalence (Figure 3). A second meta-analysis compared angular deviation between freehand and FTSG surgery (Figure 4). The odds ratio (with respective 95%CI and p-values) was adopted as the combined effect size. This information is presented in the Forest Plots. Heterogeneity between studies was assessed using I^2 statistics (and respective 95%CI) to determine the extent of heterogeneity.[15]

Deviation measurements included global deviation (spatial distance between the center of the implant platform/apex of planned and placed implants), lateral deviation (a directional component of global deviation at the level of the planned implant platform/apex), depth deviation (distance between planned and placed implants on the axis of the planned implant), and angular deviation (spatial angle between the planned and placed implant axis). Figure 5 is a schematic diagram summarizing the workflow of guided surgery and the deviation measurements.[1]

RESULTS

The literature search yielded 1952 studies, including 537 studies from PubMed/MEDLINE, 1141 from Scopus, 255 from the Web of Science, and 19 from LILACSC. After removing duplicate references, 732 articles were selected for title and abstract evaluation. A subsequent detailed review led to the selection of 35 articles for applying eligibility and exclusion criteria, resulting in the exclusion of 25 articles for reasons detailed in Table 5. The search strategy is outlined in Figure 1.

TABLE 2 Search strategy for each database by November 2022.

Databases	Search strategy
PubMed (*n* = 537)	((“partially edentulous” [All Fields] OR “tooth-supported” [All Fields] OR “dental implant” [All Fields] OR “dental implantation” [MeSH]) AND (“surgical guide” [All Fields] OR “computer guided” [All Fields] OR “static surgical guide” [All Fields] OR “fully-guided” [All Fields] OR “guide surgery” [All Fields] OR “digital guide” [All Fields] OR “3D-printed surgical guide” [All Fields] OR “computer aided design” [All Fields]) AND (“Data Accuracy” [Mesh] OR “Accuracy” OR “Accuracies” OR “Dimensional measurement accuracy” [MeSH] OR “sensitivity and specificity” [Mesh:NoExp] OR “sensitivity” OR “specificity” OR “precision” [All Fields] OR “trueness” [All Fields] OR “repeatability” [All Fields] OR “reproducibility” [All Fields]))
Scopus (*n* = 1141)	TITLE-ABS-KEY(“partially edentulous” OR “tooth-supported” OR “dental implant” OR “dental implantation” OR “surgical guide”) AND TITLE-ABS-KEY(“fully-guided” OR “surgical guide” OR “computer guided” OR “static surgical guide” OR “guide surgery” OR “digital guide” OR “3D-printed surgical guide” OR “computer aided design”) AND TITLE-ABS-KEY(“accuracy” OR “accuracies” OR “dimensional measurement accuracy” OR “sensitivity and specificity” OR “sensitivity” OR “specificity” OR “precision” OR “trueness”
Web of Science (*n* = 255)	TS = (“partially edentulous” OR “tooth-supported” OR “dental implant” OR “dental implantation”) AND TS = (“surgical guide” OR “computer guided” OR “static surgical guide” OR “fully-guided” OR “guide surgery ” OR “digital guide” OR “3Dprinted surgical guide” OR “computer aided design”) AND TS = (“data accuracy” OR “Accuracy” OR “Accuracies” OR “sensitivity” OR “specificity” OR “precision” OR “trueness” OR “repeatability” OR “reproducibility”)
LILACS (*n* = 19)	(“partially edentulous” OR “tooth-supported” OR “dental implant” OR “dental implantation”) AND (“surgical guide” OR “computer guided” OR “static surgical guide” OR “fully-guided” OR “guide surgery” OR “digital guide” OR “3D-printed surgical guide” OR “computer aided design”) AND (“Accuracy” OR “Accuracies” OR “sensitivity and specificity” OR “sensitivity” OR “specificity” OR “precision” OR “trueness” OR “repeatability” OR “reproducibility”) AND (db:(“LILACS”))

