Computer Technology Applications in Surgical Implant Dentistry: A Systematic Review

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Purpose: *To assess the literature on the accuracy and clinical performance of static computer-assisted implant surgery in implant dentistry.* ***Materials and Methods:*** *Electronic and manual literature searches were applied to collect information about (1) the accuracy and (2) clinical performance of static computer-assisted implant systems. Meta-regression analysis was performed to summarize the accuracy studies. Failure/complication rates were investigated using a generalized linear mixed model for binary outcomes and a logit link to model implant failure rate.* ***Results:*** *From 2,359 articles, 14 survival and 24 accuracy studies were included in this systematic review. Nine different static image guidance systems were involved. The meta-analysis of the accuracy (24 clinical and preclinical studies) revealed a total mean error of 1.12 mm (maximum of 4.5 mm) at the entry point measured in 1,530 implants and 1.39 mm at the apex (maximum of 7.1 mm) measured in 1,465 implants. For the 14 included survival studies (total of 1,941 implants) using static computer-assisted implant dentistry, the mean failure rate was 2.7% (0% to 10%) after an observation period of at least 12 months. In 36.4% of the treated cases, intraoperative or prosthetic complications were reported, which included: template fractures during the surgery, change of plan because of factors such as limited primary implant stability, need for additional grafting procedures, prosthetic screw loosening, prosthetic misfit, and prosthesis fracture.* ***Conclusion:*** *Different levels of quantity and quality of evidence were available for static computer-assisted implant placement, with tight-fitting high implant survival rates after only 12 months of observation in different indications achieving a variable level of accuracy. Future long-term clinical data are necessary to identify clinical indications; detect accuracy; assess risk; and justify additional radiation doses, effort, and costs associated with computer-assisted implant surgery.* Int J Oral Maxillofac Implants 2014;29 (suppl):25–42. doi: 10.11607/jomi.2014suppl.g1.2

Key words: *guided surgery, dental implants, computer planning*

Prosthetically driven implant surgery in reference to surrounding anatomical structures has been a subject of interest to dental clinicians for a number of years. Correct implant positioning has a number of advantages such as a favorable esthetic and prosthetic outcome and the potential to ensure optimal occlusion and implant loading. Moreover, the consideration of correct implant positioning may enable design optimization of the final prostheses, allowing for adequate dental hygiene. Consequently, all of these factors may contribute to the long-term success of dental implants.

The introduction of cone-beam computed tomography (CBCT) scanning to implant dentistry as a three-dimensional (3D) imaging tool has led to a breakthrough in this field, particularly because these scanning devices result in lower radiation dosages than conventional computed tomography (CT) scanners.[1–3] In combination with implant planning software, the use of CBCT images has made it possible to virtually plan the optimal implant position regarding surrounding vital anatomical structures and future prosthetic needs. The resulting planning information is then used to fabricate so-called drill guides, and this process ultimately results in the transfer of the planned implant position from the computer to the patient, with the

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drill guide directing the implant osteotomy and implant insertion. Importantly, this entire process can be performed in such a way that the predicted ideal implant position can be achieved without damaging the surrounding anatomical structures.[4]

The various so-called guided systems incorporate the planning of the implant positions, using a variety of software tools. The resulting planned implant positions are then converted into surgical guides or loaded into positioning software following a variety of methods. Jung and coworkers[5] have categorized many of these into static and dynamic systems. Static systems are those that communicate predetermined sites using surgical templates or implant guides in the operating field. Meanwhile, dynamic systems communicate the selected implant positions to the operative field with visual imaging tools on a computer monitor, instead of rigid intraoral guides. The dynamic systems include surgical navigation and computer-aided navigation technologies, and allow the surgeon to alter the surgical procedure and implant position in real time using the anatomical information available from the preoperative plan and a CT or CBCT scan. Since the surgeon can see an avatar of the drill in a 3D relationship to the patient's previously scanned anatomy during surgery, modifications can be accomplished with significantly more information. In essence, the navigation approach provides a virtual surgical guidance that may be altered according to the conditions encountered during surgery.

In their systematic review, Jung et al[5] stated that the static systems have the tendency to be more accurate than the dynamic approaches. However, most of the publications on navigation have been clinical studies, whereas the majority on static protocols has been preclinical (models or cadaver, etc), where more accurate measurements are possible. The greater accuracy of these latter studies can be explained by the better access, the greater visual control of the axis of the osteotomy, the lack of movement in the cadaver, and the absence of saliva or blood in the preclinical models. In the dynamic approach, the osteotomy and implant insertion can be altered during the surgery. Thus the osteotomy has then no other guidance than the surgeon's vision in the virtual model, giving the surgeon the ability to choose the implant position based on the visual real-time anatomy. Hence, no true comparison is possible between the planned and placed implant position. Due to this fact, in this systematic review, only the studies conducting computer-guided (static) surgery were considered for inclusion.

For computer-guided (static) surgery, one can distinguish different modalities regarding the procedure for fabricating the drill guides such as stereolithography (rapid prototyping) or the use of mechanical positioning devices that convert the radiographic template to a surgical one by executing computer transformation algorithms.[5] The different computer guided systems can also be differentiated in terms of their respective design for the drill guidance through the template. For example, some systems use surgical templates with sleeves of an increasing diameter, while others design different drills with stops to achieve depth control. Some systems allow a guided implant placement[6–8] whereas in other systems the implants are inserted without using a guided device[9–11] or after removal of the template. Some systems use pre-installed reference points such as mini-implants[8,12] while others use different reference markers (eg, gutta percha markers on the CT imaging) or no references for performing the procedures. These variations make it extremely difficult to draw a clear line in comparing the different systems. For this reason, a clear description on every system and their variation in use and precision can be beneficial to clinicians who are interested in these techniques.

Moreover, different accuracy measurement techniques and terms have been introduced in the literature in the comparison of planned implant positions to actual inserted implants. Some use baseline criteria such as entry or apical point while others use 3D coordinates (eg, x-, y-, and z-axes), making it more challenging to conduct a unified comparison.

The aim of this systematic review is to systematically assess the literature regarding the accuracy and the clinical performance, limitations, and complications of different static techniques based on computer assisted technique applications in guided surgical implant dentistry.

MATERIALS AND METHODS

An electronic search on dental literature was performed with the purpose of collecting relevant data on *(1)* the accuracy and *(2)* the clinical performance (survival) of computer-aided dental implant placement. A MEDLINE and EMBASE systematic search was completed using the following terms: dental AND (implant OR implants OR implantation OR implantology) AND (guide* OR computer*) (Table 1).

The results were limited to studies published between January 1, 2008, and January 9, 2012, and written in English, German, Italian, or French. These results were complemented by the data extracted in a previous ITI consensus paper accessing the literature from 1966 through 2008.[5] Two independent reviewers performed the article selection. In addition, hand searches were performed using the reference lists of the selected full-text articles and were also conducted in the following pertinent implant-related journals; *Clinical Implant Dentistry and Related Research, Clinical Oral Implants Research, The International Journal of Oral*

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Table 1 Systematic Search Strategy

Focus question	**How does static computer-guided surgery perform in terms of implant survival and accuracy of placement when treating (partially) edentulous patients?**
Search strategy	
Population	Edentulous or partially edentulous patients treated with dental implants
Intervention or exposure	Implant placement using static computer-guided surgery
Comparison	Nonguided/conventional methods
Outcome	*(1)* Accuracy of placement, *(2)* Implant survival
Search combination	dental AND (implant OR implants OR implantation OR implantology) AND (guid* OR compute*)
Database search	
Electronic	PubMed (MEDLINE) & EMBASE
Journals	Hand search: *Clin Implant Dent Relat Res, Clin Oral Implants Res, Int J Oral Maxillofac Implants, J Oral Maxillofac Surg, J Periodontal, J Prosthet Dent*
Selection criteria	
Inclusion criteria	*General:* Reporting on static-guided implant placement through digital planning based on CBCT imaging Clinical studies with at least 5 patients *Accuracy studies:* Primary outcome of the studies was the accuracy of computer-guided implant placement Clinical, model, or cadaver studies *Survival studies:* Follow-up period in clinical studies at least 12 months Data on complications incorporated if available
Exclusion criteria	*General:* Zygoma, pterygoid, and orthodontic implants Multiple publications on the same patient population *Accuracy studies:* Studies reporting just on position or shape of osteotomies Studies reporting freehand final drilling *Survival studies:* Insufficient information on survival rates or lost implants

& Maxillofacial implants, Journal of Oral and Maxillofacial Surgery, Journal of Periodontology, Journal of Prosthetic Dentistry, Implant Dentistry, and *The International Journal of Periodontics and Restorative Dentistry.* Only articles that reached consensus between the reviewers were selected for data extraction. Figure 1 illustrates the search strategy.

Inclusion and Exclusion Criteria

This review includes only computer-guided (static) surgery in which a CT/CBCT scan was conducted for computerized planning prior to the actual implant insertion. Therefore, articles regarding dynamic computer-navigated surgery and 2D radiographic stents were excluded. Meanwhile, for the accuracy and clinical performance studies, different inclusion criteria were considered.

Accuracy studies:

- Studies with zygomatic, pterygoid, and orthodontic implants were excluded.
- Clinical, model, and cadaver studies were included.
- The primary outcome of the studies had to be the accuracy of computer-guided implant surgery.
- The measurement of distances between the planned and actual position of the implants and/or implant angle deviations had to be clearly described.
- Only the data on the position of actual inserted implants were included, whereas data were excluded if the position of the osteotomy following computer-guided surgery was provided but no actual insertion of the implants was performed.

Clinical studies:

- Clinical studies were included when based on at least 5 patients.
- The follow-up period had to be at least 12 months. The reported data had to include implant survival based on at least one of the following parameters: clinical, radiographic, or patient-centered outcomes of computer-assisted implant dentistry in humans.
- Other factors such as prosthetic survival, complications, or bone-level changes were incorporated if available.

