

Dental Implant Positioning Accuracy Using a Key or Keyless Static Fully Guided Surgical System: A Prospective Systematic Review and Meta-analysis

Ilyès Gourdache, DDS

Department of Dentistry, Universitat Internacional de Catalunya, Josep Trueta University Hospital, Barcelona, Spain; Department of Periodontology, Cliniques Universitaires Saint Luc, Université Catholique de Louvain, Brussels, Belgium.

Oscar Salomó-Coll, DDS, MS, PhD

Department of Oral and Maxillofacial Surgery Department, Universitat Internacional de Catalunya, Josep Trueta University Hospital, Barcelona, Spain.

Federico Hernández-Alfaro, MD, DDS, PhD

Department of Oral and Maxillofacial Surgery, Universitat Internacional de Catalunya, Josep Trueta University Hospital, Barcelona, Spain.

Jordi Gargallo-Albiol, DDS, MSc, PhD

Department of Oral and Maxillofacial Surgery, Universitat Internacional de Catalunya, Josep Trueta University Hospital, Barcelona, Spain; Department of Periodontics and Oral Medicine, University of Michigan School of Dentistry, Ann Arbor, Michigan, USA.

Purpose: To realize a systematic review with prospective meta-analysis aiming to compare the accuracy of static fully guided implant placement depending on the drill key modality (conventional drill key surgery systems vs newer keyless systems) and evaluate the impact of deviation factors. **Materials and Methods:** An electronic systematic search was conducted to identify prospective clinical trials matching inclusion criteria. The variables of interest were coronal global, apical, vertical, and angular deviations. The types of edentulism and surgical guide support were investigated as deviation factors. Meta-regression (mixed-effect model) was performed. Heterogeneity was assessed using Cochrane's I^2 test and interpretation thresholds. **Results:** A total of 1,233 implants in 475 patients were analyzed (18 studies included). Coronal global deviation was significantly lower in the keyless group than in the key group (-0.36 mm; 95% CI -0.62 , -0.09 ; $P = .008$). Angulation control of the keyless system was superior to that of the key system (-0.36 degrees; 95% CI -0.75 , 0.02 ; $P = .063$). Nonsignificant differences were found between both groups in apical ($P = .684$) and vertical deviations ($P = .958$). Significant influence of the type of edentulism (single, partial, total) and surgical guide support (tooth, mucosa, bone) on the overall amount of coronal global, apical, and angular deviations was found ($P < .001$). The lowest deviations were found in partial edentulism and tooth-supported surgical guide groups. ($P < .001$). **Conclusions:** Keyless static fully guided surgical systems allowed significantly better control of coronal and angular deviations than conventional systems. The types of edentulism and surgical guide support seemed to influence the positioning accuracy. *Int J Prosthodont* 2024;37:199–209. doi: 10.11607/ijp.8212

Dental implant positioning planning requires 3D exploration, usually CBCT, integrating a 3D intraoral image that represents the teeth and mucosal perimeter contours, a standard triangle language file (STL), and adequate surgical and prosthetic knowledge. Afterward, the assistance of navigation surgery to overcome the human errors associated with the free-hand implant surgical approach is usually recommended for applying the presurgical positioning planning to the patient.^{1,2} At the top of dental implant navigation surgery, static computer-aided implant surgery represents a common modality of fully or half-guided surgery, where the fabrication of an accurate CAD/CAM template is employed.

Correspondence to:
Dr Ilyès Gourdache
ilyesgourdache@uic.es

Submitted February 27, 2022;
accepted February 9, 2023.
©2024 by Quintessence
Publishing Co Inc.



Fig 1 Drill key surgical guide involving guided sleeves, drill key, and a bone drill inserted (coDiagnostix, Straumann).



Fig 2 Drill keyless surgical guide and a bone drill inserted (no drill key or sleeve; R2gate system, Megagen Implant).

In addition to dental implant positioning accuracy, fully guided approaches facilitate flapless surgeries, which may reduce patient chair time^{1,3–5} and patient morbidity,^{1,6} and most importantly, it could enhance patient satisfaction.^{3,7} However, fully guided surgery also has some drawbacks: limited mouth openings may decrease the effectiveness of static navigation surgery, modifying the drill's position in relation to the surgical stent; making impossible the use of static navigation surgery in patients with severe opening limitations.^{2,8} Furthermore, some of the 3D-positioning control mechanisms available in the market use instruments such as guiding sleeves and key elements that require more steps in the surgical proposal and large mouth openings.

Guiding sleeves are metallic or plastic cylinders that are inserted into the surgical template, allowing drilling guidance.⁹ They are placed on the surgical template according to presurgical planning, and their characteristics have been associated with implant deviation accuracy.^{8,10,11} In key systems, bone drills are inserted into the bone through a key instrument that perfectly adapts to the guiding sleeve and is selected according to the drill's diameter. In contrast, keyless systems do not use any key instrument to adapt the drill to the sleeve diameter, because the drill is perfectly designed to adapt to the sleeve independently of the active drill diameter.¹² An illustration of both types of systems is provided in Figs 1 and 2.

The literature on these tools and their mode of operation depending on each commercial brand is scarce. However, the increasing number of brands available involving keyless guided systems sometimes complicates the system choice for the clinician, and most importantly, it could eventually impact the final implant positioning accuracy and overall treatment success.

Therefore, the primary aim of this systematic review was to compare the positioning accuracy of dental

implants using fully guided systems with key instruments vs keyless systems. The secondary aim was to assess the impact of deviation factors (surgical guide support and edentulism type) on final positioning accuracy regardless of the surgical system used. The null hypothesis was that no statistically significant differences in terms of implant positioning accuracy between the drill key and keyless guided surgical systems would be found.

MATERIALS AND METHODS

Study Registration

This study proposal was registered with the International Prospective Register of Systematic Reviews (PROSPERO) hosted by the National Institute for Health Research, University of York, Centre for Reviews and Dissemination (no. CRD42020215635). Ethics approval was not required for this systematic review.

Population, Intervention, Comparison, Outcome Question

This systematic review focused on the question of which mechanism of static-guided implant navigation surgery allows for better 3D-implant-positioning control (the key system vs keyless system), and it was performed using the population, intervention, comparison, outcome (PICO) question method according to the preferred reporting items systematic review and meta-analyses statement (PRISMA).¹³

- Population (P): Partial or complete edentulous patients who underwent static-guided surgical implant placement.
- Intervention (I): Implant placement with fully guided static navigation using a keyless system.
- Control (C): Implant placement with fully guided static navigation using a drill key system.



- Outcomes (O): The primary outcome was to assess the 3D-implant-positioning accuracy of static-guided implant surgery associated with key or keyless control mechanisms. The secondary outcome was to evaluate the impact of deviation factors (surgical guide support and edentulism type) that influence the implant positioning accuracy using drill key or keyless static navigation systems.

Eligibility Criteria

The articles included in this systematic review had to meet the following criteria: (a) prospective study design; (b) clinical trials in humans; (c) fully guided dental implant placement surgery as the intervention; (d) postoperative 3D radiographic or digital accuracy assessment was performed; and (e) accuracy variables were clearly defined (eg, global or 3D coronal deviation [mm], apical deviation [mm], vertical deviation [mm], and angular deviation [degrees]). Consequently, articles were excluded if (a) they were retrospective studies; (b) they were animal, ex vivo, case series, or case report studies; (c) they presented insufficient information regarding pre- and postoperative matching; (d) they lacked information regarding the guided surgery system used; or (e) they focused on other variables.

Information Sources and Search Strategy

Electronic and manual search results were obtained and screened by a single investigator (I.G.). Another investigator (J.G.) supervised each search step. The search terms, truncation, and Boolean operators were as follows: (((computer assisted surgery) OR (guided implant surgery) OR (computer guided surgery))) AND ((dental implant*) OR (dental) OR (implant*)) AND ((accuracy) OR (precision)) AND (systematic[*sb*] OR Randomized Controlled Trial[*ptyp*] OR Comparative Study[*ptyp*] OR Meta-Analysis[*ptyp*] OR Observational Study[*ptyp*]) AND full text[*sb*] AND "last 10 years"[*PDat*] AND English[*lang*].]. The last electronic search date was June 2021. Hand search however continued until December 2021. The search was limited to studies written in English. The main source of electronic information was the National Library of Medicine database (MEDLINE by PubMed). Additional searches were performed using the Google Scholars database for eventual inclusion. Additional searches through articles' bibliography and cross-references were used for further identification of potential articles. The following journals were also manually reviewed: *International Journal of Oral and Maxillofacial Surgery*, *Journal of Clinical Periodontology*, *Clinical Implant Dentistry and Related Research*, *Clinical Oral Implants Research*, *European Journal of Oral Implantology*, *The International Journal of Oral & Maxillofacial Implants*, *The International Journal of Periodontics & Restorative Dentistry*, *Clinical Implant Dentistry and Related Research*, *The Journal of Prosthetic Dentistry*, *Journal of Advanced Prosthodontics*, *International Journal of Clinical*

and Experimental Medicine, *International Journal of Dentistry*, and *BMC Oral Health*.

