# Influence of clinical and technical parameters on accuracy of guided implant placement. Systematic review and meta-analysis

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KEYWORDS Dental implants; Individual static guide; Computer assisted implantation; Guided implantation; Computer aided design.

## ABSTRACT

**Aim** The aim of the present review was to assess scientific literature on influence of clinical and technical parameters of guided implantation on implant position deviations.

**Methods** Two reviewers conducted electronic searches on Cochrane and PubMed databases and manual search in databases of relevant scientific journals. The date range was limited to from 2009 through 2019.

**Results** In total 36 publications were included for review and subgroup analysis. Meta-analysis revealed mean deviation of 1.14 mm (95% CI: 1.016, 1.268, SE: 0.064) at implant neck, 1.42 mm (95% CI: 1.275, 1.575, SE: 0.072) at implant apex as well as 0.415 mm (95% CI: 0.317, 0.514, SE: 0.096) of mean vertical error and 3.49° (95% CI: 3.228, 3.756, SE: 0.135) of mean angular error. Significantly lower deviations in one or more measurement points were determined in subgroups of partial edentulism, single implantation per guide, mechanical vertical control, mounted drill design and teeth-supported guides.

**Conclusion** With respect to limitations of the study, it can be concluded that type of edentulism, size of defect, type of vertical control, guide design and type of guide support influence accuracy of computer-assisted guided implantation. Future research should focus on analyzing the advantages of technical parameters of individual static guides in distinct clinical subgroups.

## INTRODUCTION

The importance of proper implant position in order to achieve best clinical and prosthetic results has been highlighted by numerous studies (1-4). The concept of prosthetically driven implantation underlines the importance of proper implant position in accordance to future prosthesis and occlusion. However, this often stands in compromise with anatomical setting of hard and soft tissues. Compromised clinical cases are critically sensitive to surgical errors (5, 6). Individual static dental implantation guide systems have been proposed to professionals as a solution for attaining the ideal implant position and preventing surgical complications. However, the reports on accuracy of individual static guides and influencing factors remain inconclusive. Deviations of guided implantation are of cumulative origin. The errors in the stages of patient assessment, virtual implant positioning, guide planning and manufacturing, surgical execution and post-operative assessment influence affect the overall deviations of implant position (7 - 12). To date there have been several systematic reviews evaluating sets of factors on their influence on implant deviations (3, 13-18). The clinical information from studies has only been increasing since then, thus, up to date reviews are needed.

Recent reviews have shown that operated jaw, flap approach, guide support might have influence on accuracy of guided surgery (16-18). These findings suggest that guided surgery might be more accurate in particular clinical circumstances. Clinical cases of guided implantation vary in size, location, and class of edentulous defect and are exposed to different anatomical and physiological obstacles that can compromise the surgical execution and affect the implant positioning.

Secondly, the differences of technical parameters of guided implantation such as: type of guide support, status of fixation, design of sleeve, type of vertical control and guiding type are a set of possible sources of errors. Reported differences in accuracy using different guiding systems lead the authors to consider the possibility of technical elements of guide systems to influence the accuracy of guided implantation (19). Preclinical studies showed influence of guide sleeve

  

tolerance on accuracy (20, 21) but no systematic reviews comparing sleeve design, vertical controls have been conducted. These technical differences are comparable and can be chosen by the clinician. Thus, identification of differences in accuracy according to technical parameters could facilitate the selection of guide type for practitioners.
The aim of this review is to assess the most recent literature on the influence of clinical and technical factors on accuracy of individual static guided implantation.

## MATERIALS AND METHODS

Protocol and registration. The methods of analysis and inclusion criteria were specified in advance and documented in the protocol. The review was registered in PROSPERO, an international prospective register of systematic reviews. Provided unique protocol number is: CRD42020159681 (22).
The reporting of this systematic review corresponded with Preferred Reporting Item for Systematic Reviews and Meta-analysis (PRISMA) statement (23).

### PICO question

To find clinically relevant evidence in scientific literature authors defined clinical question using the PICO model. The question of focus was as follows: How do the patient's clinical factors and guide's technical parameters influence the accuracy of static fully computer guided implant placement in partially or fully edentulous patients?
Specific parts of the model are as follows: P, partially of fully edentulous patients; I, dental implantation using individual static guides; C, patient's clinical parameters - guide's technical parameters; O, accuracy of implant position.