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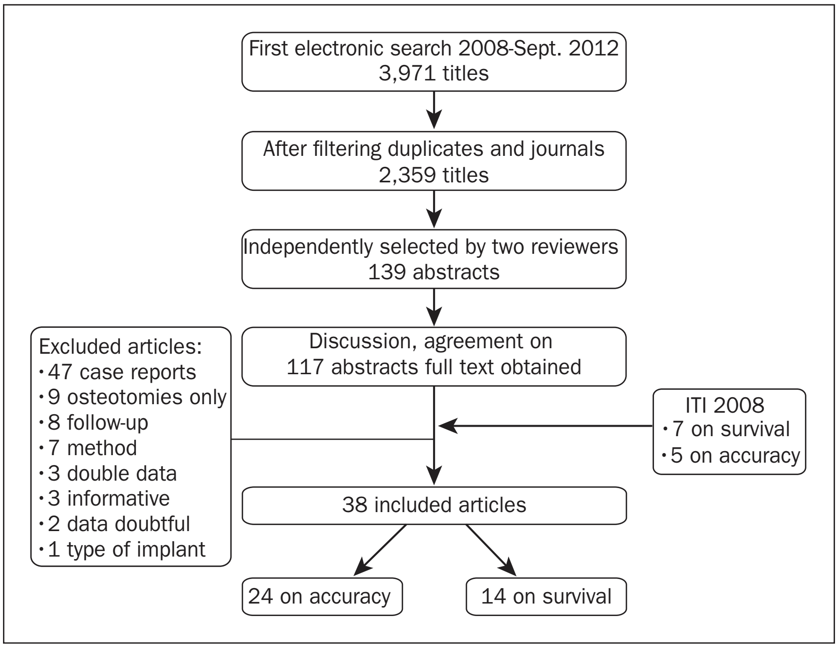

Fig 1 Schematic illustration of search strategy.

Table 2 Contacted Authors

Authors	Year	Response	Action
Behneke et al[13]	2012	Y	Data added (SDs)
Komiyama et al[14]	2008	Y	Explanation/clarification
Nickenig et al[15]	2010	N	Included (missing information not crucial)
Kuhl et al[16]	2013	Y	Data added (SDs)
Ozan et al[17]	2011	Y	Explanation/clarification
Ozan et al[18]	2009	Y	Explanation/clarification
Ersoy et al[9]	2008	Y	Explanation/clarification
Pettersson et al[19]	2012	Y	Data changed (means and SDs)
van Steenberghe et al[20]	2002	Y	Missing info not crucial

Data Extraction

Two data sheets (accuracy and clinical performance) were created in consultation between the two reviewers. The reviewers independently from each other extracted the data of the included studies using these data sheets. Any disagreements were resolved by discussion. Studies were only definitively included in the analysis if consensus was reached between the reviewers. Further, in cases of incomplete or unclear data, the respective authors were contacted to complete or clarify their data. Table 2 shows the contacted authors and their valuable contribution.

As well as a general analysis of the extracted data, the reviewers agreed to create different subgroups in the accuracy assessment to evaluate the different data correctly and to perform a clear comparison between the various techniques and protocols and their possible statistical significance.

Subgroups were created according to the following criteria:

- State of the implanted jaw: *(1)* fully edentulous or *(2)* partially edentulous
- Implanted jaw: *(1)* maxilla or *(2)* mandible
- Flapless surgery: *(1)* yes or *(2)* no
- Guide support: *(1)* mucosa, *(2)* mucosa with pins or screws, *(3)* bone, *(4)* tooth, or *(5)* reference mini-implants
- Methods of implant insertion: *(1)* freehand implant placement (guide removed) or *(2)* fully guided implant placement (using guide)
- Guide production: *(1)* produced in a laboratory, *(2)* fabricated with rapid prototyping/stereolithography (SLA)
- Study design: *(1)* clinical, *(2)* cadaver, or *(3)* model

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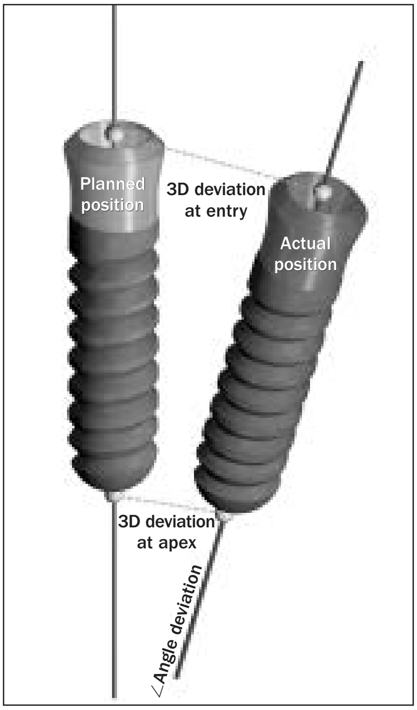

Fig 2 *(left)* Different variables for describing the deviations per implant illustrated.

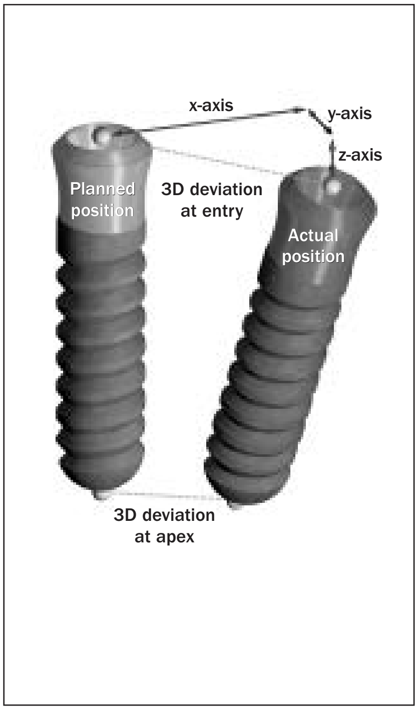

Fig 3 *(right)* Illustration of the distinction between the deviation measured in the x, y, and z-axis.

Analysis

For analyzing the accuracy, the planned position of the implant was compared with the actual position of the implant after insertion. Several measuring points were used in the studies for the comparison of these positions:

- Error at the entry point, measured at the center of the implant
- Error at the apex, measured at the center of the implant apex
- Angular deviation
- Error in implant height

Actual comparison between the different studies is only possible if the measurement mode is the same. Error at the entry and the apex and the error in the height were measured in mm or µm, while the angular deviation was measured in degrees. For angular deviation, the comparison was less complicated, since every study used degrees of deviation. The error or deviation of the other aforementioned points was 3D, though several methods were used to describe the distance between the given points. The most common method was to measure the actual distance between the planned and actual point in 3D. Other authors made a distinction between the deviation measured in the x, y, and z-axis, where x = buccolingual, y = mesiodistal, and z = apicocoronal deviation. The apicocoronal deviation was frequently expressed as a negative number if the implant was not inserted as deeply as planned (too coronal). Furthermore in some studies the deviation in a horizontal plane was measured and referred to as the x-, y-error. Figure 2 illustrates the different variables for describing the deviations.

The main purpose of this study was to compare the results of different study designs. To accomplish this goal, if data was missing, the respective authors were contacted to assist the reviewers in completing the data.

In addition, it was attempted to convert the data as uniformly as possible. Therefore, in cases where axiomatic (x, y, z) measurements were used, the values were converted to 3D deviations using the Pythagorean Theorem. Figure 3 illustrates these variables before conversion.

$$3\text{Ddev} = \sqrt{x^2 + y^2 + z^2}$$

For recalculating the combined standard deviations of the 3D deviations the following formula was used:

$$\text{SDcomb} = \sqrt{\frac{(\text{Nx}(\text{SDx}^2 = (x - 3\text{Ddev})^2) + \text{Ny}(\text{SDy}^2 + (y - 3\text{Ddev})^2) + \text{Nz}(\text{SDz}^2 + (z - 3\text{Ddev})^2))}{(\text{Nx} + \text{Ny} + \text{Nz})}}$$

Note that in some of the included studies, there was insufficient data to perform a Pythagorean calculation. In these instances the data were included, but for this part not incorporated in the metaregression analysis.

Statistical Analysis

R version 2.14 for Windows, Metatest, and Meta-Library software were used for statistical analysis.

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Table 3 Studies on Accuracy of Guided Implant Placement