Furthermore, contact with investigators and manufacturers was made when additional information was needed. If no answers were received, the study was automatically excluded. In case of doubt about a particular study's inclusion, the investigators consulted each other and reached an agreement. If no agreement could be made, the article in question was excluded.

Data Extraction

Data extraction was performed by a single investigator (I.G.) under the supervision of another investigator (J.G.). Mendeley software (Mendeley Reference Management) was used for article reading and Excel (Microsoft) for the creation of result tables summarizing each relevant detail of all included studies as follows: (1) number of patients, (2) number of implants, (3) guided system brand, (4) edentulism type, (5) guide printing technology, (6) surgical guide support, (7) flap realization, and (8) surgical guide fixation and number of pins.

Numeric data of interest were extracted (global or 3D coronal deviations, apical deviations, vertical deviations, and angular deviations) and then classified into Excel tables according to the surgical system used (drill key systems or keyless). This process resulted in the creation of two datasets: (1) static fully guided surgeries with drill key systems and (2) static fully guided surgeries with keyless systems.

In case of doubts about particular data during the data extraction process, the investigators (I.G. and J.G.) consulted each other and mutually decided on a solution. Again, eventual disagreements resulted in the exclusion of articles.

Deviation Measurement Standards

Global or 3D coronal deviations were accepted only for the coronal deviation parameter. Consequently, the linear deviations were excluded. Vertical deviation can be measured at the apex or platform level. If both were mentioned, the one with the highest deviation value was registered. Regarding vertical deviation, some studies preferred to use negative values when implants were inserted below the reference line and positive values when implants were not inserted deep enough. In such cases, the absolute value was used for the statistical analysis. The means and SDs of all variables in all studies that met our inclusion criteria were extracted.

Quality Assessment

According to the Cochrane recommendations, randomized clinical trials risk of bias were assessed using the RoB 2 tool,¹⁴ whereas ROBINS-1 tool was used for nonrandomized clinical trials.¹⁵ Traffic-light plots and summary plots were generated.

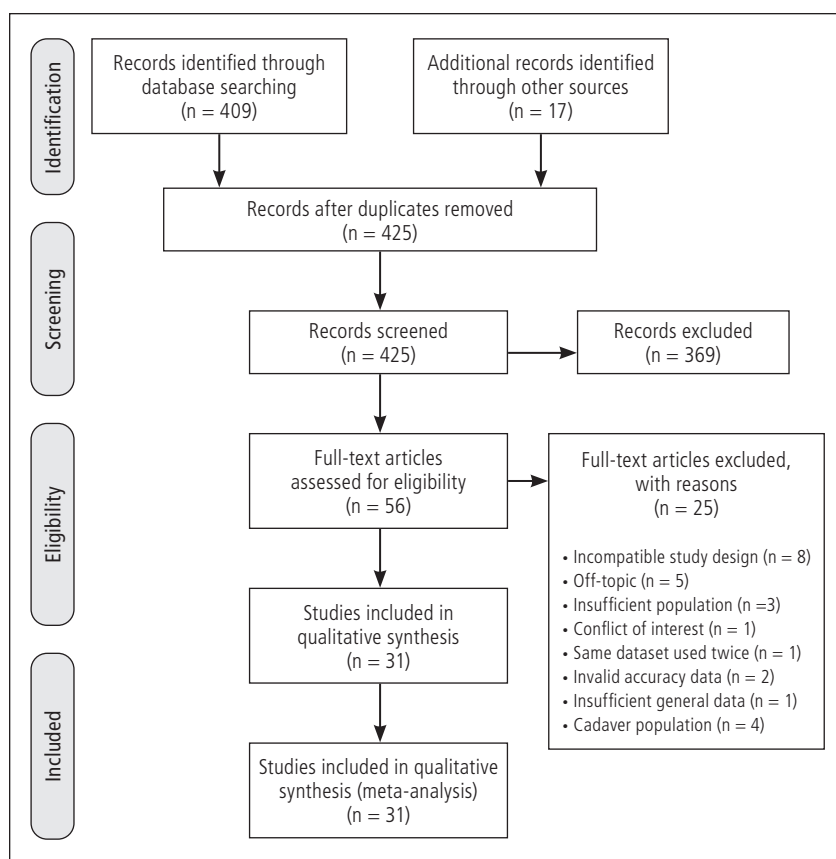


Fig 3 Flow-chart of study screening process.

Data and Statistical Analysis

Continuous variables from the included studies were analyzed with RStudio desktop software (version 1.2.5042; RStudio) using the Metafor package, and a forest plot was generated for each parameter (global coronal deviation, apical deviation, vertical deviation, and angular deviation). This process was repeated for both study groups (keyless and drill key systems). Intergroup comparisons were performed for each accuracy parameter. Additionally, heterogeneity was assessed using Cochrane's I^2 test and interpretation thresholds¹⁶: an I^2 value between 10% to 40% was considered as not important, 30% to 60% as moderate, 50% to 90% as substantial, and 75% to 100% as considerable heterogeneity. If heterogeneity was observed, either substantial or considerable, the results corresponding to the random effect model were systematically accepted.

Meta-regression analysis with a mixed-effects model was performed to explore the impact of the surgical guide support (tooth-supported, mucosa-supported, bone-supported) and edentulous type (single, partial, and total) on the final accuracy results. The reference subgroups used for this meta-regression were as follows: the tooth-supported surgical templates subgroup for the surgical guide support analysis and the single edentulous (SE) patient subgroup for the edentulism type analysis. To keep samples as homogeneous as possible, if a clinical trial involved different types of surgical template supports or edentulous populations and if the data of interest could not be isolated, it was excluded from the meta-regression analysis. The meta-regression analysis was performed using R software version 4.0.3 (The

R Foundation for Statistical Computing). The statistical significance level was not greater than 5% ($P \leq .05$).

RESULTS

Study Selection

The electronic search generated a total of 405 articles that were complemented by the inclusion of an additional 17 references identified manually. After title and abstract reading, 369 articles were excluded. Of the 56 articles remaining, only 31 studies were included after a thorough examination (full-text reading) and only 18 could be used for the quantitative analysis (meta-analysis). Details regarding the screening process are provided in the flowchart (Fig 3). The results of the bias risk assessment for the included studies resulted to be mainly low, although some studies depicted a moderate risk (Cochrane risk of bias: ROBINS-1 and RoB 2). The results of the risk of bias assessment is fully detailed in Appendix Figs 1 to 4 (see all appendix items in the online version of the article).

Characteristics of the Included Trials

All included studies aimed at assessing the accuracy of static full-guided surgery, meaning that static half-guided surgery was not employed in any included study. Overall, the drill key group included 274 patients and 781 implants, whereas the keyless group included 201 patients and 452 implants. Therefore, this meta-analysis included a total of 1,233 implants in 475 patients. A general overview of the data extracted from the included studies is provided in Tables 1 and 2.

Types of Edentulism, Surgical Guide Support, and Fixation

In the drill key group, of 781 implants, 16.6% (n = 130) of the implants were placed in an SE space, 5.5% (n = 43) were placed in partially edentulous (PE) sites in need of two or more