### Information sources

The search of studies was conducted in the National library of medicine electronic database (MEDLINE) through its electronic search engine, PubMed and Cochrane central register of controlled trials (CENTRAL). Additionally, manual search using a simplified keyword key was conducted in electronic databases of following scientific journals: Clinical Oral Implant Research (COIR), Implant dentistry, Clinical Implant Dentistry and Related Research (CIDRR), International Journal of Oral & Maxillofacial Surgery (IJOMS), Journal of Periodontology.

### Search

The following search strategy was carried out for PubMed database: (((dental OR oral OR tooth OR mandible OR maxilla)) AND (implant OR implants OR implantation OR implantology)) AND (guide OR guided OR computer OR CADCAM OR CAD OR CAM OR cad-cam OR cad cam OR computer aided OR computer assisted OR computer-aided OR computer-assisted OR stent OR 3D printed).
The chosen strategy was broader than in previous reviews to avoid leaving out the publications beyond narrower strategies.
Final search was carried out on 30th of December 2019. Previous ITI Consensus publications included clinical trials from 1966 through 2008. Low number of *in vivo* trials and varying degrees of inaccuracies lead to limiting this search from 2009.

### Study selection

Types of publications: The review included randomized clinical trials, prospective and retrospective observational studies published in English or German language between 1st of January 2009 and 1st of September 2019.
Types of studies:. Firstly, evaluation of study names and abstracts were evaluated. Studies were included for the full text read if satisfied the following inclusion criteria: clinical, *in vivo* trials related to dental implantation using individual static guides that were published during set date range and provided measurements of implant accuracy.
Selected articles were further evaluated and included or excluded to review and meta-analysis according to the following criteria: clinical trials published since 2009 with a sample size of at least 10 patients and primary objective of the study being accuracy of guided implantation useing either computed tomography (CT) or cone-beam computed tomography (CBCT) and corresponding software for treatment planning and accuracy evaluation. Studies were selected if they provided necessary description of accuracy measurements and descriptions of guiding systems used and technical parameters.
Studies were excluded if trials were conducted on cadavers, animals or anatomical models, used dynamic guides or laboratory stents, zygomatic, pterygoid or orthodontic implants, as well as studies that did not provide accurate descriptions of measurements, or where accuracy measurements were conducted without the actual implantation or in type 1 and 2 (immediate and early) implantations. Intraoperative factors that can lead to implant position deviations can be divided into clinical and technical factors. Dental arch (ipper or lower), type of edentulism, location, type and size of defect, and type of surgery are considered clinical factors; type of guide support, status of guide fixation, sleeve design, type of vertical control are technical factors.

### Data collection process

Two reviewers (DK and ES) independently extracted data from included studies; differences where resolved via discussion and consensus; a senior reviewer (RK) reviewed included studies for final confirmation.

The following authors of the articles were contacted via e-mail in case of incomplete or unclear data: Derksen (46), Komiyama (28), Zhou (38), Vieira (60), Schnutenhaus (29), Lee (67), Arisan (45), Schneider (8), Vasak (32), Vercruyssen (22), Smitkarn (39), Verhamme (57), Testori (65) and Cassetta (36).

A standardized table, according to Tahmaseb et al. (19) was used for data collection. Extracted data were as follows: patient number, age, gender, guide system, planning software, flap approach, number of implants, number of implants per guide, type of edentulism, occlusal location of implantation, guiding type, type of support, sleeve design, type of vertical control. The data was further divided into sets clinical and technical factors that included listed subgroups. Clinical factor set included subgroups of open vs flapless surgery, maxilla vs mandible, full vs partial edentulism, Kennedy III or IV (interdental) vs Kennedy I or II (free-end) classes of defect, anterior vs posterior defect location and single vs multiple defects. Sets of technical subgroups are as follows: teeth vs mucosa vs bone guide support; fixed vs non-fixed guide; fully vs half vs pilot drill guide; laser mark stopper vs mounted stopper; drill key vs double sleeve vs mounted drill sleeve system; guided vs freehand implant insertion.