Authors	Year	Study design	Comparison	System	State of dentition	Jaw	Guide support	Implant placement	Guide type
van Steenberghe et al[20]	2002	Cadaver	Postop CBCT	Nobel Guide	Edentulous	Maxilla	Bone	FG	dig
Di Giacomo et al[11]	2005	Clinical	Postop CBCT	SimPlant	Partially edentulous	Both	Bone/tooth	FHP	dig
van Assche et al[21]	2007	Cadaver	Postop CBCT	Nobel Guide	Partially edentulous	Both	Tooth + 2x anchor pins	FG	dig
Ersoy et al[9]	2008	Clinical	Postop CBCT	StentCad	Both	Both	Mixed (mucosa/tooth/bone)	FHP	dig
					Edentulous	Both	Mixed (mucosa/tooth/bone)	FHP	dig
					Partially edentulous	Both	Mixed (mucosa/tooth/bone)	FHP	dig
					Single tooth	Both	Mixed (mucosa/tooth/bone)	FHP	dig
					Both	Both	Mucosa	FHP	dig
					Both	Both	Tooth	FHP	dig
					Both	Maxilla	Mixed (mucosa/tooth/bone)	FHP	dig
					Both	Mandible	Mixed (mucosa/tooth/bone)	FHP	dig
					Both	Both	Bone	FHP	dig
					Both	Both	Mixed (mucosa/tooth)	FHP	dig
					Both	Both	Mixed (mucosa/tooth/bone)	FHP	dig
Ruppin et al[22]	2008	Cadaver	Postop CBCT	SimPlant	Both	Mandible	Bone	FHP	dig
Dreiseidler et al[23]	2009	Model	Postop CBCT	Nobel Guide	Partially edentulous	Both	Tooth	FG	dig
Ozan et al[18]	2009	Clinical	Postop CBCT	StentCad	Both	Both	Mixed (mucosa/tooth/bone)	FHP	dig
						Maxilla	Mixed (mucosa/tooth/bone)	FHP	dig
						Mandible	Mixed (mucosa/tooth/bone)	FHP	dig
						Both	Bone	FHP	dig
						Both	Mucosa	FHP	dig
						Both	Tooth	FHP	dig
Arisan et al[24]	2010	Clinical	Postop CBCT	SimPlant	Both	Both	Mucosa + pin	FG	dig
				Simplant	Both	Both	Tooth	FG	dig
				SimPlant	Both	Both	Bone	FHP	dig
				StentCad	Both	Both	Mucosa + pin	FHP	dig
				StentCad	Both	Both	Tooth	FHP	dig
				StentCad	Both	Both	Bone	FHP	dig
Nickenig et al[15]	2010	Clinical	Postop CBCT	coDiagnostiX	Partially edentulous	Mandible	Tooth	FHP	lab
Pettersson et al[19]	2012	Clinical	Postop CBCT	Nobel Guide	Edentulous	Both	Mucosa + pin	FG	mix
						Maxilla	Mucosa + pin	FG	mix
						Mandible	Mucosa + pin	FG	mix
Pettersson et al[6]	2010	Cadaver	Postop CBCT	Nobel Guide	Edentulous	Both	Mucosa + pin	FG	dig
						Maxilla	Mucosa + pin	FG	dig
						Mandible	Mucosa + pin	FG	dig
Tahmaseb et al[7]	2010	Model	Strain Gauges	Exe–plan	Edentulous	Mandible	Mini–implant	FG	dig
Viegas et al[25]	2010	Model	Postop CBCT	NeoGuide	Edentulous	Mandible L	Bone	FG	dig
						Mandible R	Bone	FG	dig
Cassetta et al[26]	2013	Clinical	Postop CBCT	SimPlant	Both	Both	Mixed (mucosa/bone/tooth)	FHP	dig
							Mixed + pin (mucosa/bone)	FG	dig
							Mixed (mucosa/bone/tooth)	FG	dig
Ozan et al[17]	2011	Clinical	Postop CBCT	StentCad	Both	Maxilla	Mucosa	FHP	dig
				StentCad	Both	Mandible	Mucosa	FHP	dig
				StentCad Beyond	Both	Maxilla	Mucosa + pin	FG	dig
				StentCad Beyond	Both	Mandible	Mucosa + pin	FG	dig
Platzer et al[27]	2011	Clinical	Pick–up Impression	SimPlant	Partially edentulous	Mandible	Tooth	FG	dig
Tahmaseb et al[8]	2011	Model	Strain Gauges	Exe-plan	Partially edentulous	Maxilla	Mini–implant	FG	dig
Vasak et al[28]	2011	Clinical	Postop CBCT	Nobel Guide	Both	Both	Mixed + pin (mucosa/tooth)	FG	dig
Arisan et al[29]	2012	Clinical	Postop CBCT	SimPlant & CBCT	Edentulous	Both	Mucosa + pin	FG	dig
				SimPlant & CT	Edentulous	Both	Mucosa + pin	FG	dig
Behneke et al[13]	2012	Clinical	Postop CBCT	Implant 3D	Partially edentulous	Both	Tooth	FG	lab
								FHP	lab
D'Haese et al[30]	2012	Clinical	Postop CBCT	Facilitate	Edentulous	Maxilla	Mucosa + pin	FG	dig
Di Giacomo et al[10]	2012	Clinical	Postop CBCT	Implant Viewer	Edentulous	Both	Mucosa + pin	FHP	dig
						Maxilla	Mucosa + pin	FHP	dig
						Mandible	Mucosa + pin	FHP	dig
Kuhl et al[16]	2012	Cadaver	Postop CBCT	coDiagnostiX	Both	Mandible	Mixed (mucosa/tooth)	FHP	lab
		Cadaver						FG	lab
Soares et al[31]	2012	Model	Postop CBCT	NeoGuide	Edentulous	Mandible	Mucosa + pin	FG	dig

FHP = freehand placement; FG = fully guided implant insertion; lab = templates produced in laboratory;
dig = digitally produced templates (stereolithographic or milled); *at entry; †at apex

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Implants (n)	Flap-less	x,y,z	Error entry (mm)			Error apex (mm)			Error angle (°)			Error height (mm)		
			Mean	SD	Max	Mean	SD	Max	Mean	SD	Max	Mean	SD	Max
10	Y	3D	0.8	0.3	–	0.9	0.3	–	1.8	1	–	–	–	1.1
21	N	3D	1.45	1.42	4.5	2.99	1.77	7.1	7.25	2.67	12.2	–	–	–
12	Y	3D	1.1	0.7	2.3	1.2	0.7	2.4	1.8	0.8	4	–	–	–
94	44%	3D	1.22	0.85	–	1.51	1	–	4.9	2.36	–	–	–	–
65	mix	3D	1.28	0.92	–	1.6	1.08	–	5.1	2.59	–	–	–	–
20	mix	3D	1.23	0.67	–	1.59	0.74	–	4.78	1.86	–	–	–	–
9	mix	3D	0.74	0.4	–	0.66	0.28	–	3.71	0.93	–	–	–	–
23	mix	3D	1.1	0.7	–	1.7	1	–	4.9	2.2	–	–	–	–
26	mix	3D	1.1	0.6	–	1.3	0.7	–	4.4	1.6	–	–	–	–
48	mix	3D	1.04	0.56	–	1.57	0.97	–	5.31	0.36	–	–	–	–
46	mix	3D	1.42	1.05	–	1.44	1.03	–	4.4	0.31	–	–	–	–
45	N	3D	1.3	1	–	1.6	1.5	–	5.1	2.7	–	–	–	–
53	N	3D	1.4	1	–	1.4	1.7	–	5	2.6	–	–	–	–
41	Y	3D	1.1	0.6	–	1.4	1	–	4.7	2	–	–	–	–
40	N	x, y	1.5	0.8	–	–	–	–	7.9	5	–	0.6	0.4	
24	N	x, y	0.22	0.099	0.38	0.34	0.15	0.62	1.09	0.51	2	0.25	0.20	0.8
110	55%	3D	1.11	0.7	–	1.41	0.9	–	4.1	2.3	–	–	–	–
58	mix	3D	0.95	0.5	–	1.41	1	–	4.85	2.4	–	–	–	–
52	mix	3D	1.28	0.9	–	1.4	0.9	–	3.32	1.9	–	–	–	–
50	N	3D	1.28	0.9	–	1.57	0.9	–	4.63	2.6	–	–	–	–
30	Y	3D	1.06	0.6	–	1.6	1	–	4.51	2.1	–	–	–	–
30	Y	3D	0.87	0.4	–	0.96	0.6	–	2.91	1.3	–	–	–	–
54	Y	3D	0.7	0.13	0.83	0.76	0.15	0.99	2.9	0.39	3.5	–	–	–
50	Y	3D	0.81	0.33	1.6	1.01	0.4	1.72	3.39	0.84	4.6	–	–	–
43	N	3D	1.56	0.25	3.48	1.86	0.4	2.6	4.73	1.28	6.9	–	–	–
43	Y	3D	1.24	0.51	2.7	1.4	0.47	2.83	4.23	0.72	6	–	–	–
45	Y	3D	1.31	0.59	2.9	1.62	0.54	3.4	3.5	1.38	5.9	–	–	–
44	N	3D	1.7	0.52	3.48	1.99	0.64	3.8	5	1.66	8.2	–	–	–
23	Y	x	0.9	1.06	–	0.6	0.57	–	4.2	3.04	–	–	–	–
		y	0.9	1.22	–	0.9	0.94	–	4.2	3.04	–	–	–	–
139	Y	3D	0.95	0.55	2.68	1.22	0.63	3.62	2.76	1.76	11.74	−0.15	0.76	−2.33
89	Y	3D	0.95	0.53	2.68	1.15	0.51	2.63	2.71	1.41	6.96	−0.06	0.7	2.05
50	Y	3D	0.96	0.57	2.45	1.35	0.8	3.62	2.85	2.27	11.74	−0.29	0.83	−2.33
145	Y	3D	1.06	0.58	3.13	1.25	0.68	3.63	2.64	1.42	7.44	0.28	0.59	1.61
78	Y	3D	0.83	0.57	2.78	0.96	0.5	2.43	2.02	0.66	5.38	0.1	0.6	1.61
67	Y	3D	1.05	0.47	3.13	1.24	0.58	3.63	2.46	0.67	7.44	0.48	0.52	1.46
6	Model	3D	0.055	0.032	–	–	–	–	–	–	–	–	–	–
11	Model	3D	0.37	0.2	–	0.41	0.22	–	0.7	0.3	–	–	–	–
11	Model	3D	0.3	0.17	–	0.36	0.25	–	1.45	0.89	–	–	–	–
116	81%	3D	1.47	0.68	3.88	1.83	1.03	6.41	5.09	3.7	21.16	0.98	0.71	3.53
57	84%	3D	1.49	0.63	3	1.9	0.83	3.98	3.93	2.34	14.34	0.85	0.63	2.29
54	83%	3D	1.55	0.59	2.79	2.05	0.89	4.23	5.46	3.38	15.25	0.63	0.43	1.58
80	Y	°	–	–	–	–	–	–	6.29	2.12	–	–	–	–
44	Y	°	–	–	–	–	–	–	4.35	1.8	–	–	–	–
49	Y	°	–	–	–	–	–	–	3.91	1.21	–	–	–	–
43	Y	°	–	–	–	–	–	–	3.55	1.08	–	–	–	–
15	Y	x	0.27	0.19	0.6	–	–	–	–	–	–	0.28	0.19	0.59
		y	0.15	0.13	0.34	–	–	–	–	–	–	–	–	–
4	Model	x	0.027	0.015	0.046	–	–	–	–	–	–	0.0104	0.057	0.016
		y	0.025	0.022	0.061	–	–	–	–	–	–	–	–	–
86	Y	x	0.46	0.35	1.42	0.7	0.49	1.84	3.53	1.77	8.1	0.53*	0.38	1.85
		y	0.43	0.32	1.5	0.59	0.44	1.89	–	–	–	0.52†	0.42	2.02
52	Y	3D	0.81	0.32	1.31	0.81	0.32	1.33	3.47	1,144	5.12	–	–	–
50	Y	3D	0.75	0.32	1.26	0.8	0.35	1.34	3.3	1,085	4.98	–	–	–
24	Mix	x,y	0.21	0.19	0.6	0.28	0.2	0.77	1.49	1.1	4.53	–	–	–
86	Mix	x,y	0.3	0.21	0.78	0.47	0.27	1.3	2.06	1.19	6.26	–	–	–
78	Y	3D	0.91	0.44	2.45	1.13	0.52	3.01	2.6	1.61	8.86	–	–	–
60	Y	3D	1.35	0.65	2.69	1.79	1.01	4	6.53	4.31	18.64	–	–	–
22	Y	3D	1.51	0.62	–	1.86	1.07	–	8.54	4.2	–	–	–	–
38	Y	3D	1.26	0.66	–	1.75	0.99	–	5.37	3.98	–	–	–	–
19	Y	3D	1.56	0.53	3.43	1.84	0.41	3.22	4.3	3.12	11.09	–	–	–
19	Y	3D	1.52	0.81	3.54	1.55	0.68	3.64	3.6	2.68	8.75	–	–	–
18	Y	3D	1.38	0.42	–	1.39	0.4	–	2.16	0.91	–	0.8	0.58	–