Table 1 Control Group Results (Drill Key)—Results Expressed as Means and SDs

Study design		Group	nP	nI	System	Dental status	Guide	Guide Support	Flap
Smithkarn, 2019	RCT	Static computer-assisted	26	30	Straumann	SE	SLA	Tooth	Yes
Farley, 2013	Prospective nonrandomized, split-mouth design	Test	5	10	Biomet	SE	SLA	Tooth	No
Vercryussen, 2014	RCT	Mat Mu	12	55	Materialise	TE	SLA	Mucosa	No
		Mat Bo	12	53				Bone	Yes
		Fac Mu	14	52	Facilitate	TE	SLA	Mucosa	No
		Fac Bo	12	52				Bone	Yes
Younes, 2018	RCT	Fully guided	10	21	NM	PE	N.M	Tooth	No
Schneider, 2019	RCT	T1	11	11	Straumann/Facilitate	PE	SLA	Tooth	Yes
		T2	11	11			Pjet		
Kaewsiri, 2019	RCT	Static	30	30	Straumann	SE	SLA	Tooth	No (25) Yes (5)
Kiatkroekkram, 2019	RCT	Intraoral	20	30	Straumann	SE	SLA	Tooth	Both
		Extraoral	22	30					
Pettersson, 2012	Prospective nonrandomized	Test	25	139	Nobel Guide	TE	SLA	Mucosa	No
D'haese, 2012	Prospective nonrandomized	Test	13	78	Astra Tech	TE	SLA	Mucosa	No
Van de Wiel, 2014	Prospective nonrandomized	Test	16	75	Facilitate	TE	SLA	Mucosa	No
Verhamme, 2013	Prospective nonrandomized	Test	30	104	Nobel Guide	TE	SLA	Mucosa	No
Study design		Guide fixation (no. of pins)	Coronal deviation (mm)		Apical deviation (mm)		Vertical deviation (mm)		Angular deviation (degrees)
Smithkarn, 2019	RCT	No	1.0 (0.6)		1.3 (0.6)		0.7 (0.6)		3.1 (2.3)
Farley, 2013	Prospective nonrandomized, split mouth design	No	1.45 (0.06)		1.82 (0.60)		−1.24 (0.68)		3.68 (2.19)
Vercryussen, 2014	RCT	Yes (3–4)	1.23 (0.60)		1.57 (0.71)		NM		2.86 (1.6)
			1.60 (0.92)		1.65 (0.82)		NM		3.79 (2.36)
		Yes (3–4)	1.38 (0.64)		1.60 (0.70)		NM		2.71 (1.36)
			1.33 (0.82)		1.50 (0.72)		NM		3.20 (2.70)
Younes, 2018	RCT	NM	0.73 (0.10)		0.97 (0.19)		NM		2.30 (0.92)
Schneider, 2019	RCT	No	0.54 (0.33)		0.9 (0.43)		0.11 (0.62)		2.41 (1.4)
			0.61 (0.27)		1.02 (0.64)		−0.32 (0.9)		2.69 (1.78)
Kaewsiri, 2019	RCT	No	0.97 (0.44)		1.28 (0.46)		NM		2.84 (1.71)
Kiatkroekkram, 2019	RCT	No	0.87 (0.49)		1.10 (0.53)		0.59 (0.48)		2.41 (1.47)
			1.01 (0.56)		1.38 (0.68)		0.69 (0.54)		3.23 (2.09)
Pettersson, 2012	Prospective nonrandomized	Yes (NM)	0.91 (0.44)		1.13 (0.52)		NM		2.60 (1.61)
D'haese, 2012	Prospective nonrandomized	Yes (4)	0.85 (0.47)		1.07 (0.54)		0.09 (0.46)		2 (1.41)
Van de Wiel, 2014	Prospective nonrandomized	Yes (3)	0.87 (0.50)		1.10 (0.53)		0.48 (0.50)		2.79 (1.48)
Verhamme, 2013	Prospective nonrandomized	Random	1.37 (0.17)		1.59 (0.18)		−0.84 (0.23)		2.82 (0.36)

nP = number of patients; nI = number of implants; SLA = stereolithography; Pjet = polyjet; NM = not mentioned. Mat Mu = materialize mucosa; Mat Bo = materialize bone; Fac Mu = facilitate mucosa; Fac Bo = facilitate bone

Table 2 Experimental Group Results (Keyless)—Results Expressed as Means and SDs

Study design		Group	nP	nI	System	Dental status	Guide	Guide Support
Tallarico (2), 2019	RCT	Fully digital	10	28	Osstem Taper Kit	SLA	SE, PE	Tooth
		Conventional	10	29				
Tallarico (3), 2019	RCT	Metallic sleeve	15	41	Osstem Guide	SLA	SE, PE	Tooth
		Without metallic sleeve	15	49				
Varga et al, 2019	RCT	Fully guided	28	52	Alpha-Bio	MJM	SE, PE	Tooth
Schnutenhaus et al, 2020	Prospective randomized	With augmentation	25	25	Camlog	SLA	SE	Tooth
		Without augmentation	23	23				
Tallarico, 2019	Prospective randomized multicenter	Test	39	119	Osstem Guide	SLA	SE, PE	Tooth
D. Lee et al, 2016	Prospective nonrandomized	Test	11	21	R2Gate	DLP	PE	Tooth
Cristache et al, 2016	Prospective nonrandomized	Test	25	65	R2Gate	SLA	PE	Tooth

Study design		Coronal deviation (mm)	Apical deviation (mm)	Vertical deviation (mm)	Angular deviation (degrees)
Tallarico (2), 2019	RCT	0.52 (0.30)	NM	0.58 (0.44)	2.25 (1.41)
		0.44 (0.26)		0.46 (0.34)	2.10 (1.18)
Tallarico (3), 2019	RCT	0.52 (0.30)	NM	0.58 (0.44)	2.25 (1.41)
		0.61 (0.49)		0.37 (0.28)	1.98 (2.38)
Varga et al, 2019	RCT	1.40 (0.54)	1.59 (0.59)	NM	3.04 (1.51)
Schnutenhaus et al, 2020	Prospective randomized	0.7 (0.3)	1.4 (0.6)	0.3 (0.3)	4.1 (2.1)
Tallarico, 2019	Prospective randomized multicenter	0.53 (0.46)	NM	0.42 (0.37)	1.43 (1.98)
D. Lee et al, 2016	Prospective nonrandomized	0.69 (0.34)	NM	0.92 (0.38)	2.39 (1.14)
Cristache et al, 2016	Prospective nonrandomized	0.79 (0.52)	1.17 (0.63)	0.50 (0.38)	2.34 (0.85)

nP = number of patients; nI = number of implants; SLA = Stereolithography; Pjet = polyjet; MJM = multijet modeling; DLP = digital light processing; NM = not mentioned.

implants, and 77.8% (n = 608) of the implants were placed in totally edentulous (TE) patients. In the keyless group, of 452 implants, 318 (70.4%) were placed in either SE or PE patients because the authors did not make a distinction between both types of edentulism. Lastly, 86 implants (19%) were placed in the PE group and 48 (10.6%) in the SE group.

Surgical guides were all tooth-supported in patients with SE and PE in both study groups. The surgery of TE patients involved the use of mucosa- or bone-supported templates.⁴ In the keyless group, only one clinical trial involved full arch cases,¹⁷ and the surgical guides were supported by the remaining failing teeth that were extracted after implant placement. In the drill key group, surgical templates in TE patients were always fixated with intrabony pins. Nevertheless, in the keyless group, the use of surgical template fixation was also found in patients with SE and PE.^{12,17,18}

Navigation Surgical System

The most commonly used drill key fully guided implant surgical system was the Straumann Guided Surgery system (coDiagnostiX-Straumann) in four clinical trials.^{19–22} Other brands with similar 3D control key mechanisms were used: the Nobel Guide (Nobel Biocare)^{23,24} and Biomet 3i (Zimmer Biomet).⁶ The most used keyless systems in the included studies were the Osstem OneGuide system (Osstem Implant)^{12,17} and R2Gate system (MegaGen Implant).^{25,26}

Type of Flap

Of a total of 781 implants in the drill key group, 79.3% (n = 619) were placed flapless, while 20.7% (n = 162) were placed only after flap elevation. One clinical trial was excluded from this calculation because the information provided was not sufficiently specific.²¹ In the keyless group, of 400 implants, 88% (n = 352) were



placed flapless, while 12% ($n = 48$) were placed with flap elevation. Again, because of insufficient information, one clinical trial was excluded from these results.²⁷

Printing Guides Protocol

In the drill key group, all surgical guides used were printed with stereolithographic (SLA) printers (photopolymerization 3D printing), and they all required the use of metallic sleeves. The only exception was one study group where a Polyjet technology printer (Stratasys; photopolymerization point after point with laser beam) was used, and no metallic sleeves were incorporated into the surgical template.²⁰ In the keyless group, however, none of the surgical templates used metallic sleeves, and five of seven clinical trials used SLA-printed surgical templates^{12,17,18,26,28}; the remaining two used MultiJet Modeling technology (3D Systems; the addition of binding agents to powder and polymerization with heat, layer by layer), and digital light processing (DLP) technology (photopolymerization layer by layer).

Positioning Accuracy

Coronal Global Deviation

The results from the meta-analysis demonstrated a statistically significant mean difference between both groups, in favor of the keyless static fully guided surgical systems (-0.36 mm; 95% CI -0.62 , -0.09 ; $P = .008$; $I^2 = 98\%$). These results suggest the superiority in the accuracy of such systems when compared to conventional static fully guided drill key surgical systems. Indeed, the mean coronal global deviations were 1.04 mm (95% CI 0.87 , 1.22) and 0.68 mm (95% CI 0.53 , 0.84) in the drill key group and keyless group. These findings are illustrated in a forest plot (Appendix Fig 5).