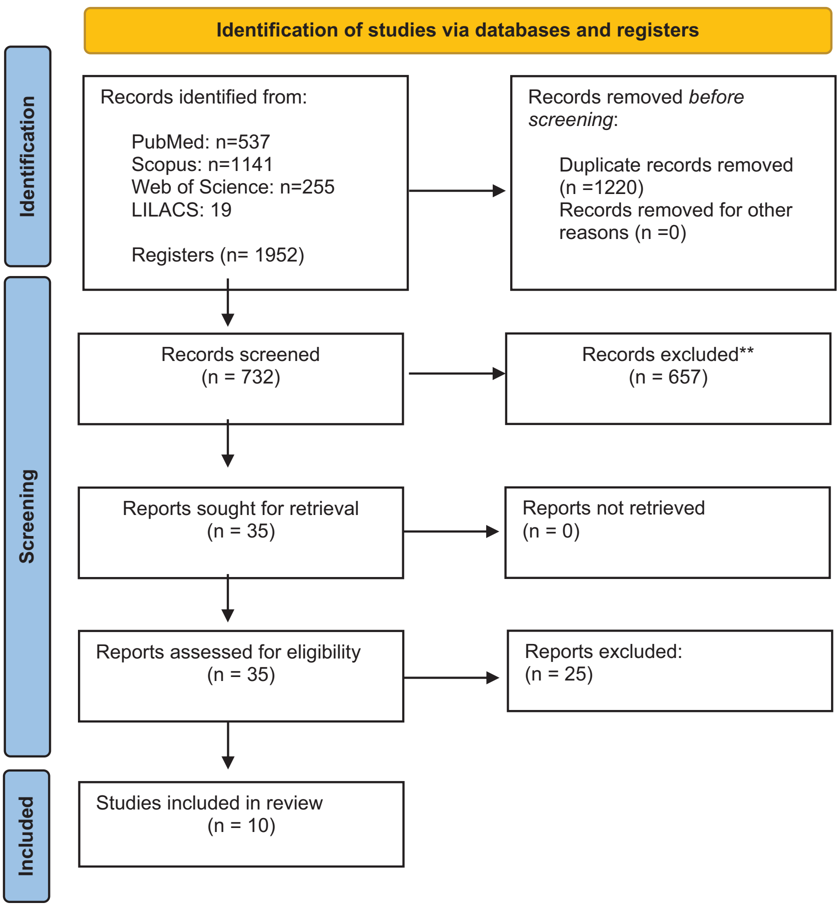

FIGURE 1 Flowchart diagram.

TABLE 3 Characteristics of each included study.

Study, year/study design	Number of patients/number of implants	Implant characteristics	Tooth-supported surgical guide
Schneider, 2018 Randomized controlled clinical trial	73 patients 20 implants	Length (-) Diameter (-)	Sites with single edentulous spaces in upper and lower arch
Bencharit, 2018 Cross-sectional study	16 patients 31 implants	Bio Horizon Zimmer Taper Zimmer Biomet Length (-) Diameter (-)	Sites with single edentulous spaces and neighboring natural teeth in upper and lower arch.
Fang, 2018 Prospective clinical research	32 patients 40 implants (20 implants in the maxilla and 20 implants in the mandible)	Implants: (UFII; DIO Inc) Length (-) Diameter (-)	Sites with edentulous spaces and neighboring natural teeth in anterior maxilla/
Varga, 2019 Randomized controlled clinical trial	101 patients 207 implants	MultiNeO® (Alpha-Bio Tec). Length (-) Diameter (-)	Partial edentulous spaces between neighboring natural teeth in upper and lower arch (1−6 teeth).
Derksen, 2019 Prospective cohort study	66 patients 145 implants	Tissue level Straumann implants (Straumann, AG) Length 8mm (45) 10mm (83) 12 mm (17)	Partial edentulous spaces between neighboring natural teeth in upper and lower arch.
Smitkarn, 2019 Randomized controlled clinical trial	52 patients 60 implants	Bone-level Straumann implants (Straumann, AG) Length (-) Diameter (-)	Sites with single edentulous spaces between neighboring natural teeth.
Lin, 2020 Prospective clinical research	21 patients 25 implants	Tissue level Straumann implants (Straumann AG) Length 8/10 mm (23) 11.5 mm (11) 13/16 mm (9) Diameter 3.5 mm 3.75 mm 4.2 mm	Sites with single edentulous spaces and neighboring natural teeth in anterior maxilla (1−6 teeth).
Lou, 2020 Randomized controlled clinical trial	60 patients 63 implants	BLT Straumann implants (Straumann, AG) Length (-) Diameter (-)	Sites with single edentulous spaces and neighboring natural teeth in anterior maxilla.
Ngamprasertkit, 2021 Randomized controlled clinical trial	15 patients 15 implants	NOVEM®, Novem Innovations Co., Ltd., Chiang Mai, Thailand Length (-) Diameter (-)	Sites with single edentulous spaces and neighboring natural teeth.
Huang, 2023 Cross-sectional study	48 patients 48 implants	Bone level and Bone level tapered Straumann implants (Straumann AG) Length 10 mm (24) 12 mm. (17) Diameter 3.3 mm 4.1 mm 4.8 mm	Sites with single edentulous spaces and neighboring natural teeth in anterior maxilla.

TABLE 4 Characteristics of digital workflows in included studies.

Study, year/study design	Workflows	Software CAD/Guided System	Angular Distortion in ° (mean; range) Depth Distortion in ° (mean; range)	Conclusions
Varga, 2019 **Randomized controlled clinical trial**	Comparison of the digital planned and actual implant positions in freehand and fully guided surgery Alignment of CBCT scan and desktop scan by dental surface. Post-operative CBCT scanning, to calculate the deviations between the planned and the placed implants.	**Implant planning**: SMART Guide System **Surgical Guide Planning**: SMART Guide System with Alpha-Bio Tec **Deviation Measurement**: Amira 5.4.0 (Thermo Fisher Scientific) with dedicated algorithms. Pre- and postoperative CBCT scans of any given patient were registered.	**Angular Distortion** Freehand (Open flap) 7.03° ± 3.44 Fully guided surgery (Open flap) 3.04° ± 1.51 **Depth Distortion NR**	Static-guided approach significantly improves the accuracy of dental implant surgery as compared to freehand surgery. Furthermore, the results suggest that any degree of guidance yields better results than freehand surgery and that increasing the level of guidance increases accuracy.
Smitkarn, 2019 **Randomized controlled clinical trial**	Accuracy of implant positions between static computer-assisted implant surgery and freehand implant surgery Alignment of CBCT scan and intraoral scan by dental surface	**Implant planning**: coDiagnostiX® software version 9.7 (Dental WingsInc) **Surgical Guide Planning**: coDiagnostiX® software version 9.7 (Dental Wings Inc) **Deviation Measurement**: Pre-operative CBCT images using automated surface best-fit matching with the iterative closest point algorithm in the treatment evaluation mode. coDiagnostiX®software version 9.7 (Dental Wings Inc)	**Angular Distortion** Freehand (Open flap) 6.9° ± 4.44 Fully guided surgery (Open flap) 2.3° ± 3.10 **Depth Distortion** Fully guided surgery (Open flap) 0.7 (0.5) mm Freehand (Open flap) 1.0 (0.8) mm	Static-guided approach significantly improves the accuracy of dental implant surgery as compared to freehand surgery. Furthermore, the results suggest that any degree of guidance yields better results than freehand surgery and that increasing the level of guidance increases accuracy.
Ngamprasertkit, 2021 **Randomized controlled clinical trial**	Accuracy of a single-tooth implant in partial guided (implant placement without guided); and surgical drill guide with implant insertion guide (fully guided) Alignment of CBCT scan and intraoral scan by digital wax-up	**Implant planning**: Planmeca Romexis™ **Surgical Guide Planning**: A virtual wax-up and planned implant position regarding final prosthesis **Deviation Measurement**: The postoperative CBCT data were matched to the preoperative planning data	**Angular Distortion** Partially guided surgical guides (Open Flap) 3.44° ± 1.61 Fully guided surgery (Open flap) 2.03° ± 1.00 **Depth Distortion** Fully guided surgery (Open Flap) 0.19 ± 0.14 Partially guided surgical guides (Open Flap) 0.36 ± 0.27	Guided implant surgery by fully digital workflow is a practical procedure and provides precise implant position regarding the prosthetic-driven concept.