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Table 4 Guided Systems Used in Selected Studies

System	No. of studies using system
Nobel Guide	15
SimPlant	9
StentCad Classic/Beyond	4/1
coDiagnostiX	3
Exe-plan	3
Dental Slice/NeoGuide	2
Implant Viewer 1.9	2
Facilitate (AstraTech)	1
Implant 3D	1

Differences in accuracy between each group were assessed by means of metaregression. A separate analysis was performed for each of the three types of deviation (eg, error at the entry point and apex, error in the angle).

In addition, forest plots were prepared to visualize the difference between groups. Since evidence of heterogeneity was observed between the publications, the totals were calculated using random effects meta-analysis for continuous variables.

For survival, a generalized linear mixed model for binary outcomes and a logit link was used to model implant failure rate.

RESULTS

After the initial search, a total of 3,971 titles were found. Because multiple search engines were used (PubMed & EMBASE) the duplicates needed to be filtered out, which reduced the number of articles to 2,359 titles. Subsequently, 139 abstracts of relevant studies were then selected by two reviewers. After reviewers examined and discussed the abstracts, 117 publications were selected, in consensus, for full-text evaluation. In addition, 12 full-text articles that were selected from the 2008 consensus statement[5] were analyzed and added to selected publications. The final selection as based upon full-text analysis and the inclusion and exclusion criteria resulted in 24 accuracy studies and 14 survival studies that could be used for data extraction (Fig 1).

Accuracy Studies

Twenty-four articles provided useful information on the accuracy of computer-guided (static) implant surgery (Table 3). Fourteen of these articles were clinical studies, while ten were in vitro (model, cadaver) studies. The sample size of the groups varied considerably with 15 to 279 implants in the clinical studies and 4 to 145 in vitro studies. Nine computer-guided systems were used (Table 4). Fifteen of all selected studies (and therefore the majority of the studies) used NobelGuide.

The deviation at the implant entry point was reported in 23 of the 24 studies while the angle and apex deviations were mentioned in 21 and 19 studies, respectively. For comparing the data as accurately as possible, the data were converted to 3D deviation when possible. This conversion resulted in suitability of 21 studies on entry point error and 17 on implant apex error for comparison. The deviations in implant height were only rarely reported and were converted to 3D deviation when available. Because of the limited reporting on this parameter, the implant height deviations were solely reported in the results (Table 3).

The overall average deviation at the implant entry point was 1.12 mm as measured in 1,530 implants, and the maximum reported deviation was 4.5 mm. As determined for 1,465 implants, the average deviation reported at the apex was 1.39 mm, with a maximum reported deviation of 7.1 mm. The largest number of measurements (1,854 implants) was performed on the implant angle; the average angular deviation was 3.89 degrees with a maximum reported deviation of 21.16 degrees.

Statistically significant differences were observed when the following parameters were compared:

- Study design
- Flapless versus flap approach
- Freehand versus guided implant placement
- Guide support

No statistically significant differences were found in the testing of modalities in maxilla vs mandible, fully edentulous vs partially edentulous, or the guide production. Table 5 shows the *P* values of the differences per compared parameter.

Study Design

Cadaver Studies. As measured in 390 implants, the lowest and highest mean deviations at the entry point in the cadaver studies were 0.8 and 1.5 mm, respectively. The minimum and maximum measured values were 0.07 and 3.54 mm, respectively. The lowest and highest mean errors at the apex were 0.9 and 1.84 mm, respectively, where as the lowest and highest values were 0.12 and 3.64 mm, respectively. The lowest and highest mean angular deviations were 1.8 and 7.9 degrees with the minimum and maximum values of 0.08 and 11.9 degrees, respectively.

Model Studies. As determined in only 74 implants, the lowest and the highest mean deviations at the entry point were 0.025 and 1.38 mm, respectively. The maximum and minimum deviations at the entry

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Table 5 Significant Differences Per Compared Parameter for Accuracy

	Group 1			Group 2				
Grouping	Method	n	mean	Method	n	mean	Error	*P*-value difference
Implant insertion	Freehand placement	868	1.38 mm	Fully guided	1,011	0.78 mm	Entry	.002
	Freehand placement	868	1.74 mm	Fully guided	1,011	1.08 mm	Apex	0
	Freehand placement	868	4.35 Degree	Fully guided	1,011	2.57 Degree	Angle	0
Flap	Flap raised	306	1.34 mm	Flapless	1,225	1.01 mm	Entry	.012
	Flap raised	306	5.13 Degree	Flapless	1,225	3.42 Degree	Angle	.02
Guide support	Bone	275	1.19 mm	Mini-implant	10	0.05 mm	Entry	.026
	Bone (Clinical)	203	1.43 mm	Mucosa + pin (Clinical)	568	0.98 mm	Entry	.01
	Bone (Clinical)	203	1.87 mm	Mucosa + pin (Clinical)	568	1.20 mm	Apex	.022
	Bone (Clinical)	203	5.32 Degree	Mucosa + pin (Clinical)	568	3.57 Degree	Angle	.02
	Bone (Clinical)	203	1.43 mm	Mucosa (Clinical)	177	1.07 mm	Entry	.015
	Bone (Clinical)	203	1.87 mm	Tooth (Clinical)	299	1.15 mm	Apex	.007
	Bone (Clinical)	203	5.32 Degree	Tooth (Clinical)	299	3.28 Degree	Angle	.006
	Bone (Clinical)	203	1.43 mm	Tooth (Clinical)	299	0.84 mm	Entry	.001
	Mucosa	177	4.73 Degree	Mucosa + pin	731	3.25 Degree	Angle	.041
	Mucosa	177	4.73 Degree	Tooth	335	2.76 Degree	Angle	.024
	Mucosa (Clinical)	177	1.64 mm	Tooth (Clinical)	299	1.15 mm	Apex	0
	Mucosa (Clinical)	177	4.73 mm	Tooth (Clinical)	299	3.28 Degree	Angle	.034
	Mucosa + pin	731	1.05 mm	Tooth	335	0.78 mm	Entry	.023
	Mucosa + pin	731	1.05 mm	Mini-implant	10	0.05 mm	Entry	0
	Tooth	335	0.78 mm	Mini-implant	10	0.05 mm	Entry	.016
Study design	Cadaver	245	1.22 mm	Model	74	0.36 mm	Entry	.015
	Clinical	1,560	0.78 mm	Model	74	0.36 mm	Entry	.002
	Clinical	1,560	4.06 Degree	Model	74	1.44 Degree	Angle	.003
	Clinical	1,560	1.45 mm	Model	74	0.73 mm	Apex	.017

point were not often reported. The lowest reported value was 0 whereas the maximum measured value was 2.25 mm. The lowest and highest mean error at the apex was 0.34 and 1.39 mm, whereas the minimum and maximum reported values were 0.12 and 2.25 mm, respectively. The lowest mean angular deviation was 0.7 degrees, while the highest observed mean was 2.16 degrees. The minimum and maximum values were 0.3 and 2.16 degrees, respectively.

Clinical Studies. The majority of accepted studies were clinical studies, which assessed a total of 2,355 implants. The lowest and highest mean error at the entry point was 0.15 and 1.7 mm with minimum and maximum values of 0 and 4.5 mm, respectively. The mean apical deviation varied from 0.28 to 2.99 mm with a minimum and maximum of 0.3 and 7.1 mm respectively. The mean angular deviation ranged from 1.49 to 8.54 degrees with a minimum and maximum of 0 and 21.16 degrees, respectively.

A forest plot (Fig 4) shows the data for the deviation at the point of entry, the apex, and for the angulation based on the study design. Statistically significant differences were observed for all three parameters in the clinical trials versus the model studies. Model studies showed a significantly better accuracy. However, the number of implants (n = 245) tested in these studies was much lower than that (n = 1,560) used in the clinical assessments.

Flapless versus Flap Approach

Figure 5 illustrates a forest plot presenting significant differences ($P < .05$) between cases treated with a flapless protocol compared to those in which a flap was raised. The flapless procedures seemed to show a significantly better accuracy.

Freehand versus Guided Implant Placement

Guided implant placement showed a statistically superior accuracy when they are compared with freehand placement after guided osteotomy (Fig 6).

Guide Support

When all study types (clinical, in vitro) were concerned, the accuracy of mini-implant–supported guides was significantly higher than all other types of support, except mucosa. Bone-supported guides showed significantly larger deviations than other types of guide support. Tooth-supported guides tended to be slightly more accurate than mucosa or mucosa and pin–supported guides; however, these differences were only found in some of the compared parameters. When only clinical studies were assessed, the accuracy of bone-supported guides were significantly lower in almost every compared parameter (Table 5). There were no clinical studies available that investigate accuracy when using mini-implants.