Apical Deviation

Regarding apical deviation, the results of the meta-analysis did not demonstrate superiority of either surgical system. Indeed, the difference between both systems was not statistically significant (-0.08 mm; 95% CI -0.30 , 0.46 ; $P = .684$; $I^2 = 95.5\%$). Drill key systems averaged an apical deviation of 1.30 mm (95% CI 1.14 , 1.45), and the keyless systems averaged a deviation of 1.39 mm (95% CI 1.14 , 1.63). The forest plot illustrates these findings (Appendix Fig 6).

Vertical Deviation

Again, the results from the meta-analysis demonstrated a minor mean difference between the groups. The mean vertical deviation in the drill key group was 0.51 mm (95% CI 0.27 , 0.75), whereas that in the keyless group was 0.50 mm (95% CI 0.40 , 0.60). This difference was not statistically significant (-0.01 mm; 95% CI -0.25 , 0.24 ; $P = .958$; $I^2 = 94.2\%$). The forest plot presents these findings (Appendix Fig 7).

Angular Deviation

The results from the meta-analysis tended to divulge mean difference between the groups of angular deviation (-0.36 degrees; 95% CI -0.75 , 0.02 ; $P = .063$; $I^2 = 81.3\%$). The mean angular deviations were 2.74 degrees (95% CI 2.55 , 2.93) and 2.42 degrees (95% CI 2.00 , 2.83) in the drill key and keyless groups, respectively. The forest plot illustrates these findings (Appendix Fig 8).

Related Factors Influencing Implant Positioning Accuracy

Influence of the Type of Edentulism

All detailed results regarding the influence of the type of edentulism on implant positioning accuracy are shown in Table 3.

Coronal Global Deviation

The overall meta-analysis results revealed a significant influence of the type of edentulism on the amount of coronal global deviation ($P < .001$). The coronal global deviation in PE patients approximated an average deviation of 0.70 mm (95% CI 0.63 , 0.77), whereas the average deviations in SE and TE patients were 1.00 mm (95% CI 0.65 , 1.35) and 1.18 mm (95% CI 0.97 , 1.39). The meta-regression analysis with the SE group as the reference showed no significant difference between the groups, although deviation values were somewhat lower in the PE group (-0.33 mm; 95% CI -0.70 , 0.01 ; $P = .091$) and slightly higher in the TE group (0.18 mm; 95% CI -0.15 , 0.51 ; $P = .296$).

Apical Deviation

The global analysis revealed a significant influence of the type of edentulism on the amount of apical deviation generated ($P < .001$). The PE patients exhibited the smallest apical deviation of 1.02 mm (95% CI 0.90 , 1.15) compared to the SE and TE patients (1.34 mm; 95% CI 1.20 , 1.48 and 1.39 mm; 95% CI 1.19 , 1.60 , respectively). The difference between the SE and PE groups tended to be significant (-0.34 mm; 95% CI -0.69 , 0.01 ; $P = .053$; $I^2 = 92.8\%$). No significant difference was found when comparing the SE and TE patients (0.03 mm; 95% CI -0.25 , 0.32 ; $P = .813$).

Vertical Deviation

The type of edentulism did not significantly influence the amount of vertical deviation ($P = .629$). The average vertical deviations were 0.58 mm (95% CI 0.37 , 0.79) in the SE group, 0.51 mm (95% CI 0.19 , 0.83) in the PE group, and 0.47 mm (95% CI 0.01 , 0.95) in the TE group. None of the mean differences were significant in the PE and TE groups (-0.09 mm; 95% CI 0.59 , 0.41 ; $P = 0.715$ and -0.11 mm; 95% CI 0.58 , 0.64 ; $P = .635$, respectively).

Table 3 Edentulism Type—Meta-regression Results

Coronal deviation (mm)	SE (reference)	PE	TE
Overall	1.00 [0.65; 1.35]	0.70 [0.63; 0.77]	1.18 [0.97; 1.39]
Difference		−0.32 [−0.71; −0.05]	0.18 [−0.16; 0.52]
<i>P</i> value		.09	.297
Apical deviation (mm)	SE (reference)	PE	TE
Overall	1.34 [1.20; 1.48]	1.02 [0.90; 1.15]	1.39 [1.19; 1.60]
Difference		−0.34 [−0.69; 0.01]	0.01 [−0.27; 0.29]
<i>P</i> value		.053	.813
Vertical deviation (mm)	SE (reference)	PE	TE
Overall	0.58 [0.37; 0.79]	0.50 [0.19; 0.83]	0.47 [−0.00; 0.95]
Difference		−0.09 [−0.59; 0.41]	−0.11 [−0.64; 0.41]
<i>P</i> value		.715	.635
Angular deviation (mm)	SE (reference)	PE	TE
Overall	3.18 [2.62; 3.75]	2.35 [2.18; 2.51]	2.77 [2.52; 3.02]
Difference		−0.77 [−1.29; −0.25]	−0.38 [−0.84; 0.07]
<i>P</i> value		.004	.096

SE = single edentulous; PE = partially edentulous; TE = totally edentulous.

Angular Deviation

The overall meta-analysis results revealed a significant influence of the type of edentulism on the amount of angular deviation ($P < .001$). The PE group demonstrated a significantly better control of angular deviation—with an average value of 2.35 degrees (95% CI 2.18, 2.51)—than the SE and TE groups (3.18 degrees; 95% CI 2.62, 3.75 and 2.77 degrees; 95% CI 2.52, 3.02, respectively). The difference between the SE and PE groups was statistically significant (−0.77 degrees; 95% CI −1.29, −0.25; $P = .004$; $I^2 = 72.2\%$). However, the difference between the SE and TE patients was not significant (−0.39 degrees; 95% CI −0.84, 0.07; $P = .096$).

Influence of Surgical Guide Support

All detailed results regarding the influence of the surgical template (tooth- [T], mucosa- [M], and bone- [B] supported groups) on the implant positioning accuracy are shown in Table 4.

Coronal Global Deviation

The overall meta-analysis revealed a significant influence of the type of surgical guide support on the amount of coronal global deviation ($P = .015$). Coronal global deviation was lowest for the T group with an average deviation of 0.79 mm (95% CI 0.58, 0.99) followed by the M group (1.10 mm; 95% CI 0.86, 1.34) and B group (1.46 mm; 95% CI 1.20, 1.72). The meta-regression analysis of the T and B groups revealed a statistically significant mean difference of 0.68 mm (95% CI 0.08, 1.28; $P = .027$; $I^2 = 98.6\%$) in favor of the T group. However, no significant difference was found between the T and M groups (0.31 mm; 95% CI −0.06, 0.68; $P = .096$).

Apical Deviation

The global analysis revealed a significant influence of the type of surgical guide support on the amount of apical deviation generated ($P = .015$). The average apical deviations were 1.26 mm (95% CI 1.10, 1.41) in the T group, 1.34 mm (95% CI 1.10, 1.58) in the M group, and 1.57 mm (95% CI 1.42, 1.71) in the B group. No significant differences were found between the T and M groups (0.08 mm; 95% CI −0.20, 0.36; $P = .58$) and the T and B groups (0.31 mm; 95% CI −0.13, 0.76; $P = .16$).

Vertical Deviation

No significant influence of the type of surgical guide on the amount of vertical deviation was observed ($P = .84$). The average vertical deviations were 0.52 mm (95% CI 0.43, 0.61) in the T group and 0.47 mm (95% CI −0.00, 0.95) in the M group. No significant difference was found between the T and M groups (0.02 mm; 95% CI −0.22, 0.27; $P = .85$). Groups T and B could not be compared because no data were available.

Angular Deviation

The overall meta-analysis revealed a significant influence of the type of surgical guide support on the amount of angular deviation generated ($P = .01$). Angular deviation was smaller in the T group at 2.55 degrees (95% CI 2.27, 2.84) than in the M group (2.63 degrees; 95% CI 2.39, 2.88) and the B group (3.53 degrees; 95% CI 2.95, 4.10). The meta-regression revealed a significant mean difference between the T and B groups (0.98 degrees; 95% CI 0.21, 1.76; $P = .01$; $I^2 = 81\%$). Nevertheless, the mean difference between the T and M groups was not significant (0.1 degrees; 95% CI 0.21, 1.76; $P = .64$).