(Continues)

TABLE 4 (Continued)

Study, year/study design	Workflows	Software CAD/Guided System	Angular Distortion in ° (mean; range) Depth Distortion in ° (mean; range)	Conclusions
Lou, 2020 **Randomized controlled clinical trial**	Accuracy of partially guided and fully guided templates applied to implant surgery of anterior teeth Alignment of CBCT scan and intraoral scan by dental surface	**Implant planning**: Implant Studio, (3Shape TRIOS Denmark) **Surgical Guide Planning**: Implant Studio, (3Shape TRIOS Denmark) **Deviation Measurement**: The postoperative CBCT data were matched to the preoperative planning data	**Angular Distortion** Freehand (Open flap) 6.61° ± 1.09 Fully guided surgery (Open flap) 2.05° ± 0.45 mm **Depth Distortion** Freehand (Open flap) 1.02 ± 0.13 mm Fully guided surgery (Open flap) 0.24 ± 0.06 mm	Digital surgical guides can improve the accuracy of the three-dimensional position of implants in the maxillary aesthetic zone. The fully guided template has higher precision than the partially guided template, and plays an important role in obtaining ideal aesthetic effects in the maxillary anterior region.
Fang, 2018 **Prospective clinical research**	Post-operative CBCT scanning, to calculate the deviations between the planned and the placed implants. Alignment of CBCT scan and intraoral scan by dental surface	**Implant planning**: Implant Studio, (3Shape TRIOS Denmark) **Surgical Guide Planning**: DIO Navi Guide (DIO Inc) **Deviation Measurement**: Mimics 21.0 (Materialise De)	**Angular Distortion** Fully guided surgery (Flapless) 1.40° **Depth Distortion** Fully guided surgery (Flapless) 0.15 mm	The accuracy of computer-guided implant placement may be enhanced by using a long drill key in anterior regions.
Derksen, 2019 **Prospective cohort study**	Accuracy of fully guided applied to implant surgery. Alignment of CBCT scan and intraoral scan by fiducial marker on the coronal part of the teeth. Accuracy was evaluated by superimpose the scanned arches with the CBCT Scan.	**Implant planning**: coDiagnostiX® software version 9.7 (Dental Wings Inc.) **Surgical Guide Planning**: coDiagnostiX® software version 9.7 (Dental Wings Inc.) **Deviation Measurement**: coDiagnostiX® software version 9.7 (Dental Wings Inc) into treatment evaluation tool	**Angular Distortion** Fully guided surgery (Open Flap) 2.81° ± 1.45 Flapless 2.42° ± 1.30 Partially guided surgical guides (Open Flap) 2.81° ± 1.45 **Depth Distortion** NR	FTSG surgery made in a digital workflow is a feasible treatment option. However, deviations do occur and the implant's length, location, cortical interference and the number of unrestored teeth have a significant influence on the accuracy.

(Continues)

TABLE 4 (Continued)