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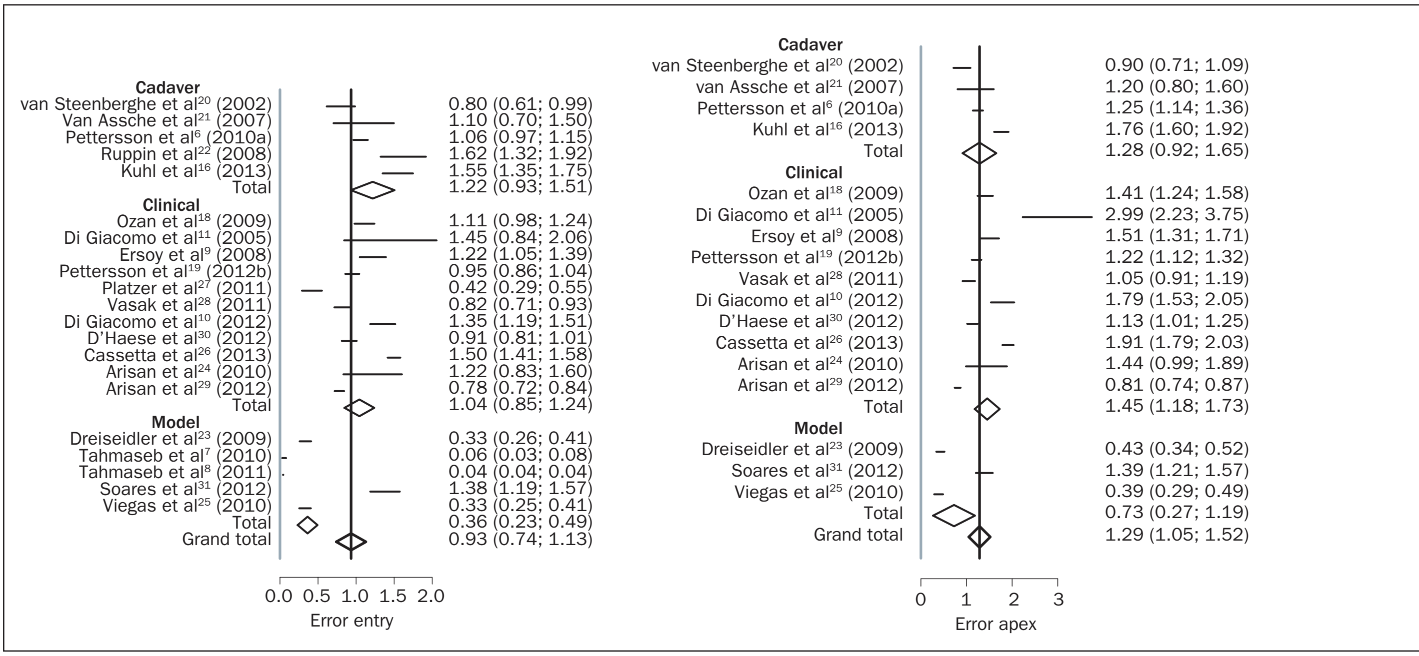

Fig 4 Forest plot illustrating mean deviation at all parameters, stratified by principle of study design.

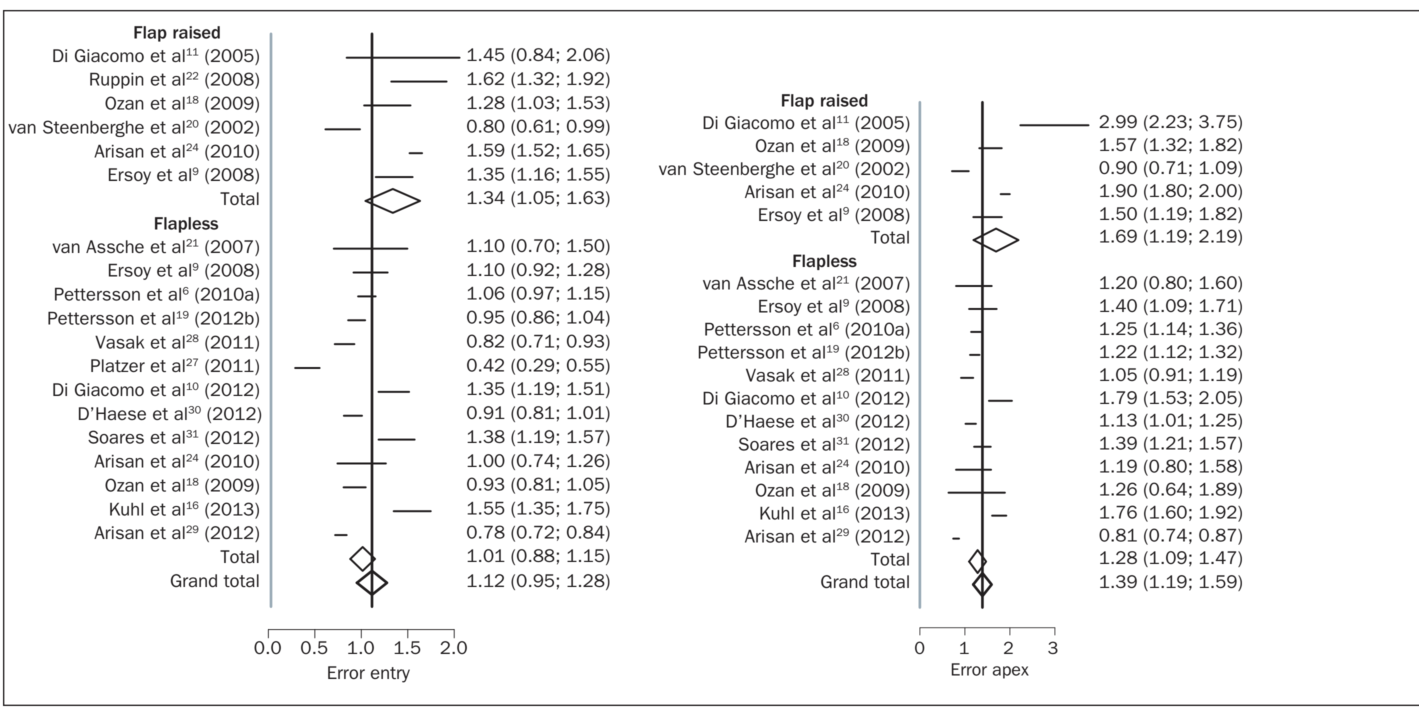

Fig 5 Forest plot illustrating mean deviation at all parameters, stratified by principle of the surgery (flap raised vs flapless).

Although no overall statistically significant differences were found in the remaining comparisons for guided implant placement, it may be of interest to state them briefly:

Maxilla versus mandible: No overall significant difference was found for any of these parameters between the two groups. However, some studies found significantly better accuracy in one arch compared to the other. Ozan et al[17] reported significantly better accuracy in the mandible when compared to the maxilla within the same study, whereas Pettersson et al[6] observed a statistically significant higher deviation

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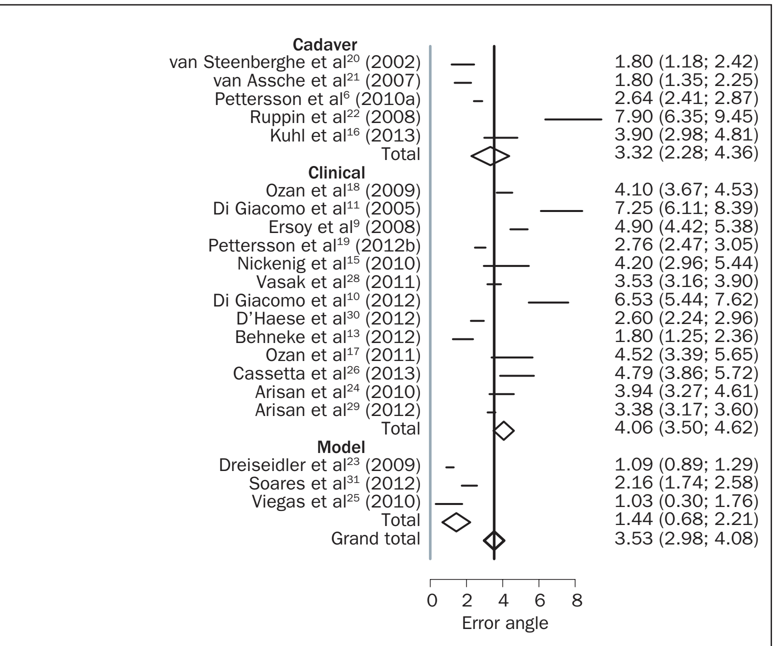

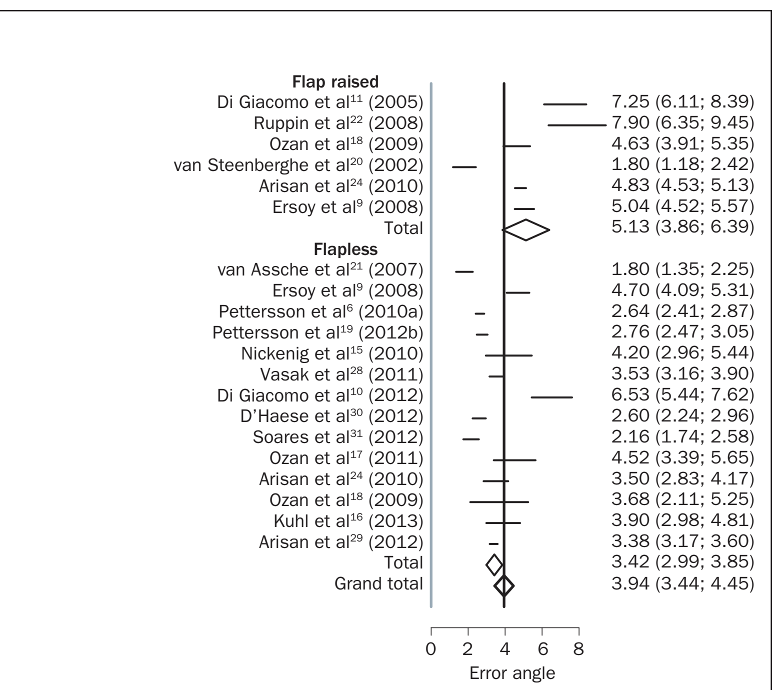

in the mandible. Of note, these studies used different supports for the surgical guides (eg, mucosa, mucosa and pin, tooth support).