Table 4 Surgical Guide Support—Meta-regression Results

Coronal deviation (mm)	T (reference)	M	B
Overall	0.79 [0.58; 0.99]	1.1 [0.86; 1.34]	1.46 [1.20; 1.72]
Difference		0.31 [−0.06; 0.68]	0.68 [0.08; 1.28]
P value		.096	.027
Apical deviation (mm)	T (reference)	M	B
Overall	1.26 [1.10; 1.41]	1.34 [1.10; 1.59]	1.57 [1.42; 1.71]
Difference		0.08 [−0.20; 0.36]	0.31 [−0.13; 0.76]
P value		.584	.163
Vertical deviation (mm)	T (reference)	M	B
Overall	0.52 [0.43; 0.61]	0.47 [−0.00; 0.95]	NP
Difference		−0.05 [−0.36; 0.26]	NP
P value		.757	NP
Angular deviation (mm)	T (reference)	M	B
Overall	2.55 [2.27; 2.84]	2.63 [2.39; 2.88]	3.52 [2.95; 4.10]
Difference		0.10 [−0.32; 0.52]	0.98 [0.21; 1.76]
P value		.639	.012

T = teeth, B = bone, M = mucosa, NP = not performed.

DISCUSSION

The findings from this meta-analysis revealed that static fully guided keyless systems are significantly more accurate than conventional drill key systems, mainly in terms of coronal deviation ($P = .009$). Angular deviation values were also smaller for the keyless systems, and there was a statistically significant difference from those with the drill key systems ($P = .063$). Therefore, the null hypothesis was rejected. In contrast, no significant differences were found between the systems in apical and vertical deviations. To the best of our knowledge, no previously published meta-analysis has focused on the accuracy of static-guided systems according to the drill key modality. Because keyless static-guided systems are relatively new, they have not been used in clinical trials included in previous meta-analysis studies.^{10,29}

In terms of coronal deviation, the present review found a mean deviation of 1.04 mm vs 1.0 mm reported by Van Assche et al¹⁰ in 2012 and 1.10 mm reported by Bover-Ramos et al²⁹ in 2018. Regarding apical deviation, Bover-Ramos et al²⁹ and Van Assche et al¹⁰ found identical mean apical deviations of 1.40 mm, while the present meta-analysis revealed a mean value of 1.31 mm. Vertical deviation also remained similar: in the present study, a mean vertical deviation of 0.50 mm was estimated, while Van Assche et al¹⁰ found a value of 0.6 mm and Bover-Ramos et al²⁹ reported slightly higher values at 0.74 mm. Angulation control seems to be significantly improving over time, with an angulation deviation of 2.74 degrees, while Bover-Ramos et al²⁹ estimated a mean of 3.98 degrees and Van Assche et al¹⁰ reported a mean of 4.2 degrees, considering that all three meta-analyses

included different studies. Only one common randomized controlled trial was found between this study and the meta-analysis by Bover-Ramos et al.²⁹ The accuracy of a conventional static-guided surgery system involving the use of a drill key appears to improve over time and allow certain predictability. In contrast, the same assumption cannot be made for keyless systems because more perspectives and investigations are required.

The type of edentulism was shown to have a considerable influence on the amount of deviation generated. Overall, the PE group had lower deviation values than the SE and TE groups. Angular deviation was significantly lower in patients with PE than in those with SE. Although lower, no statistically significant difference was found in coronal, apical, and vertical deviations. Again, although overall deviation values were somewhat lower in the SE group than in the TE group, no statistically significant difference was found between these groups. Overall, our results are in accordance with the International Team for Implantology consensus published in 2018, which reported that the state of edentulism (partial or full) influences the final accuracy of static-guided surgery, with lower mean deviations for PE patients than for fully edentulous patients.³⁰

Regardless of the drill key modality and type of edentulism, surgical guide support had a significant influence on the amount of deviation generated. Tooth-supported templates provided significantly more accuracy than bone-supported templates for all parameters except for vertical deviation, where data were insufficient to perform meta-regression analysis. However, these differences were not significant between mucosa-supported and teeth-supported templates, although the

latter showed minor deviations. These results are in line with most of the recent literature,^{10,31–33} even though a few older studies found better accuracy with mucosa-based templates.^{1,34} It was assumed that the use of fixation screws and the consequent guide stability may be responsible for these results.^{1,17,35,36} Nevertheless, although fixated, micromovements of mucosa-based surgical templates have also been reported.^{24,31,37,38}

Finally, the presence of tolerance between the drill and sleeves is often considered to be responsible for increased deviation values,^{6,10,11,20,24,29,34,36,39} influencing the overall deviation resulting from the accumulation of errors throughout the entire workflow.^{10,20,22,24,29,40–42} The 62.7% of the total implant positioning error may be related to the properties of the sleeve/drill combination.^{43,44} To minimize the tolerance-originated deviation, it was suggested to increase the drill key height or reduce the free drilling distance apical to the guided sleeve.^{8,39,45} Reducing the sleeve diameter was also suggested.^{39,46} As a consequence of these observations, tolerance deviation control seems to be superior in keyless systems vs conventional drill key systems, which could explain the overall accuracy results.^{12,17,25,26,39} Thus, using keyless systems may enhance the implant positioning accuracy of guided systems by minimizing deviation-related factors associated with the sleeve and drill combination.^{17,25,26,39}

Additionally, keyless surgical systems may or may not require the use of metallic sleeves, depending on the manufacturer. In the present study, sleeveless surgical templates were used in five studies of the seven clinical trials in the keyless group, whereas metallic sleeves were still used in two studies.^{27,28} The use of CAD/CAM sleeveless templates was shown to reduce the tolerance by increasing the contact between the drill and the drill guide or drill key.^{12,17,39,47} Although friction was confirmed both with and without a metallic sleeve,⁴⁷ the contact between the sleeveless templates and the drill shank was smooth, and the friction coefficient was low.²⁵ Recent observation of sleeveless templates after drilling under a scanning electron microscope confirmed these findings and revealed a pressed, flat, and squeezed surface of the template as if the “skin was pressed against a glass window.”⁴⁷ After drilling, the inner surfaces of the metallic sleeves revealed obvious marks of friction with the drill, indicating a higher tolerance level than that of the sleeveless templates.⁴⁷

The main limitation of this meta-analysis was the lack of high homogeneity between publications. Although only prospective clinical trials were included, high and inevitable heterogeneity was present due to the diversity of clinical procedures between the authors. The large number of study variables and potential deviation factors made interstudy comparisons difficult. In particular, the discrepancy between the studied populations in terms of the type of guide support and the type of edentulism

involved an eventual risk of bias. Additionally, the limited literature available regarding keyless systems is a relative limitation. Indeed, three of the seven clinical trials included in the keyless group were conducted by the same investigation team, which could have influenced the overall results. Also, data screening was not performed by two calibrated reviewers as recommended by Cochrane guidelines but by a single investigator. Moreover, only a single database was searched. Considering those limitations, the results of this meta-analysis should therefore be interpreted with caution.

CONCLUSIONS

Keyless static fully guided surgical systems allow for significantly better control of coronal implant deviation than conventional drill key systems. Angulation control is also superior when using keyless systems. The types of edentulism and surgical guide support seemed to influence the positioning accuracy. Partially edentulous patients and tooth supported guides showed the best accuracy results. Future investigation about guided implant surgery development should focus on keyless mechanisms because they seem to enhance implant positioning accuracy.