Study, year/study design	Workflows	Software CAD/Guided System	Angular Distortion in ° (mean; range) Depth Distortion in ° (mean; range)	Conclusions
Lin, 2020 **Prospective clinical research**	Comparison of the digital planned and actual implant positions in Partially guided surgical guides and fully guided surgery Alignment of CBCT scan and intraoral scan by fiducial marker or dental surface Accuracy was evaluated by superimpose the scanned arches with the CBCT Scan by fiducial marker or dental surface.	**Implant planning**: BenQ AB Guided Service (Ashdod, Israel) **Surgical Guide Planning**: PlastyCAD, (3DIEMME Bioimaging Tecnologies, Figino Serenza, Italy) **Deviation Measurement**: Geomagic Design X (3D Systems Inc., Rock Hill)	**Angular Distortion** Fully guided surgery (Flapless) 1)Fiducial Marker: 3.38° ± 1.81 2)Dental Surface: 4.96° ± 3.32 Partially guided surgical guides (Flapless) 1. Fiducial Marker: 3.78° ± 1.01 2. Dental Surface: 5.16° ± 2.32 **Depth Distortion** Fully guided surgery Open flap 0.46 ± 0.36 mm Flapless 0.45±0.33	A larger mean value of the angular deviation was observed when matching CBCT scan with intraoral scan by the direct registration of the dental surface images, probably owing to the effect of metallic artifact of the crown restorations in CBCT image.
Schneider, 2018 **Randomized controlled clinical trial**	Compare the Accuracy of fully guided and freehand conventional implant surgery. Alignment of CBCT scan and intraoral scan by dental surface. The postoperative implant position was recorded and compared to the position originally planned to use a master cast with the implant replica was optically scanned, and the *STL* file was uploaded to the implant planning.	**Implant planning**: Simplant (Dentsply Sirona) **Surgical Guide Planning**: Simplant (Dentsply Sirona) **Deviation Measurement**: Simplant (Dentsply Sirona)	**Angular Distortion** Freehand 7.36° ± 3.36 Fully guided surgery (Open flap) 4.23° ± 2.68 **Depth Distortion** Freehand 0.28 mm Fully guided surgery 0.2 mm	Fully guided surgery protocols for single implants provided high accuracy in transferring the planned implant position to the ideal position. In areas of important anatomical structure, to avoid inaccuracy, a safety margin of about two millimeters around the implant should be respected in the planning phase.

(Continues)

TABLE 4 (Continued)

Study, year/study design	Workflows	Software CAD/Guided System	Angular Distortion in ° (mean; range) Depth Distortion in ° (mean; range)	Conclusions
Huang, 2023 **Cross-sectional study**	Load the scanned maxillary and mandibular arches into a commonly surgical planning software program (Implant Studio; 3shape A/S), Orient the arches to the virtual articulator conduct to a digital tooth set-up driven prosthetic considerations. Accurately superimpose the scanned arches with the cone-beam computed tomography (CBCT) data.	**Implant planning**: Implant Studio, (3Shape TRIOS Denmark **Surgical Guide Planning**: Implant Studio, (3Shape TRIOS Denmark) **Deviation Measurement**: 3D reconstruction of the postoperative CT using third-party software (Mimics Medical 21.0) to create a 3D model. Importing the postoperative 3D model into the surgical planning software program (Implant Studio; 3Shape A/S)	**Angular Distortion** Fully guided surgery (Open flap) 1. Dental Surface: 2. 36° ± 1.70 Freehand (Open flap) 1. Dental Surface: 4.31° ± 3.37 **Depth Distortion** Fully guided surgery (Open flap) 1. Dental Surface: 0.60 ± 0.52 Freehand (Open flap) 1. Dental Surface: 1.18 ± 0.77	Fully guided surgery protocols provide more accurate implant placement than freehand.
Bencharit,2018 **Cross-sectional study**	Accuracy of partially guided and fully guided templates. Alignment of CBCT scan and intraoral scan by dental **surface** The pre-and postoperative CBCT Scan position was recorded, the panned implant position of the implant was compared to the final implant position.	**Implant planning**: Implant Studio, (3Shape TRIOS Denmark) 360 imaging **Surgical Guide Planning**: Implant Studio, (3Shape TRIOS Denmark) 360 imaging **Deviation Measurement**: 360 tps (360 imaging) or 3Shape Implant Studio (3Shape)	**Angular Distortion** Partially guided surgical guides (Flapless) 0.59° ± 6.83 Fully guided surgery (Flapless) −0.32° ± 2.36 **Depth Distortion** NR	Guided implant surgery is more accurate in the anterior area compared to the posterior. Fully guided implant surgery is more accurate than partially-guided implant surgery. Implant systems or software does not influence the surgery accuracy.