Guide production: No overall significant differences were noted between different guide production types.

Survival Studies

Fifteen clinical studies reporting on implant survival for at least 12 months were selected (Table 6). Seven of these studies reported on bone loss. The average survival rate of the 1,941 implants included in this review was 97.3%. Several studies showed longer follow-up periods, while others had large dropouts at 12 months. Nevertheless, when only studies reporting on survival at 12 months were examined and further corrected for dropouts, the survival percentage was the same: 97.3%.

In 12 out of the 14 selected studies the implants were immediately loaded. Three studies even reported on immediate definitive prostheses. Sanna et al[32] and Johansson et al[34] used adjustable abutments while Tahmaseb et al[12] achieved sufficient accuracy to install the final prosthesis without adjusting abutments.

Eight studies reported on prosthetic survival. The average prosthetic survival rate based on these 211 prostheses was 95.5%.

There were no statistically significant differences between the various groups (immediate loading versus delayed loading, guide support). However, a slight difference in survival was observed between the maxilla and mandible in favor of the maxilla (*P* value difference of .14). Table 7 demonstrates the *P* value differences per reported parameter.

Complications

Within the 2,355 implants inserted in 343 treated cases, a total of 125 cases reported complications. Although the numbers should be interpreted with caution (not every study reports on all possible complications), a cumulative complication rate of 36.4% per case was calculated.

Eight studies recorded template fractures occurring during surgery. The incidence was 3.6% (7 out of 192 templates). All the fractures occurred in three of eight studies.

Ten studies reported surgical plan changes per implant. The overall incidence was 2.0% (23 out of 1,133 implants).

Five studies reported on implants lost during placement because of the lack of primary stability. This complication was recorded as occurring two times in one study and three times in another study.[10,16] The overall incidence was 1.3% (5 out of 383 planned implants). These implants were not counted in the implant survival since they were not successfully inserted in the first place.

Ten studies recorded the occurrence of prosthesis fracture. The incidence was 10.19% (26 out of 238 prostheses).

Five studies registered the occurrence of screw loosening. The incidence was 2.9% (23 out of 798).

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Table 6 Data of Clinical Studies on Implant Survival

Author	Year	Study design	System	Implant	Prosthetic appliance	Jaw	Guide support
Sanna et al[32]	2007	Prospective	NobelGuide	Nobel	FB	Maxilla	Mucosa + pin
Balshi et al[33]	2008	Retrospective	Nobel Guide	Nobel	FB	Both	Mucosa + pin
Johansson et al[34]	2009	Prospective	Nobel Guide	Nobel	FB	Maxilla	Mucosa + pin
Komiyama et al[14]	2008	Retrospective	Nobel Guide	Nobel	FB	Both	Mucosa + pin
Barter[35]	2010	Case series	CoDiagnostiX	Straumann	4 FPDs + 2 IOD	Maxilla	Mucosa + pin
Gillot et al[36]	2010	Retrospective	Nobel Guide	Nobel	FB	Maxilla	Mucosa + pin
Meloni et al[37]	2010	Retrospective	Nobel Guide	Nobel	FB	Maxilla	Mucosa + pin
Nikzad et al[38]	2010	Prospective	SimPlant	div.	FPDs	Mandible	Tooth
Pomares[39]	2010	Retrospective	Nobel Guide	Nobel	FB	Both Maxilla Mandible	Mucosa + pin
Van de Velde et al[40]	2010	RCT	SimPlant	Straumann	FB	Maxilla	Tooth
Landázuri-Del Barrio et al[41]	2013	Prospective	Nobel Guide	Nobel	FB	Mandible	Mucosa + pin
Abboud et al[42]	2012	Retrospective	NobelGuide	Nobel	3 FPDs + 3 FB	Both	Tooth or Mucosa + pin
			SimPlant	Ankylos	4 FPDs + 4 FB	Both	Tooth, bone, or mucosa
Di Giacomo et al[10]	2012	Prospective	Implant Viewer 1.9	E-fix	FB	Both	Mucosa + pin
Tahmaseb et al[12]	2012	Prospective	Exe-plan	Straumann	FB	Both Maxilla Mandible	Mini–implants

FB = fixed full-arch bridge; FPDs = fixed partial dentures; IOD = implant-supported overdentures; NR = not reported; div = diverse;
*cumulative survival rate.

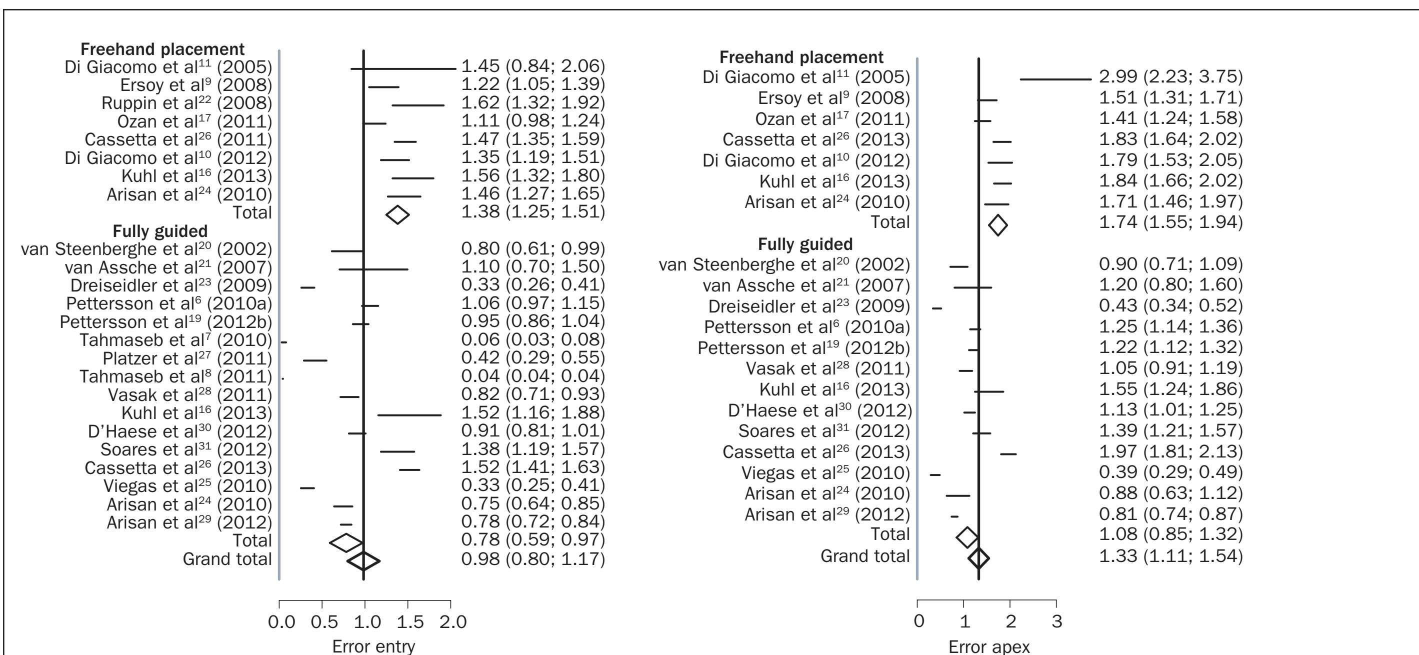

Fig 6 Forest plot illustrating mean deviation of all parameters, stratified by principle of the implant insertion (freehand placement vs guide implant placement).

Seven studies reported on the occurrence of misfit at the time of the superstructure connection. The incidence was 18.0% (34 out of 189 prostheses).

Five studies reported on the need for extensive occlusal adjustment after placement of the superstructures. The incidence was 4.6% (7 out of 153 prostheses).

DISCUSSION

This review systematically evaluated the literature regarding accuracy and clinical outcome of static computer-assisted (static) implant dentistry. The main differences between this systematic review and the

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Immediate loading	Mean age (y)	Age range	Patients (prosthesis)	Implants	Implants placed with flapless surgery	Lost to follow-up at 12 mo	Implant survival (mo)	Implants lost (n)	Implant survival (%)	Prosthesis survival (%)
Y	56	38–74	30	212	212	NI = 13	12	0	100	NR
							12–66	9	91.5*	NR
Y	NR	NR	23	168	168	NI = 122	12	4	97.6*	100
Y	72	37–85	52	312	312	NP = 4	12	2	99.4*	96.2
Y	71.5	42–90	29 (31)	176	176	NI = 45	12	19	91.5*	83.9*
N	63	54–71	6	43	43	0	60	1	97.7	NR
Y	61.2	46–80	33	211	211	NP = 1	12	2	99.1*	100
			1–32	8–204	204		12–51	4	98.1*	100
Y	52	40–70	15	90	90	0	18	2	97.8	NR
N	51.9	42–66	16	57	57	0	12	2	96.5	NR
Y	53	35–84	30 (42)	195	191	0	12	4	98.0	NR
			25	128	NR	0	12	2	98.5	NR
			17	67	NR	0	12	2	97.5	NR
Y	55.7	39–75	13	36	36	NP = 1	12	1	97.3*	NR
							18	1	97.3*	NR
Y	59	49–73	16	64	64	0	12	6	90.0	93.8
Y	60.1	56–66	6	41	41	0	12	1	97.6	100
Y	59.2	51–77	8	34	0	0	12	0	100	100
Y	60.3	41–71	12	62	60	0	30	1	98.3	91.7
Y	NR	NR	35 (40)	240	234	0	12	11	95.4	97.5
			(25)	150	144	0	12	10	93.6	96.0
			(15)	90	90	0	12	1	98.8	100