### Risk of bias among studies assessment

The Newcastle–Ottawa Scale (NOS) adapted by Chambrone et al. was used to assess the risk of bias in the prospective and retrospective included studies (24, 25). The recommendations for systematic reviews of the interventions of the Cochrane collaboration (Higgins & Green, 2011) were performed to evaluate the risk of bias of the RCT included (26).

### Accuracy measurement points

The following implant deviation parameters were evaluated.

- 3D deviation at entry point.
- 3D deviation at implant apex.
- 3D depth deviation, measured at implant neck.
- Angular deviation of implant vertical axis.

The deviations between planned and actual implant position must have been evaluated using preoperative and postoperative CT data. The deviations of positional differences were provided in millimetric scale and angular deviations in degrees of arc. Entry point and apical deviations were measured by deriving the line in 3D space between central points of implant at neck and apex. This distance was considered global deviation. Depth deviations were determined evaluating the most apical point of implant neck. It was considered as positive value error if the implant was inserted deeper than planned and negative value error if it was not inserted deep enough.

Angular deviation was determined by measuring the degree between intersected axial lines of implants. The axial lines were derived through apical and coronal central points of implants. If the publications presented the linear measurements of mesiodistal, apicocoronal and buccolingual planes, global deviations were calculated using the standardized formula displayed below. The measurements were conducted twice. If the results of the two measurements did not match, mistakes and repeated calculations were conducted until matching results were obtained consecutively.

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

- 3Ddev= Global deviation.
- x = Mesiodistal plane deviation.
- y = Buccolingual plane deviation.
- z = Apicocoronal plane deviation.

SDcomb

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

- SDcomb = Global stadand deviation.
- N = sample size.
- SD(x, y, z) = Stadard deviation in x, y, z planes.

### Statistical analysis

Meta-analysis was conducted using Comprehensive Meta Analysis (CMA software. Version 3.0. Englewood, JAV, Biostat, 2020). Heterogeneity between studies (84) was evaluated using Cochrane's Q and $I^2$ tests. Values of $I^2$ test were interpreted according to Higgins et al. (respectively: >25% = low heterogeneity, >50% = medium heterogeneity, >75% = high heterogeneity). Separate subgroup analyses were made for angular, global apical, global entry and depth deviations and each subgroup of listed factors. Due to high heterogeneity between selected studies inverse variance weighted random effects model was used.

## RESULTS

### Systematic evaluation of studies

A total of 3497 publications were identified through electronic and manual database search. After exclusion of studies based on their titles and abstracts, 81 full text articles were read by two reviewers. Finally, 36 publications that met the inclusion criteria were included into review and meta-analysis (27-60) (Fig. 1).

### Study characteristics

Risk of bias assessment values ranged between 5 and 8 points for observational studies. None of the publications had a high risk of bias. All included RCT's reported unclear risk of bias for one or more domains. Evaluations are summarized in tables 1 and 2.