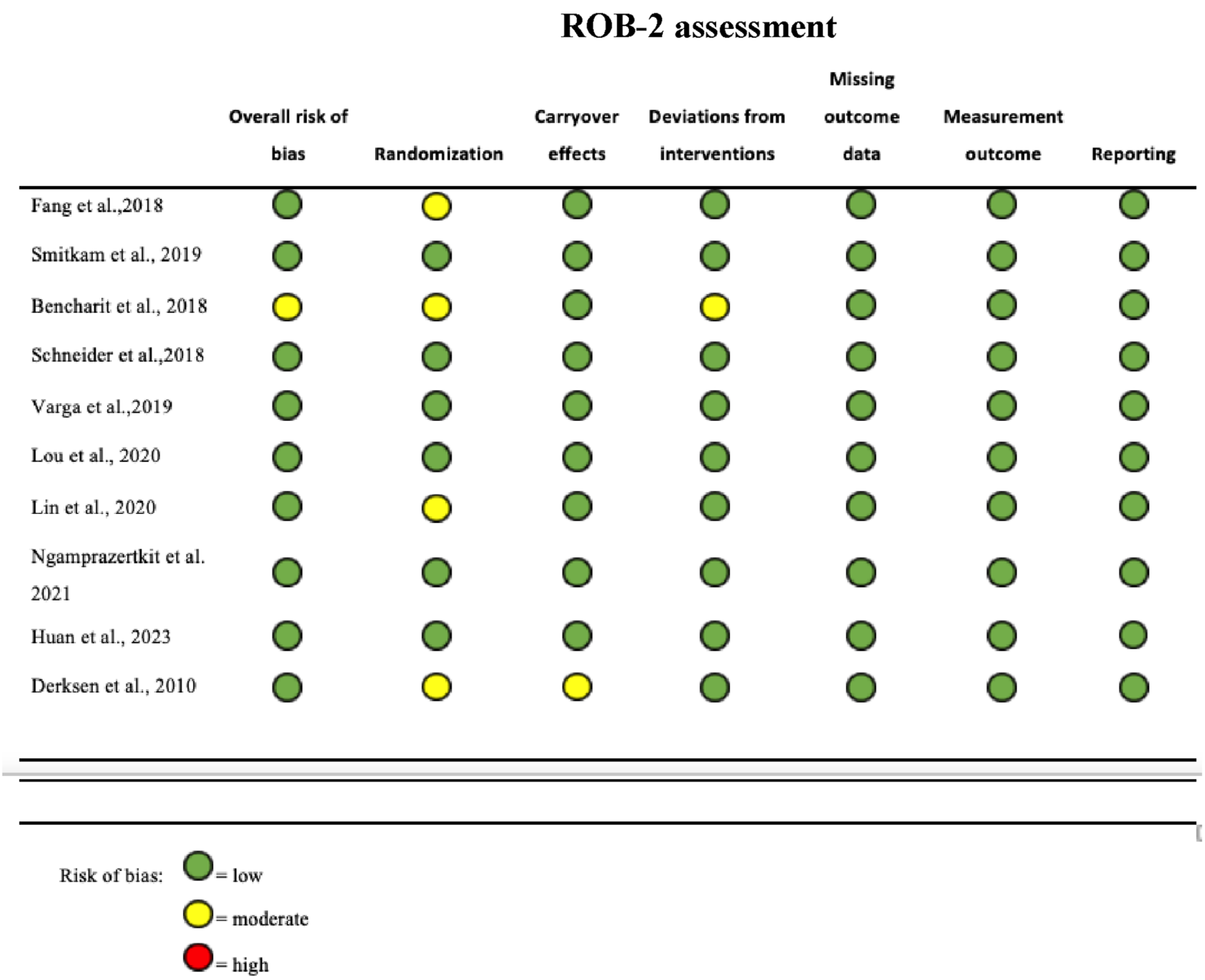

FIGURE 2 Quality assessment and risk of RCTs according to the Cochrane guidelines.

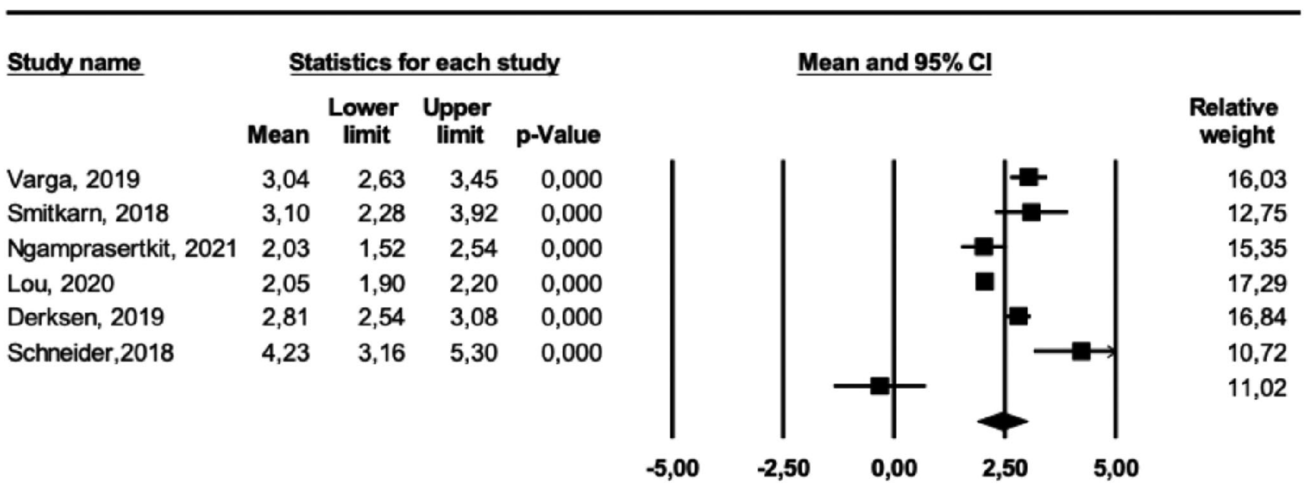

FIGURE 3 Forest plot results for mean and deviation (SD) of fully-guided tooth-supported in open-flap technique.

TABLE 5 Excluded articles and reasons.