ACKNOWLEDGMENTS

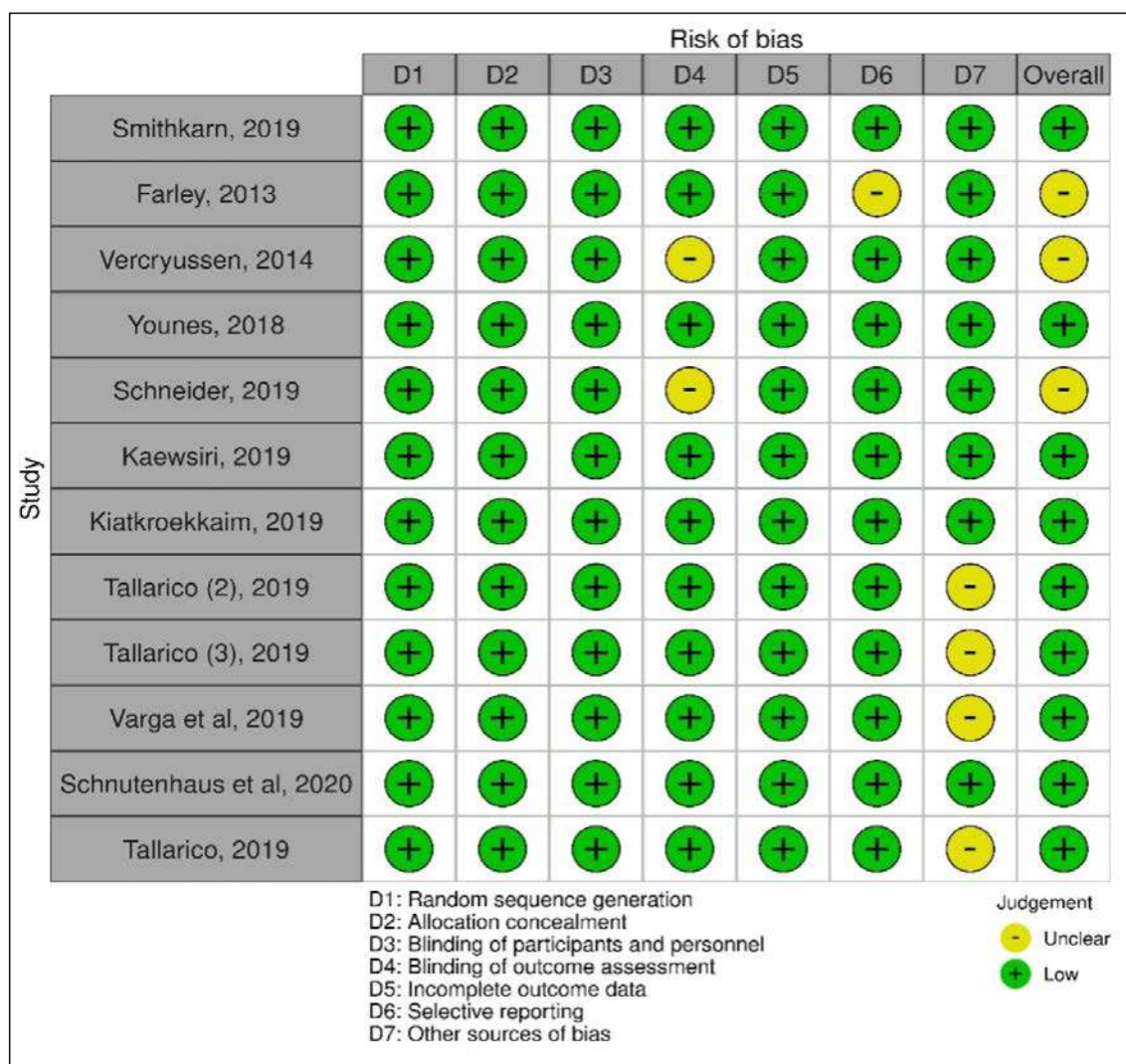
The authors would like to thank the Methodological and Statistical Advisory Service of UIC Barcelona for their assistance with statistical analysis. The authors declare no conflicts of interest. The authors report no funding sources. All data generated or analyzed during this study are included in this article.

REFERENCES

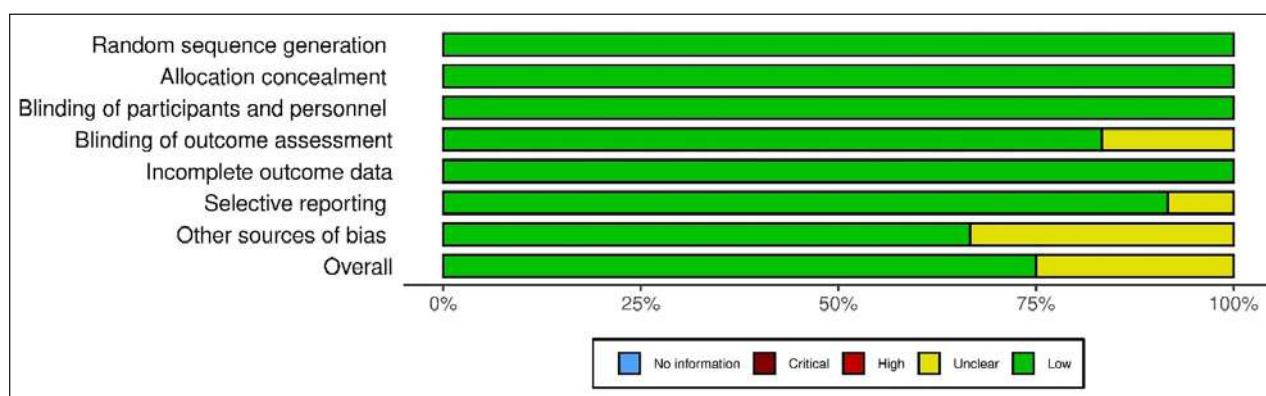
1. Arisan V, Karabuda CZ, Mumcu E, Özdemir T. Implant positioning errors in freehand and computer-aided placement methods: A single-blind clinical comparative study. *Int J Oral Maxillofac Implant* 2013;28:190–204.
2. Gargallo-Albiol J, Barootchi S, Salomó-Coll O, Wang HL. Advantages and disadvantages of implant navigation surgery. A systematic review. *Ann Anat* 2019;225:1–10.
3. Pozzi A, Tallarico M, Marchetti M, Scarfò B, Esposito M. Computer-guided versus free-hand placement of immediately loaded dental implants: 1-year post-loading results of a multicentre randomised controlled trial. *Eur J Oral Implantol* 2014;7:229–242.
4. Vercruyssen M, Cox C, Coucke W, Naert I, Jacobs R, Quirynen M. A randomized clinical trial comparing guided implant surgery (bone- or mucosa-supported) with mental navigation or the use of a pilot-drill template. *J Clin Periodontol* 2014;41:717–723.
5. Arisan V, Bölükbaşı N, Öksüz L. Computer-assisted flapless implant placement reduces the incidence of surgery-related bacteremia. *Clin Oral Investig* 2013;17:1985–1993.
6. Farley NE, Kennedy K, McGlumphy EA, Clelland NL. Split-mouth comparison of the accuracy of computer-generated and conventional surgical guides. *Int J Oral Maxillofac Implant* 2013;28:563–572.
7. Amorfini L, Migliorati M, Drago S, Silvestrini-Biavati A. Immediately loaded implants in rehabilitation of the maxilla: A two-year randomized clinical trial of guided surgery versus standard procedure. *Clin Implant Dent Relat Res* 2017;19:280–295.