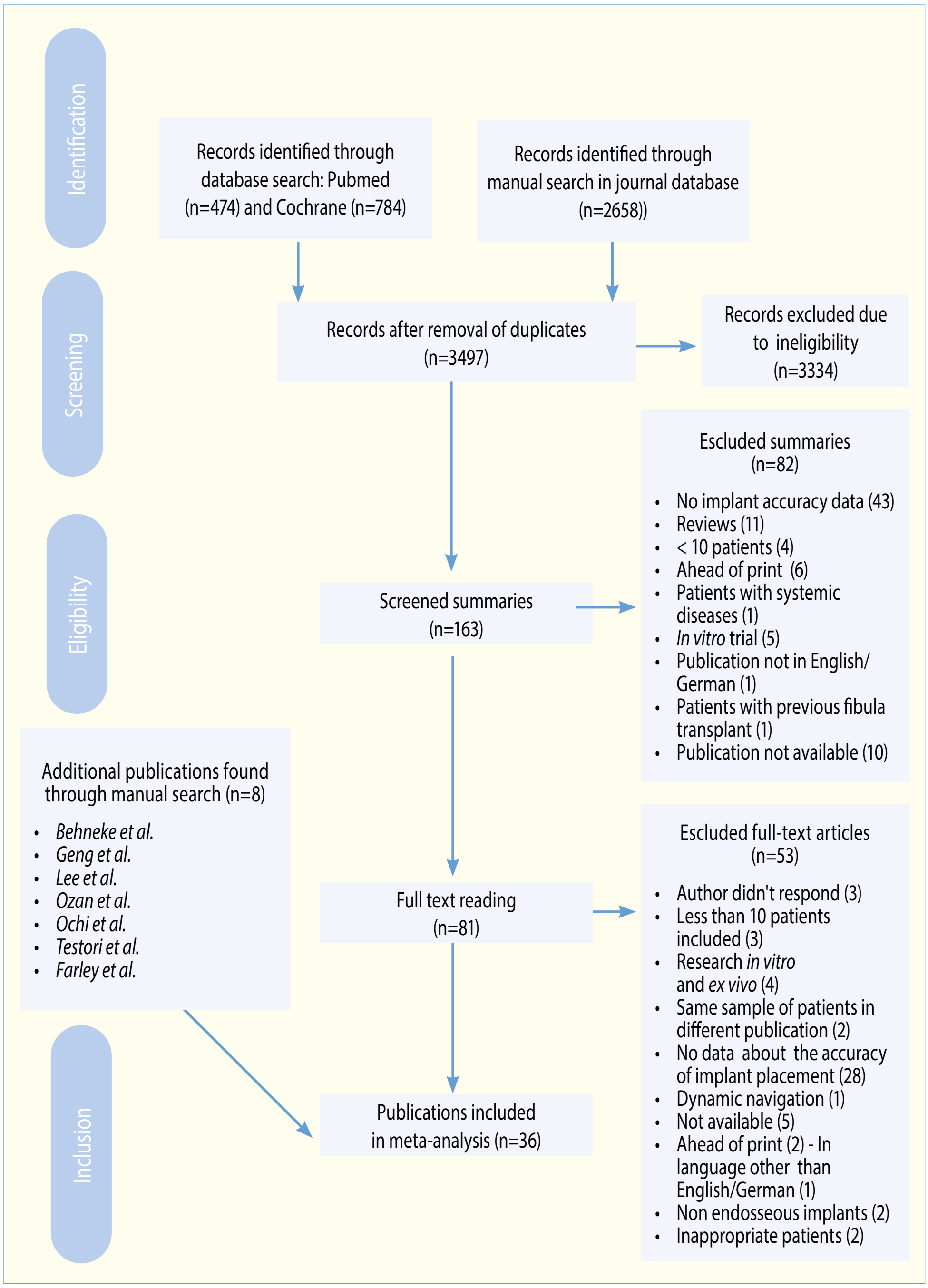


FIG. 1 Prisma flowchart.

Distribution of studies that provided data on particular subgroup analysis are displayed in table 3.
Authors names, year of publication, sample sizes, guide systems, implant systems, sample characteristics, implant deviations (mean with standard deviations) and other features of the included studies are presented in table 4.
Included articles provided results from more than 991 patients, though Cassetta et al. (43) and Testori et al. (57) did not provide data on the number of patients, and 3723 implants. The gender distribution among patients was ~ 45% for men and ~ 55% for women. Information on patient gender was not provided by Schneider (28), Smitkarn (32), Pettersson (35), Cassetta (45), Vieira (53), Testori (57), Farley (58). Patients' age ranged from 21 to 92 years, with a mean age being 55 years. In total 38 different planning softwares were used in 36 publications: Simplant® (14/38), Procera Clinical Design® (5/38), CoDiagnostiX® (4/38), 3Diagnosys® (2/38), SMOP (2/38), R2Gate (2/38), Aytasarim (2/38 ImplantViewer 1.9 (1/38), Mimics 9.0 (1/38), med3D (1/38), Implant Master (1/38), OnDemand3D (1/38), Rhinoceros 4.0 (1/38), Dental Slice (1/38). Various implant systems were used: Nobel Biocare (9), Straumann (7), P1H (4), Astra Tech AB (5), Dentsply Sirona (2), Osstem (2), Megagen (2), Thommen (2), Biomet 3i (2), Impladent (1), Ankylos (1), E-fix (1), Zimmer (1), Dentium (1).