Author, year	Article title	Reason
Cunha RM, 2019	Accuracy evaluation of computer-guided implant surgery associated with prototyped surgical guides.	Prototyped surgical guides
Amin S, 2017	Digital v conventional full-arch implant impressions: a comparative study.	Compared conventional to digital impressions
Zhou M, 2021	Accuracy of implant placement guided with surgical template: an in vitro and in vivo study.	In vitro study
Lin CC, 2020	Fully digital workflow for planning static guided implant surgery: a prospective accuracy study.	Edentulous patient
Xu LW, 2016	Impact of surgical template on the accuracy of implant placement.	Edentulous patient
Poli PP, 2021	Computer-guided implant placement associated with computer-aided bone regeneration in the treatment of atrophied partially edentulous alveolar ridges: A proof-of-concept study.	Evaluated the GBR simultaneously to implant insertion were enrolled
Zhao XZ, 2014	Accuracy of computer-guided implant surgery by a CAD/CAM and laser scanning technique.	Compared computer-aided design and computer-aided manufacturing (CAD-CAM)
Rungcharassaeng K, 2015	Accuracy of computer-guided surgery: A comparison of operator experience.	Operator experience
Cho JY, 2021	The accuracy of a partially guided system using an in-office 3D-printed surgical guide for implant placement.	Observational study
Skjerven H, 2019	In vivo accuracy of implant placement using a full digital planning modality and stereolithographic guides.	Stereolithographic guides
Kiatkroekkrai P, 2020	Accuracy of implant position when placed using static computer-assisted implant surgical guides manufactured with two different optical scanning techniques: a randomized clinical trial.	Compared CAIS guides produced by intraoral and extraoral (model) scanning
Matsumura A, 2021	Multivariate analysis of causal factors influencing accuracy of guided implant surgery for partial edentulism: a retrospective clinical study.	Retrospective clinical study
Cristache CM, 2017	Accuracy evaluation of a stereolithographic surgical template for dental implant insertion using 3D superimposition protocol.	Stereolithographic guides
Kühl S, 2015	Technical accuracy of printed surgical templates for guided implant surgery with the coDiagnostiX ™ software.	Only evaluated the guided implant surgery did not provide intervention group
Abduo J, 2021	Seating accuracy of implant immediate provisional prostheses fabricated by digital workflow prior to implant placement by fully guided static computer-assisted implant surgery: An in vitro study.	Implant immediate provisional prostheses
Farley NE, 2013	Split-mouth comparison of the accuracy of computer-generated and conventional surgical guides.	Split-mouth design
Abduo J, 2020	Effect of manufacturing technique on the accuracy of surgical guides for static computer-aided implant surgery.	Manufacturing technique evaluation
Sarhan MM, 2021	Evaluation of the accuracy of implant placement by using fully guided versus partially guided tissue-supported surgical guides with cylindrical versus C-shaped guiding holes: A split-mouth clinical study.	Edentulous patient, full arches
Ravidà, 2018	Clinical outcomes and cost-effectiveness of computer-guided versus conventional implant-retained hybrid prostheses: A long-term retrospective analysis of treatment protocols.	Clinical outcomes
Gargallo-Albiol J, 2022	Accuracy of static fully guided implant placement in the posterior area of partially edentulous jaws: a cohort prospective study.	No comparison
El Kholy K, 2019	Influence of implant macrodesign and insertion connection technology on the accuracy of static computer-assisted implant surgery.	Only evaluated the guided implant surgery did not provide intervention group
Giordano M, 2012	Accuracy evaluation of surgical guides in implant dentistry by non-contact reverse engineering techniques.	Edentulous patient, full arches
Ritter L, 2012	Registration accuracy of three-dimensional surface and cone-beam computed tomography data for virtual implant planning.	Accuracy of CBCT
Nicchio N, 2023	Accuracy of partially and fully guided surgical techniques for immediate implant placement: An in vitro assessment.	In vitro research
Wang QF, 2020	Study on the influence of sleeve height and implant length on accuracy of static computer-assisted implant surgery.	Influence of sleeve height

Study name	Difference in means	Standard error	Lower limit	Upper limit	p-Value	Relative weight
Varga, 2019	-3,99	0,52	-5,01	-2,97	0,000	21,29
Smitkarn, 2018	-3,80	0,91	-5,59	-2,01	0,000	8,09
Schneider, 2018	-3,13	0,86	-4,82	-1,44	0,000	8,94
Lou, 2020	-4,56	0,21	-4,97	-4,15	0,000	61,68
	-4,25	0,27	-4,78	-3,72	0,000	

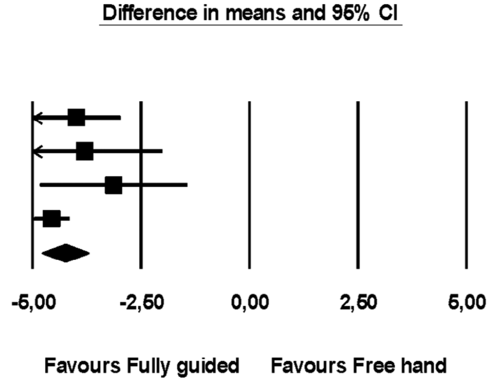

FIGURE 4 Forest plot results for mean and deviation (SD) of fully-guided tooth-supported compared to freehand.

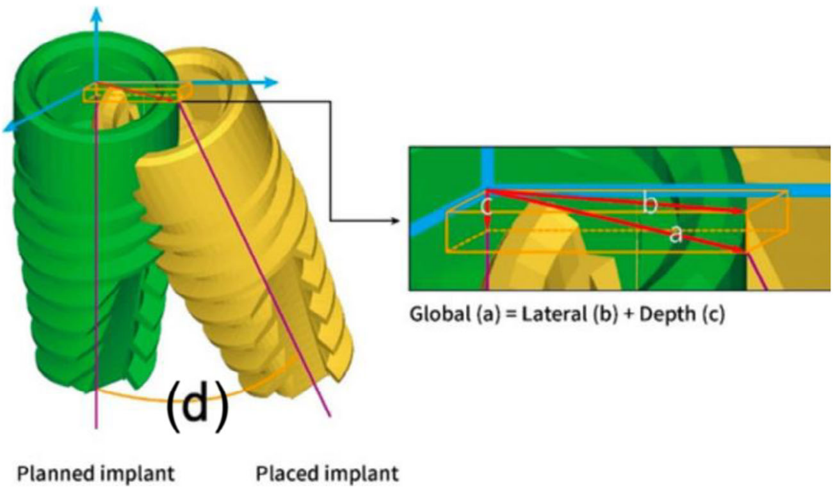

FIGURE 5 Definitions of the deviations between planned and placed implants: (a) global deviation, (b) lateral deviation, (c) depth deviation, and (d) angular deviation. (Lin et al., 2020).[1]

The characteristics of the included studies are summarized in Tables 3 and 4. A total of 10 studies published between 2018 and 2023 involving 484 clinical study participants and 654 implants are summarized in Table 3. Among these, five were RCTs, three were prospective clinical studies, and two were cross-sectional studies. Data extracted from these articles included information about the authors, year of study, study type, number of patients, implant characteristics, and tooth-supported surgical guide (Table 4).