8. Koop R, Vercruyssen M, Vermeulen K, Quirynen M. Tolerance within the sleeve inserts of different surgical guides for guided implant surgery. *Clin Oral Implants Res* 2013;24:630–634.
9. Kühl S, Zürcher S, Mahid T, Müller-Gerbl M, Filippi A, Cattin P. Accuracy of full guided vs. half-guided implant surgery. *Clin Oral Implants Res* 2013;24:763–769.
10. Van Assche N, Vercruyssen M, Coucke W, Teughels W, Jacobs R, Quirynen M. Accuracy of computer-aided implant placement. *Clin Oral Implants Res* 2012;23(suppl 6):112–123.
11. Van Assche N, Quirynen M. Tolerance within a surgical guide. *Clin Oral Implants Res* 2010;21:455–458.
12. Tallarico M, Kim YJ, Cocchi F, Martinolli M, Meloni SM. Accuracy of newly developed sleeve-designed templates for insertion of dental implants: A prospective multicenters clinical trial. *Clin Implant Dent Relat Res* 2019;21:108–113.
13. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *J Clin Epidemiol* 2009;62:1006–1012.
14. Higgins JPT, Savović J, Page MJ, Elbers RG SJ. Chapter 8: Assessing risk of bias in a randomized trial. In: Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ WV (eds). *Cochrane Handbook for Systematic Reviews of Interventions* version 63. Cochrane Training, 2022.
15. Sterne JAC, Hernán MA, McAleenan A, Reeves BC, Higgins JPT. Chapter 25: Assessing risk of bias in a non-randomized study. In: Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ WV (eds). *Cochrane Handbook for Systematic Reviews of Interventions* version 63. Cochrane Training, 2022.
16. Deeks JJ, Higgins JPT, Altman DG. Chapter 10: Analysing data and undertaking meta-analyses. In: Higgins JPT, Thomas J, Chandler J, Cumpston M, Li T, Page MJ WV (eds). *Cochrane Handbook for Systematic Reviews of Interventions* version 61. Cochrane Training, 2022.
17. Tallarico M, Martinolli M, Kim YJ, et al. Accuracy of computer-assisted template-based implant placement using two different surgical templates designed with or without metallic sleeves: A randomized controlled trial. *Dent J* 2019;7:1–11.
18. Tallarico M, Khanari E, Kim YJ, et al. Accuracy of computer-assisted template-based implant placement using conventional impression and scan model or intraoral digital impression: A randomised controlled trial with 1 year of follow-up. *Int J Oral Implantol* 2019;12:197–206.
19. Smitkarn P, Subbalekha K, Mattheos N, Pimkhakham A. The accuracy of single-tooth implants placed using fully digital-guided surgery and freehand implant surgery. *J Clin Periodontol* 2019 Sep;46:949–957.
20. Schneider D, Sancho-Puchades M, Mir-Marí J, Mühlemann S, Jung R, Hämmeler C. A randomized controlled clinical trial comparing conventional and computer-assisted implant planning and placement in partially edentulous patients. Part 4: Accuracy of implant placement. *Int J Periodontics Restorative Dent* 2019;39:e111–122.
21. Kiatkroekkrai P, Takolpuckdee C, Subbalekha K, Mattheos N, Pimkhakham A. Accuracy of implant position when placed using static computer-assisted implant surgical guides manufactured with two different optical scanning techniques: A randomized clinical trial. *Int J Oral Maxillofac Surg* 2020;49:377–383.
22. Kaewsiri D, Panmekiate S, Subbalekha K, Mattheos N, Pimkhakham A. The accuracy of static vs. dynamic computer-assisted implant surgery in single tooth space: A randomized controlled trial. *Clin Oral Implants Res* 2019;30:505–514.
23. Pettersson A, Komiyaama A, Hultin M, Näsström K, Klinge B. Accuracy of virtually planned and template guided implant surgery on edentate patients. *Clin Implant Dent Relat Res* 2012;14:527–537.
24. Verhamme LM, Meijer GJ, Boumans T, de Haan AFJ, Bergé SJ, Maal TJJ. A clinically relevant accuracy study of computer-planned implant placement in the edentulous maxilla using mucosa-supported surgical templates. *Clin Implant Dent Relat Res* 2015;17:343–352.
25. Lee DH, An SY, Hong MH, Jeon KB, Lee KB. Accuracy of a direct drill-guiding system with minimal tolerance of surgical instruments used for implant surgery: A prospective clinical study. *J Adv Prosthodont* 2016;8:207–213.
26. Cristache CM, Gurbanescu S. Accuracy evaluation of a stereolithographic surgical template for dental implant insertion using 3D superimposition protocol. *Int J Dent* 2017;2017:1–9.
27. Varga EJ, Antal M, Major L, Kiscsátári R, Braunitzer G, Piffkó J. Guidance means accuracy: A randomized clinical trial on freehand versus guided dental implantation. *Clin Oral Implants Res* 2020;31:417–430.
28. Schnutenhaus S, Brunken L, Edelmann C, Dreyhaupt J, Rudolph H, Luthardt RG. Alveolar ridge preservation and primary stability as influencing factors on the transfer accuracy of static guided implant placement: A prospective clinical trial. *BMC Oral Health* 2020;20:178.
29. Bover-Ramos F, Viña-Almunia J, Cervera-Ballester J, Peñarocha-Diogo M, García-Mira B. Accuracy of implant placement with computer-guided surgery: A systematic review and meta-analysis comparing cadaver, clinical, and in vitro studies. *Int J Oral Maxillofac Implant* 2018;33:101–115.
30. 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(suppl 1):416–435.
31. Tahmaseb A, Wismeijer D, Coucke W, Derksen W. Computer technology applications in surgical implant dentistry: A systematic review. *Int J Oral Maxillofac Implants* 2014;29(suppl):25–42.
32. Raico Gallardo YN, da Silva-Olivio IRT, Mukai E, Morimoto S, Sesma N, Cordaro L. Accuracy comparison of guided surgery for dental implants according to the tissue of support: A systematic review and meta-analysis. *Clin Oral Implants Res* 2017;28:602–612.
33. Pozzi A, Polizzi G, Moy PK. Guided surgery with tooth-supported templates for single missing teeth: A critical review. *Eur J Oral Implantol* 2016;9(suppl 1):S135–S153.
34. Valente F, Schirolli DDSG, Sbrenna DDSA. Accuracy of computer-aided oral implant surgery: A clinical and radiographic study. *Int J Oral Maxillofac Implant* 2009;24:234–242.
35. D'haese J, Van De Velde T, Elaut L, De Bruyn H. A prospective study on the accuracy of mucosally supported stereolithographic surgical guides in fully edentulous maxillae. *Clin Implant Dent Relat Res* 2012;14:293–303.
36. Van Assche N, Van Steenberghe D, Guerrero M, Hirsch E, Schutyser F, Quirynen M, et al. Accuracy of implant placement based on pre-surgical planning of three-dimensional cone-beam images: A pilot study. *J Clin Periodontol* 2007;34:816–821.
37. Cassetta M, Stefanelli LV, Giansanti M, Di Mambro A, Calasso S. Depth deviation and occurrence of early surgical complications or unexpected events using a single stereolithographic surgi-guide. *Int J Oral Maxillofac Surg* 2011;40:1377–1387.
38. Cassetta M, Stefanelli LV, Giansanti M, Di Mambro A, Calasso S. Accuracy of a computer-aided implant surgical technique. *Int J Periodontics Restorative Dent* 2013;33:317–325.
39. Schneider D, Schober F, Grohmann P, Hammerle CHF, Jung RE. In-vitro evaluation of the tolerance of surgical instruments in templates for computer-assisted guided implantology produced by 3-D printing. *Clin Oral Implants Res* 2015;26:320–325.
40. Mora MA, Chenin DL, Arce RM. Software tools and surgical guides in dental-implant-guided surgery. *Dent Clin North Am* 2014;58:597–626.
41. Van de Wiele G, Teughels W, Vercruyssen M, Coucke W, Temmerman A, Quirynen M. The accuracy of guided surgery via mucosa-supported stereolithographic surgical templates in the hands of surgeons with little experience. *Clin Oral Implants Res* 2015;26:1489–1494.
42. Widmann G, Bale RJ. Accuracy in computer-aided implant surgery—A review. *Int J Oral Maxillofac Implant* 2006;21:305–313.
43. Apostolakis D, Kourakis G. CAD/CAM implant surgical guides: Maximum errors in implant positioning attributable to the properties of the metal sleeve/osteotomy drill combination. *Int J Implant Dent* 2018;4:34.
44. Cassetta M, Di Mambro A, Giansanti M, Stefanelli LV, Barbato E. How does an error in positioning the template affect the accuracy of implants inserted using a single fixed mucosa-supported stereolithographic surgical guide? *Int J Oral Maxillofac Surg* 2014;43:85–92.
45. El Kholy K, Janner SFM, Schimmel M, Buser D. The influence of guided sleeve height, drilling distance, and drilling key length on the accuracy of static computer-assisted implant surgery. *Clin Implant Dent Relat Res* 2019;21:101–107.
46. Cassetta M, Di Mambro A, Giansanti M, Stefanelli LV, Cavallini C. The intrinsic error of a stereolithographic surgical template in implant guided surgery. *Int J Oral Maxillofac Surg* 2013;42:264–275.
47. Oh KC, Shim JS, Park JM. In vitro comparison between metal sleeve-free and metal sleeve-incorporated 3D-printed computer-assisted implant surgical guides. *Materials (Basel)* 2021;14:1–10.