| | | Selection | | | | | Comparability | | Outcomes | Statistical nalysis | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Study design | Sample size | Representativeness of patients | Selection of patients | Description surgical protocol | Demonstration that outcome of interest was not present at start of study | Patient groups (study design) | Confounders | Evaluation of results | Appropriate statistical analysis | Total |
| Tallarico 2018 | Prospective | ★ | ★ | | ★ | ★ | ★ | | ★ | ★ | 7/9 |
| Di Giacomo 2012 | Prospective | ★ | ★ | ★ | ★ | | ★ | | | ★ | 6/9 |
| Cristache 2017 | Prospective | ★ | ★ | | ★ | ★ | ★ | ★ | | ★ | 7/9 |
| Derksen 2019 | Prospective | ★ | ★ | ★ | ★ | | ★ | ★ | | ★ | 7/9 |
| Skjerven 2019 | Prospective | ★ | ★ | | ★ | | ★ | ★ | | ★ | 6/9 |
| Sun 2013 | Retrospective | ★ | ★ | | ★ | ★ | ★ | ★ | | ★ | 7/9 |
| Behneke 2011 | Prospective | ★ | ★ | | ★ | | | ★ | | ★ | 5/9 |
| Lee 2016 | Prospective | ★ | ★ | ★ | ★ | | ★ | | | ★ | 6/9 |
| Ochi 2013 | Prospective | ★ | ★ | | ★ | ★ | ★ | | | ★ | 6/9 |
| Testori 2014 | Prospective | ★ | ★ | ★ | ★ | | ★ | | | ★ | 6/9 |
| Farley 2013 | Prospective | ★ | ★ | ★ | ★ | | | | | ★ | 5/9 |
| Arisan 2010/2012 | Prospective | ★ | ★ | ★ | ★ | | ★ | | | ★ | 6/9 |
| Cassetta 2013a/b | Retrospective | ★ | ★ | ★ | ★ | | ★ | | | ★ | 6/9 |
| Cassetta 2011a/b | Retrospective | ★ | ★ | ★ | ★ | | ★ | | | ★ | 6/9 |
| D'haese 2012 | Prospective | ★ | ★ | ★ | ★ | | ★ | | | ★ | 6/9 |
| Fürhauser 2015 | Retrospective | ★ | ★ | ★ | ★ | | ★ | | | ★ | 6/9 |
| Geng 2015 | Prospective | ★ | ★ | ★ | ★ | | ★ | | | ★ | 6/9 |
| Lee 2013 | Retrospective | ★ | ★ | ★ | ★ | | ★ | | | ★ | 6/9 |
| Ozan 2009 | Retrospective | ★ | ★ | ★ | ★ | | ★ | | | ★ | 5/9 |
| Pettersson 2012 | Prospective | ★ | ★ | ★ | ★ | | ★ | | | ★ | 6/9 |
| Schnutenhaus 2016 | Retrospective | ★ | ★ | | ★ | | ★ | | | ★ | 5/9 |
| Stübinger 2014 | Prospective | ★ | ★ | ★ | ★ | | ★ | | | ★ | 6/9 |
| Van de Wiele 2015 | Prospective | ★ | ★ | ★ | ★ | | ★ | | | ★ | 6/9 |
| Vasak 2011 | Prospective | ★ | ★ | ★ | ★ | | ★ | | | ★ | 6/9 |
| Verhamme 2014 | Prospective | ★ | ★ | ★ | ★ | | | | | ★ | 5/9 |
| Verhamme 2015 | Prospective | ★ | ★ | ★ | ★ | | ★ | | | ★ | 6/9 |
| Vieira 2013 | Retrospective | ★ | ★ | ★ | ★ | ★ | ★ | | | ★ | 7/9 |

Risk of bias in individual studies (Newcastle-Ottawa Scale (NOS) adapted by Chambrone et al. 2010, 2015)

- Low risk of bias: Plausible bias unlikely to seriously alter the results
- Unclear risk of bias: Plausible bias that raises some doubt about the results
- High risk of bias: Plausible bias that seriously weakens confidence in the results