Regarding implant surgery, six studies assessed the freehand surgical approach reporting angular deviations ranging from 1.40° to 7.36°. For partially guided surgical guides, two studies reported angular deviations ranging from 0.59° to 3.44°. In terms of FTSG surgical approaches, seven studies examined the open flap technique for FTSG, reporting mean angular deviations ranging from 2.03° to 4.23°. Meanwhile, four studies evaluated flapless FTSG, reporting angular deviations ranging from −0.32° to 3.38°. The mean depth distortion ranged between 0.19 mm to 2.05 mm for open flap FTSG, and between 0.15 mm to 0.45 mm for flapless FTSG. In terms of digital methods assessed in FTSG for surgical guide design with dental surfaces, the angular deviations of six studies ranged between 1.40° and 4.96° for fiducial markers, the angular deviations of two studies ranged between 2.81° and 3.38 (Table 4).

The angular deviation values from clinical studies ranged between 2.03° ± 1.00 and 4.23° ± 2.68 in FTSG surgery using the open flap technique.[7,12,16] For FTSG surgery with flapless technique, the range was 3.38° ± 1.81 (alignment of CBCT scan and intraoral scan by fiducial marker)[1] and −0.32° to 4.96° (alignment of CBCT scan and intraoral scan by dental surface).[1,5]

In the 10 studies included, the angular distortion of fully-guided implant placement was described employing deviation/discrepancy values.[13] This is done through different methodologies of Software CAD Planning Technique; two studies used coDiagnostiX® software version 9.7 (Dental Wings Inc),[8,4] three studies used Implant Studio (3 Shape TRIOS Denmark),[2,5,6,16] and one study used Simplant (Dentsply Sirona).[9] In other studies the digital planning was conducted by Planmeca Romexis™,[7] SMART Guide System,[8] and BenQ AB Guided Service (Ashdod, Israel).[1]

The risk of bias in the studies was assessed using the ROB II tool for RCTs and crossover trials in 10 studies.[16] Six studies scored all green, indicating low risk, while one had three yellow markers each, two had one yellow marker each, and one had two yellow markers each. Consequently, all studies were judged to have a low risk of bias (Figure 2). Outcomes measurements collected from included studies were absolute frequencies, interventions, and findings. In addition, seven studies were eligible for meta-analysis, revealing high heterogeneity (I^2 (95%CI) = 92.3% (88.7%–96.4%)) for FTSG surgery open flap techniques. In contrast, when analyzing deviations of FTSG versus freehand surgery techniques in open flap cases, heterogeneity was low ((I^2 (95%CI) = 21.3% (00.0%–67.8%)), favoring the fully-guided approach (Figure 4).[15]

DISCUSSION

This systematic review and meta-analysis, synthesizing data from 10 clinical studies, provides substantial evidence on the angular deviation and depth distortion of FTSG in tooth-supported applications within different surgical approaches, flapless and open-flap techniques. The experimental data invalidated the corresponding research hypothesis that (1) there is no difference in depth distortion and angular deviation in fully-guided tooth-supported sCAIS compared to partially-guided surgical guides or freehand in an open flap and flapless surgical approach. The results indicated that fully-guided tooth-supported systems, demonstrate reduced angular deviations compared to partially guided surgical guides and freehand implant surgery in partially edentulous arches. Angular deviations ranged from −0.32° to 4.96° in fully guided, 0.59° to 3.44° in partially guided surgical guides and 1.40° to 7.36° in freehand approaches.[5,7,12] The mean depth distortion observed in FTSG with the open flap technique varied from 0.19 ±0.14 mm to 2.05 ± 0.45 mm, while in the flapless technique, it ranged from 0.15 mm to 0.45 ±0.33 mm, aligning with previous studies.[2–9] According to Tallarico et al.,[17] the maximum acceptable value for angular discrepancy should range between 5.9° and 16.7°, depending on the implant length and diameter.[17]

The findings underscore the clinical relevance of angular deviation over horizontal distortion, in line with earlier research,[18–20] and highlight the potential risks associated with depth distortion, particularly in proximity to vital anatomical structures. In the present systematic review, in FTSG surgery with flapless surgical approaches, the use of fiducial markers or dental surface markers for aligning CBCT and intraoral scans was found to offer greater clinical accuracy. The study by Lemos et al.,[21] and Lin et al.,[1] corroborate these results, emphasizing the influence of surgical approach and alignment techniques on the accuracy of FTSG systems. Smitkarn et al.,[8] showed that the deviation of implant position was not affected by implant location diameter or length for both FTSG and freehand implant surgery.[8] Furthermore, the most notable error associated with FTSG surgery occurs in the vertical direction, often resulting in an overly superficial implant position. This issue often arises due to the blockage of the implant holders in the sleeves of the template during surgery.[8] In the FTSG protocol, the implant is fully inserted via the 3D surgical guide and the operator has very little tactile perception of the implant stability other than the torque value. In the present systematic review, the FTSG protocol increased the clinical accuracy. There is a difference in depth distortion and angular deviation in fully-guided tooth-supported sCAIS compared to partially-guided surgical guides or freehand in an open flap and flapless surgical approach. The quantitative analysis showed significantly better results in terms of deviations among FTSG than freehand surgery techniques in open flap cases; heterogeneity was low ((I^2 (95%CI) = 21.3% (00.0%–67.8%)), favoring the fully-guided approach (Figure 4).