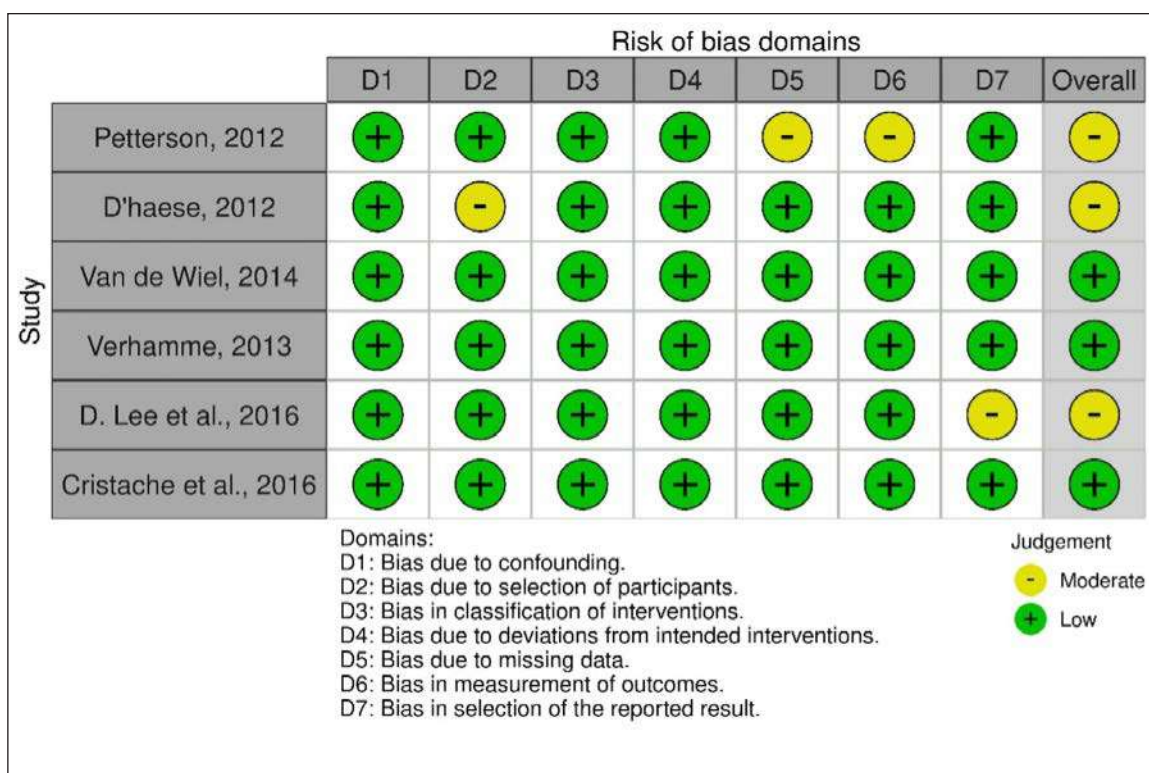
APPENDICES



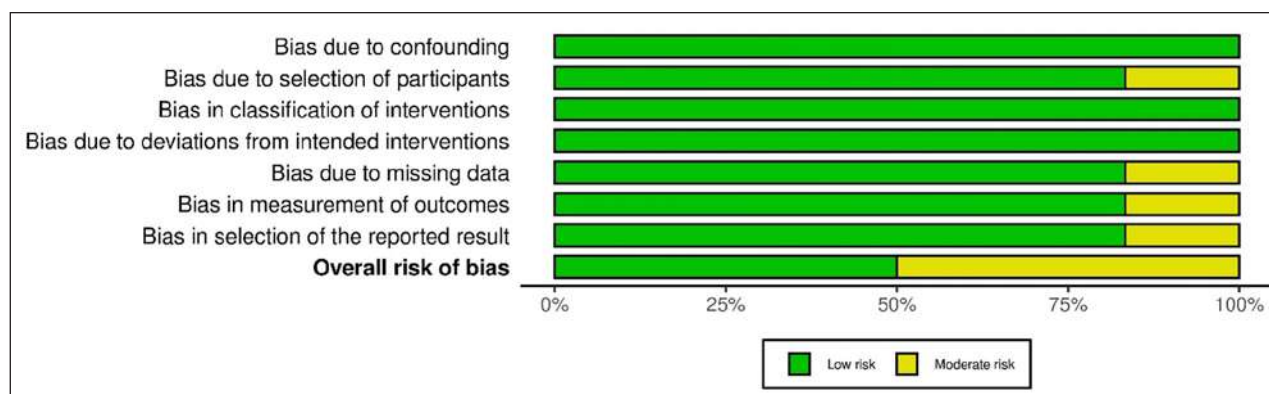
Appendix Fig 1 Traffic light plot—bias risk assessment for studies involving a randomization process (Cochrane Risk of Bias—RoB 2).



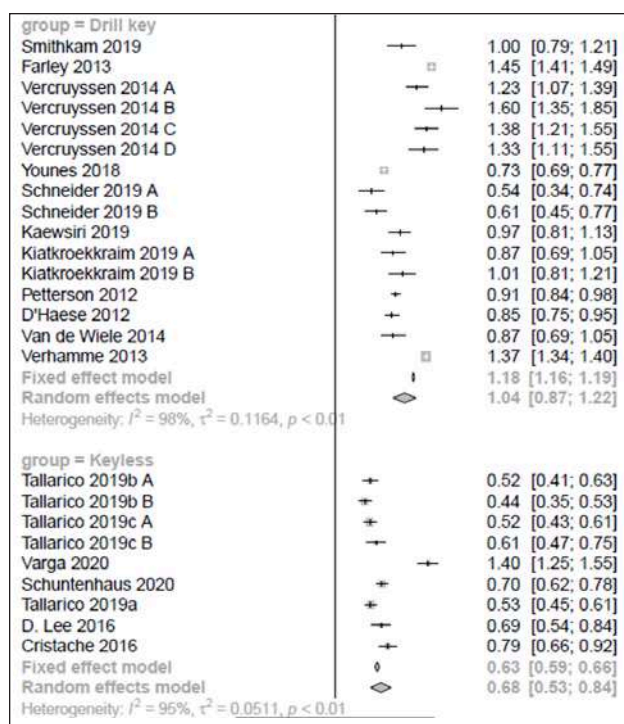
Appendix Fig 2 Summary plot—bias risk assessment for studies involving a randomization process (Cochrane Risk of Bias—RoB 2).



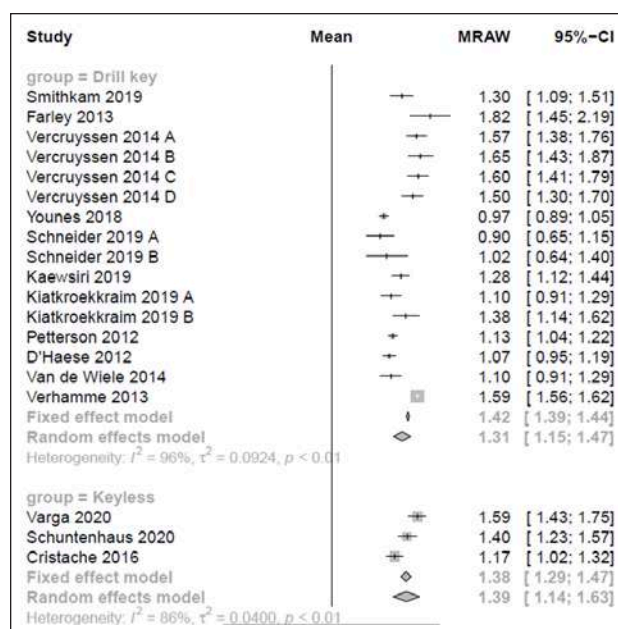
Appendix Fig 3 Traffic light plot—bias risk assessment for nonrandomized trials (Cochrane Risk of Bias—Robins 1).



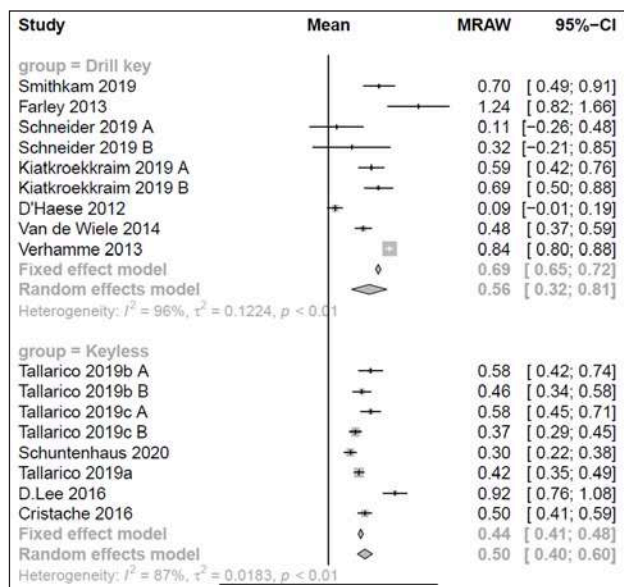
Appendix Fig 4 Summary plot—bias risk assessment for nonrandomized trials (Cochrane Risk of Bias—Robins 1).



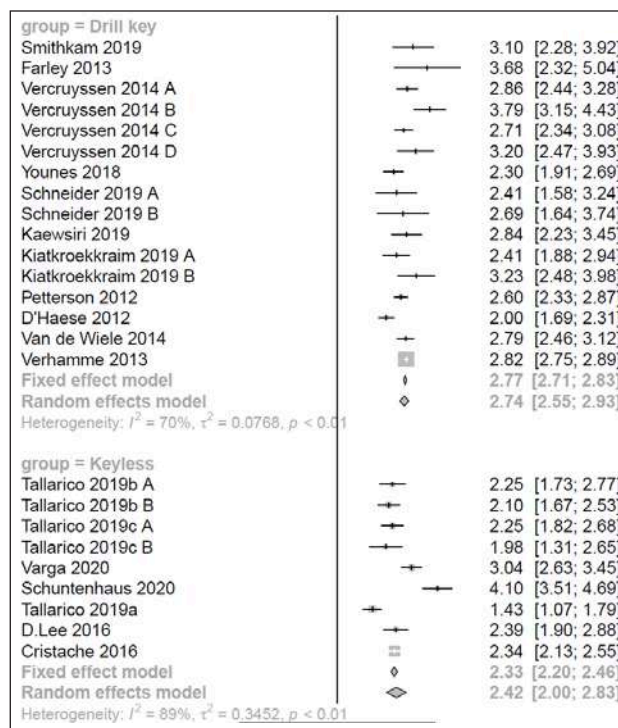
Appendix Fig 5 Forest plot for coronal deviation analysis.



Appendix Fig 6 Forest plot for apical deviation analysis.



Appendix Fig 7 Forest plot for vertical deviation analysis.



Appendix Fig 8 Forest plot for angular deviation analysis.