TABLE 1 **Risk of bias of observational studies by Newcastle-Ottawa.**

| Study | Random sequence gen. | Aloc. con-cealmeant | Blinding of partic. / personnel | Blinding of outcome assessment | Incomplete outcome data | Selective report. | Overall |
|---|---|---|---|---|---|---|---|
| Vercruyssen et al. 2014 | + | ? | ? | + | + | + | ? |
| Younes et al. 2018 | + | + | ? | ? | + | + | ? |
| Schneider et al. 2018 | + | ? | ? | ? | + | + | ? |
| Cassetta et al. 2017 | + | + | + | ? | + | + | ? |
| Vercruyssen et al. 2015 | + | ? | ? | ? | + | + | ? |
| Smitkarn et al. 2019 | + | ? | ? | ? | + | + | ? |
| Kaewsiri et al. 2019 | + | ? | ? | ? | + | + | ? |

+ - low risk of bias ? – unclear risk of bias

TABLE 2 Risk of bias assessment of included RCTs

### 3D deviation at entry point

Of the 36 works, 35 reported deviation at the entry point. In total entry deviations of 3484 implants were included. Total mean deviation at the entry point was 1.14 mm (95% CI range: 1.016, 1.268, SE: 0.064) (Fig. 2). The mean deviation at implant neck deviation between studies ranged from 0.27 mm (95% CI: 0.225, 0.315, SE: 0.023) (58) to 2.97 mm (95% CI: 2.813, 3.127, SE: 0.08) (26). Highest reported deviation at implant neck was 7.815 mm (27). Results were heterogeneous ($I^2$ = 99.58, p <0.01).
Subgroup analysis of clinical factors revealed the following results:

- deviations of guided implantation in the open gap area (Kennedy Class I or II) vs. closed gap area (Kennedy Class III or IV) 0.959 mm±0.181 vs. 0.928 mm±0.117, I2: 91.2;
- posterior segment of the mouth vs. anterior segment 1.054 mm±0.207 vs. 0.970 mm±0.198, I2: 93.5;
- mandible vs. maxilla 1.065 mm±0.122 vs. 1.017 mm±0.092, I2: 96.8;
- fully edentulous jaws vs. partially edentulous jaws 1.112 mm±0.115 vs. 0.806 mm±0.139, I2: 99.1;
- open-flap vs. flapless 1.076 mm±0.194 vs. 1.026 mm±0.113; I2, 98.9;
- multiple implantation per guide vs. single 1.132 mm±0.069 vs. 1.017 mm±0.140, I2: 94.9.

None of the results were statistically significant.
Subgroup analysis of technical factors of surgical guides revealed the following results:

- mounted stoppers vs. visual vertical control 1.030 mm±0.097 vs. 1.365 mm±0.357; I2: 98.89;
- fixed vs. non-fixed 1.092 mm±0.146 vs. 1.127 mm±0.135; I2: 98.81;

| Group | Subgroup | Number of studies by subgroup | Number of included studies to subgroup analysis |
|---|---|---|---|
| Location of defect | Anterior | 0 | 6 |
| | Posterior | 1 | |
| | Both | 5 (5)* | |
| | Not given | 30 | |
| Jaw | Mandible | 1 | 19 |
| | Maxilla | 6 | |
| | Both | 23 (12)* | |
| | Not given | 6 | |
| Edentulism | Full | 16 | 27 |
| | Partial | 11 | |
| | Both | 9 (0)* | |
| | Not given | 0 | |
| Flap approach | Open flap | 3 | 30 |
| | Flapless | 16 | |
| | Both | 15 (11)* | |
| | Not given | 2 | |
| Type of defect | Interdental | 4 | 6 |
| | Free-end | 0 | |
| | Both | 2 (2)* | |
| | Not given | 30 | |
| Sleeve design | Double sleeve | 1 | 32 |
| | Drill key | 17 | |
| | Mounted drill | 12 | |
| | Multiple | 4 (2)* | |
| | Not given | 2 | |
| Guide support | Mucosa | 13 | 32 |
| | Bone | 1 | |
| | Teeth | 11 | |
| | Multiple | 11 (7)* | |
| | Not given | 0 | |
| Vertical control | Mounted drill | 28 | 32 |
| | Laser marking | 2 | |
| | Both | (2)* | |
| | Not given | 2 | |
| Implant placement | Guided | 26 | 34 |
| | Free-hand | 2 | |
| | Both | 6 (6)* | |
| | Not given | 2 | |
| Size of defect | Single | 4 | 25 |
| | Multiple | 19 | |
| | Both | 4 (2)* | |
| | Not given | 9 | |
| Guiding type | Full | 24 | 34 |
| | Half | 2 | |
| | Pilot drill | 0 | |
| | Multiple | 8 (8) * | |
| | Not given | 2 | |