The first drill has a significant impact on the final accuracy of the implants because it determines the drilling axis; if an error occurs in the drilling axis inside the bone, it is difficult to correct or adjust the error.[16] Therefore, the conditions for the first drill should be optimized to reduce deviation of the implant placement. For instance, even though the present systematic review offers greater clinical results in FTSG than partially guided surgical guides, the angular deviations do not differ from each other, ranging from −0.32° to 4.96° in fully guided, 0.59° to 3.44° in partially guided surgical guides. However, when the osteology cavity is enlarged with drills, the implantation position and direction may gradually shift.[22] In contrast, freehand implant surgery allows the operator direct vision of the bone level and the vertical implant position. This direct view enables the operator to adjust the depth in response to the tactile perception of primary stability, potentially allowing for a slightly deeper implant placement in the bone if required.[8] Furthermore, implants placed with FTSG had significantly lower primary stability than freehand.[8]

Another important factor for the accuracy of guided surgery is the proportions and distances involved. The higher the guiding part of the template and the shorter the drill used, the higher the accuracy that may be achieved.[17] However, in anterior regions, this can be mitigated by enhancing implant placement with the use of a long drill key, which may enable more accurate implant placement, particularly in these regions.[5] Choi et al.,[23] evaluated the effects of the surgical guide length and drill length on implant placement error in an in vitro investigation and found that drill length was the primary controlling factor in minimizing deviated implant angulations. They recommended the use of the longest drill possible to reduce deviation.[23]

Interestingly, the current review also reveals that the choice of digital workflow, particularly the software used for implant planning, significantly impacts the accuracy of fully-guided tooth-supported systems.[24] For instance, the accuracy in coDiagnostiX® digital software was noted as 2.3° ± 3.10,[8] compared to Simplant and Implant Studio, which showed deviations of 4.23° ± 2.68 and −0.32° ± 2.36, respectively.[2,12] Even though differences in accuracy were noticed between implant software and surgical guide design, previous studies revealed no statistical differences between implant software with acceptable clinical implant position,[16] and implant systems or software did not influence the surgery accuracy.[2,25,26] This variation underscores the importance of software selection in clinical practice.

Moreover, the advent of navigation-guided surgery as a dynamic alternative to static surgical guides suggests potential improvements in surgical accuracy.[27] However, the literature still recommends further clinical studies to validate these outcomes.[27–29] Additional studies have indicated that the dynamic surgical guides method exhibits lower precision than FTSG and partially guided surgical guides.[30–32] Currently, static surgical guides offer superior accuracy compared to dynamic surgical guide surgeries. However, as digital technologies advance, clinicians must adapt to the changing landscape and the associated learning curves of these technological enhancements.[33]

The precision of implant positioning using FTSG, or partially guided surgical guides can be influenced by multiple factors, such as image acquisition, image data post-processing, site preparation for implantation, the implant placement itself, and ultimately, the image registration process.[34,35] In addition, a static surgical guide might be further influenced by the 3D printing of the surgical guide and the support structure of the guide.[10,11] Previous research has suggested that the orientation of 3D printing of implant surgical templates made using a DLP desktop printer impacts the precision of the templates.[11] Templates printed horizontally consistently demonstrated enhanced precision. To minimize deviations in implant positioning, it is advised to print the surgical templates with their largest dimension aligned parallel to the printing platform.[11] Several studies have advocated for 3D printing the object with an orientation that positions its largest dimension horizontally to optimize the printing area.[10,11] Moreover, 3D printing inaccuracies are linked to the step-by-step application and hardening of resin material, which can cause polymerization shrinkage of each layer, creation of internal tensions, and build-up of dimensional inaccuracies.[35]

In summary, the integration of 3D imaging and planning software has markedly improved surgical procedures by increasing the precision of diagnostics and treatment strategies, which facilitates enhanced healing and a faster resumption of daily activities, by minimizing the surgical trauma that is commonly linked with implant placement. Patients typically experience improved comfort and greater satisfaction with the treatment, particularly when a flapless method is applied.[33]

Despite these findings, one limitation of the present systematic review is the heterogeneity among the included studies, attributable to variables such as guide support mechanisms, bone density, and surgical protocols, a common challenge to a systematic review in this field. To address this, a meta-analysis focused on fully guided tooth-supported open-flap techniques and their comparison with freehand approaches, which helped to some extent in mitigating data heterogeneity. Hence, further long-term clinical studies are needed to fully assess the impact of a fully guided tooth-supported static surgical guide on implant survival and placement and how accurate the long key technique is compared to a conventional control group.

CONCLUSION

Based on the findings of this systematic review, a few conclusions were drawn and must be interpreted with caution. FTSG demonstrates minimizing angular deviations compared to freehand and partially guided surgical guides surgery techniques. The choice of surgical approach, whether open-flap or flapless, significantly influences the accuracy of FTSG. Flapless surgical approaches are associated with reduced angular deviation and depth distortion, indicating a potential preference for FTSG surgery in partially edentulous arches.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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