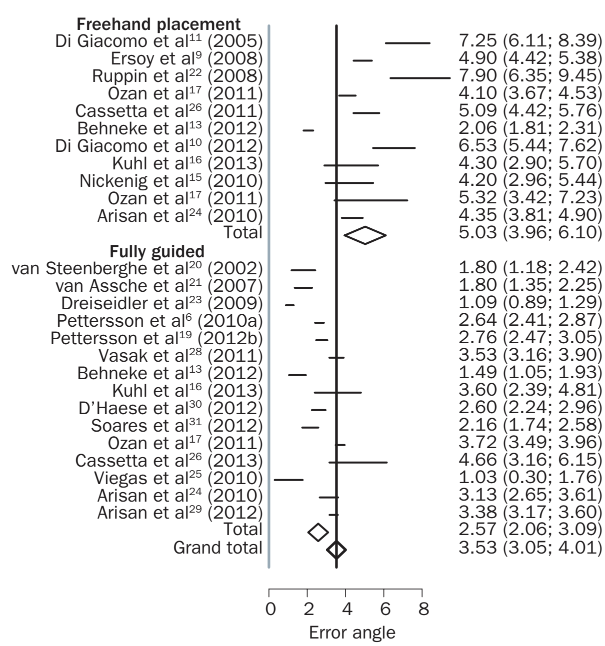

Table 7 *P* Values by Survival Parameters

Effect	*P* value
Differences in survival rate per jaw	
Mandible–maxilla	.1459
Differences in survival rate per guide support	
Mini-implants–mucosa + pin	.6717
Mini-implants–tooth	.9787
Mucosa + pin–tooth	.9142
Differences in survival rate per time of loading	
Not immediate–immediate	.7207

recent publication by Van Assche et al[43] can be summarized in the fact that in this review only the measurements based on actual implant placement were included, whereas in the European Association for Osseointegration consensus publication, the osteotomies without implant placement were also analyzed.

In addition, in this systematic review, both accuracy and survival studies were analyzed and there were slightly more accuracy studies included.

Nine different static image guidance systems were reported in the literature. Based on 14 included clinical studies with a total of 1,941 implants using static computer-assisted guided implant surgery, it was demonstrated that the mean failure rate was 2.7% (0% to 10%) after an observation period of at least 12 months. Twenty-four clinical and preclinical studies that assessed the accuracy of static implant density demonstrated the accuracy at the entry point to have a mean error of 1.12 mm, with a maximum of 4.5 mm, while at the apex the mean error was 1.39 mm, with a maximum of 7.1 mm.

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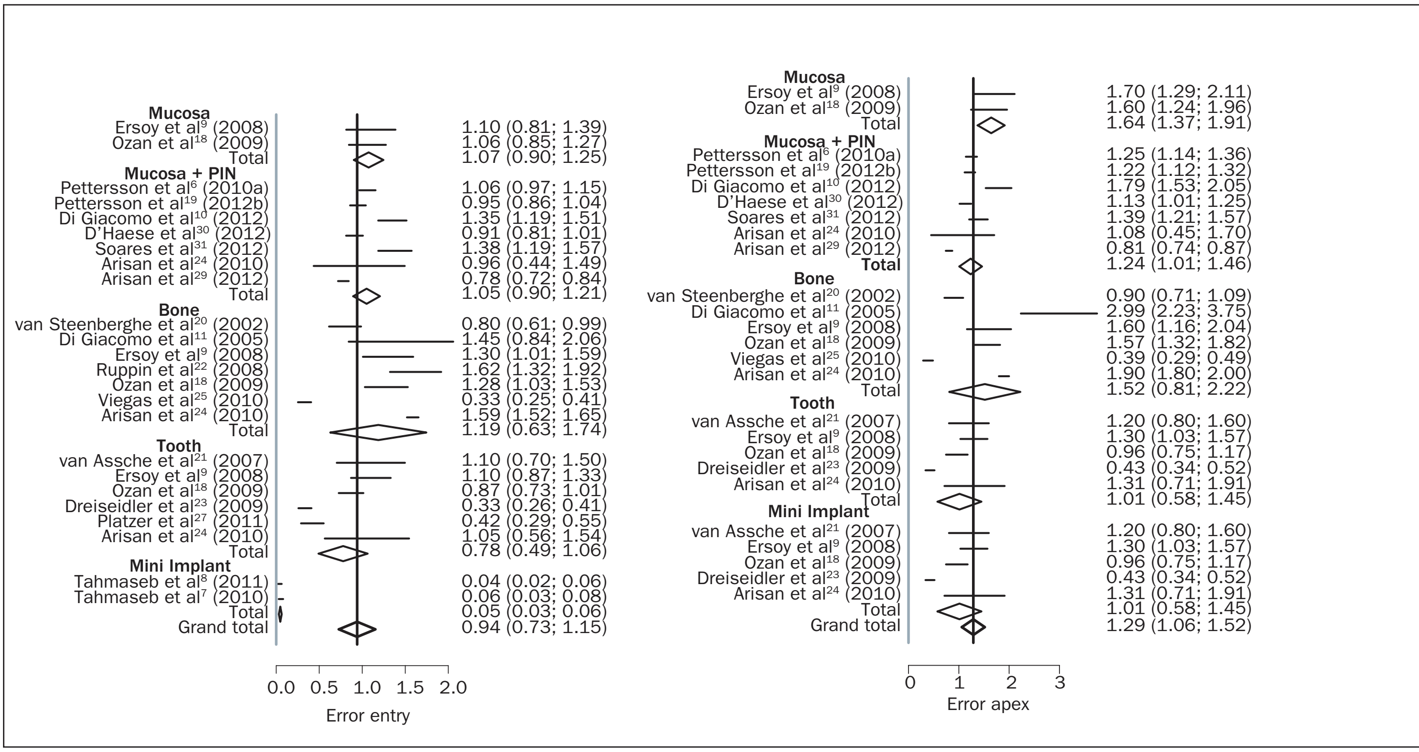

Fig 7 Forest plot illustrating statistical evaluation based on the guide support (tooth, bone, mucosa, and mucosa + pin support).

Survival Studies

This review systematically demonstrated with the limitation of the executed studies that the overall success rates of implants inserted using computer-guided surgery are comparable to implants placed following a non-guided protocol.[44,45]

However, several issues need to be considered before any significant conclusions can be drawn. For example, considerable inconsistency was observed between implants placed in the maxilla and those placed in the mandible. Pomares[39] reported more failures in the lower jaw whereas Tahmaseb et al[12] reported a higher failure rate in the upper jaw. However, different external factors, such as sinus augmentation procedures, could have influenced the results. In addition, some selected studies[14,33] suffered a substantial number of dropouts, which could have affected the survival rate considerably, as well as the different approaches used to restore the patients. Furthermore, most of the studies reported on the superstructures involving only provisional prostheses where the existing dentures were post-surgically adapted to the inserted implants postsurgical.[36,39,40] Tahmaseb et al[12] used a system in which provisional mini-implants were inserted prior to actual surgery, thus achieving a level of accuracy that allowed the fabrication of the final prosthesis.

An overall, surgical and prosthetic, complication rate of 36.4% was found for the selected studies. The incidence of surgical complications was significantly lower (35) than the prosthetic complication rate (90). However these numbers (ie, 125 complications in 343 treated cases) have to be interpreted with caution, since even minor complications, such as a loose screw in a single implant, were considered as a prosthetic complication.

Accuracy Studies

Computer-guided implant procedures have often been recommended for flapless surgery for situations with a limited bone quantity, or in critical anatomical situations (eg, an implant to be placed adjacent to mandibular nerve). Therefore, knowledge of the potential maximal implant deviations of these systems are highly relevant to daily clinical practice. The analyzed data showed an inaccuracy at the implant entry point of 1.12 mm with maximum of 4.5 mm and an inaccuracy of 1.39 mm at the apex of implants with maximum of 7.1 mm. However, the maximal measured deviations occurred in two studies[11,26] and were far from the acceptable range. The outliers might be related to external factors. For example, Di Giacomo et al[11] proposed that the differences in the deviation

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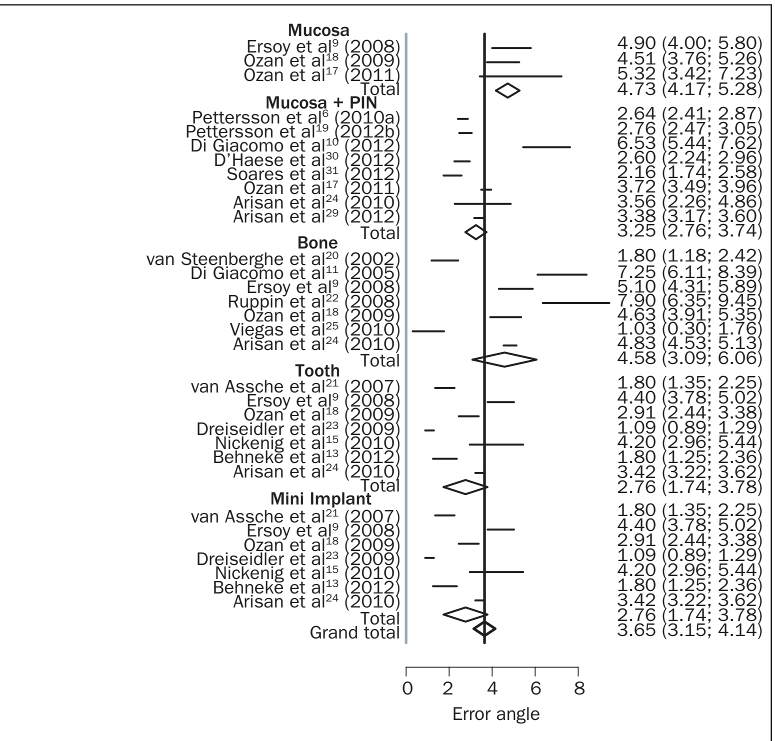

might be caused by movements of the surgical guide during implant preparation. This group suggested further improvements that could provide better stability of the template during surgery when unilateral bone-supported and non–tooth-supported templates are used. Moreover, SLA (computer-assisted manufacture [CAM]) guides had slightly better accuracy than the lab guides (non-CAM), although the number of cases was significantly lower for the non-CAM group (171 vs 1,569 implants). Furthermore, the support of guides has a significant impact on accuracy (Fig 7). Tahmaseb et al[7] showed that guides supported by mini-implants provided better accuracy than all the other types of support. This might be the result of the reproducibility of the template position during the acquisition of radiographic data and during implantation, especially in edentulous patients. This group also used a system with a vertical control device and adjustable osteotomy drills, which might have improved the precision. Moreover, for the clinical studies (Fig 8), a statistically significant lower accuracy was observed in the bone-supported guides. These results could also explain why the flapped approaches had a much lower accuracy than the flapless ones (Fig 4), as the majority of treatments where a flap was raised conducted bone-supported surgical guides.

The authors intentionally decided not to include studies that analyzed the accuracy of computer-guided surgery if they only reported the position of the osteotomy, but the actual implant was not inserted.[15,18–20,22–26,29] The reason for this exclusion is that guided drill holes after osteotomy are only an indication of the position and cannot be compared with the actual implant positions, since implants can be inserted in a deviant position. This exclusion would lead to a more meaningful comparison. Nonetheless, Table 8 shows a list of the studies assessing the accuracy based only on osteotomies.

When comparing the data for the maxilla and mandible, some publications reported no differences.[9,29] Ozan et al[17] reported significantly better accuracy in the mandible compared to the maxilla within the same study, while others[10] reported profoundly higher deviations in the maxilla as well. However, Pettersson et al[6] observed a statistically significant higher deviation in the mandible. RCTs looking to these factors individually might shed light on their impact on overall precision.

Even though implant placement with a flapless approach seems to show significantly more accuracy, one has to interpret these numbers with care. All six studies where a flap was raised reported the use of bone-supported drill guides. The inaccuracy might thus be related to the guide design rather than to the raising of a flap as such.

As demonstrated in the studies selected in this systematic review as well as recent EAO consensus publication on the same topic,[43] different factors (teeth- versus mucosa- versus implant-supported; type of guidance, etc) can play a crucial role in the overall success of these advanced techniques. Therefore, it would be of high importance to perform randomized clinical trials, analyzing the importance of one specific factor separately and the impact of their mutual interactions. Generally it can be assumed that an accumulation of series of different types of errors can occur during the entire diagnostic and operative procedure leading to larger implant deviations. Finally, because of different study designs (human versus cadaver or model, drill holes versus implants, or different evaluation methods), it is not possible to identify one system as superior or inferior to others.

CONCLUSIONS

As observed in this systematic review, nine different computer-assisted (static) guided implant systems are described in the literature. The clinical performance of these systems reveals a high implant survival rate of 97.3% after 12 months of observation in different

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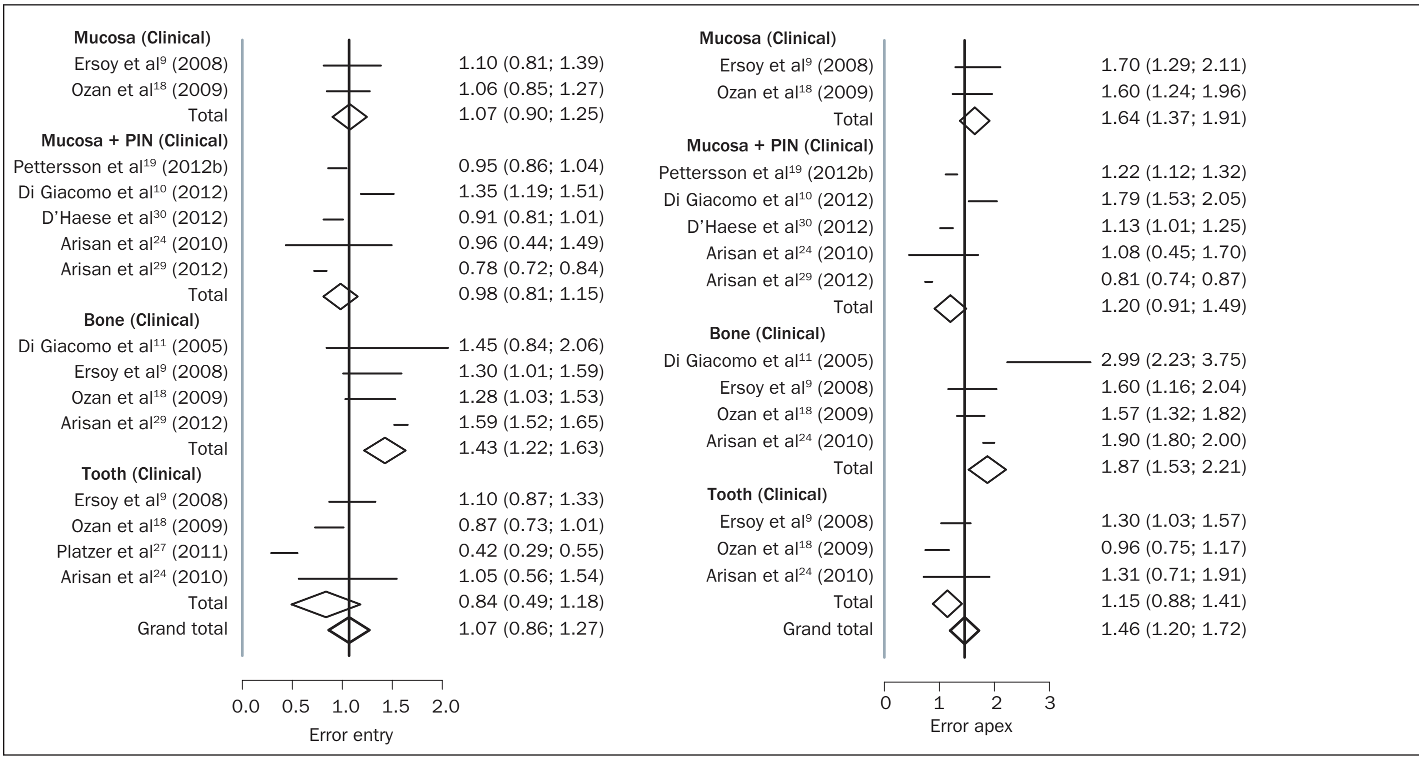

Fig 8 Forest plot illustrating statistical evaluation based on the guide support in clinical studies only (tooth, bone, mucosa, and mucosa + pin support).

Table 8 Studies Excluded Reporting Only Osteotomy Position

Author	Year	Study design	Method
Sarment et al	2003	Model	CBCT scanning of drill holes
Widmann et al	2007	Model	Distance between drill holes measured on CBCT
Widmann et al	2009	Model	CBCT scanning of drill holes
Kero et al	2010	Cadaver	Just virtual implantation; but part 1 was included[6]
Abboud et al	2011	Model	Distance between two drill holes measured on CBCT
Chan et al	2011	Model/clinical	Angular deviations of several systems compared with CBCT scans of inserted wooden sticks
Murat et al	2011	Cadaver	CBCT of cadaver with guided inserted drills
Nokar et al	2011	Model	Optical scanning of drill holes
Paris et al	2011	Cadaver	Not implants but fit of special tubes was compared

clinical situations. Furthermore, a high overall rate of surgical and prosthetic complications and unexpected events of 36.4% occurred at different levels of complexity.

The accuracy of these systems depends on all the cumulative and interactive errors involved, from dataset acquisition to the surgical procedure. The meta-analysis of the in vitro and in vivo studies revealed a total mean error of 1.12 mm at the entry point and 1.39 mm at the apex.

Furthermore, it can be stated that the tooth- and mucosa-supported guides seem to have a better accuracy compared to the bone-supported guides. A different level of evidence was stated although long-term RCTs were lacking. Long-term clinical data and randomized clinical trials are necessary to detect and understand the different factors individually and their mutual interaction influencing the accuracy of these techniques. Additionally, as it was concluded in the ITI systematic review in 2008,[5] no evidence yet suggest that computer-assisted surgery is superior to conventional procedures in terms of safety, outcomes, morbidity, or efficiency.

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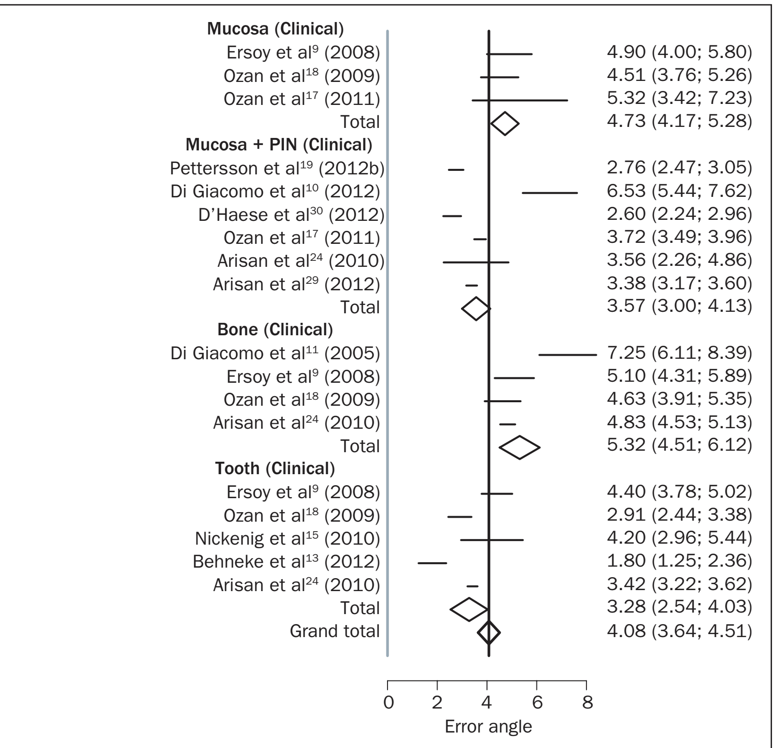

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