** - studies that reported detailed information on separate subgroup*

TABLE 3 Overall results of individual studies included to subgroup analyses.

| Nr. | Authors (doi) | Year | N | Study Design | Software | Edentulism (P/F) | Jaw (Mx/Md) | Guiding type | Number of implants per guide (single/multiple) | Guide support | Guide/Implant system | Depth control | Guiding Concept |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Vasak et al. (10.1111/j.1600-0501.2010.02070.x) | 2011 | 85 | OS, prospective | Procera (Nobel Biocare) | B (6/12) | B (11/7) | FG | N.G | M or T+M+P | NobelGuide | MDS | MD |
| 2 | Vercruyssen et al. (10.1111/jcpe.12231) | 2014 | 311 | RCT | Simplant | F (72) | B (6/6) | HG | Multiple | M+P | MaterialiseMucosa + AstratechOsseospeed | LM | DK |
| | | | | | | | B (9/3) | HG | | B+P | MaterialiseBone + AStratech Osseospeed | LM | DK |
| | | | | | | | B (7/5) | FG | | M+P | FacilitateMucosa + AstratechOsseospeed | MDS | MD |
| | | | | | | | B (6/6) | FG | | B+P | FacilitateBone + AstratechOsseospeed | MDS | MD |
| | | | | | | | B (3/9) | FH | | - | | - | - |
| | | | | | | | B (8/4) | PDG | | M | LaboratoryStent + Astratech Osseospeed | - | - |
| 3 | Younes et al. (10.1111/clr.13399) | 2019 | 71 | RCT | Simplant | P (32) | Mx (32) | FH | Multiple | - | Dentsply Sirona Implants | - | - |
| | | | | | | | | PDG | | T | Simplant, Pilot drill guide | MDS | - |
| | | | | | | | | FG | | T | Simplant SAFE guide | LM | DK |
| 4 | Tallarico et al. (10.1111/cid.12704) | 2018 | 119 | OS, prospective | Center 1 - 3Diagnosys Center 2 -3Shape | P (119) | B (65/54) | FG | Multiple | T+P | Osstem | MDS | DK |
| 5 | Schneider et al. (10.11607/prd.4147) | 2018 | 47 | RCT | C: - | P (73) | - | FH | Multiple | - | - | - | - |
| | | | | | T1: Simplant | | | FG | | T | Dentsply guide + Dentsply/Straumann | - | DK |
| | | | | | T2: SMOP, SwissMeda | | | FG | | T | Objet Eden guide + Denstyply+Straumann | - | - |
| 6 | Cassetta et al. (10.1016/j.ijom.2017.03.010.) | 2017 | 70 | RCT | 3Diagnosys; 3Diemme | F (10) | - | FG | | M+P | RealGUIDE (3Diemme) + Sharp Implant, ImplaDent | MDS | DK |
| 7 | Vercruyssen et al. (10.1111/clr.12583) | 2015 | 90 | RCT | Simplant | F (15) | Mx (15) | FG | | M+P | ExpertEase (Simplant) + Ankylos | MDS | DK |
| 8 | Di Giacomo (10.1902/jop.2011.110115) | 2012 | 60 | OS, prospective | ImplantViewer 1.9, Anne Solutions, Sa˜o Paulo, Brazil | F(12) | Mx (22) Md (38) | HG | Multiple | M+P | E-Fix, AS Technology | LM | DK |
| 9 | Smitkarn et al. (10.1111/jcpe.13160) | 2019 | 60 | RCT | coDiagnostiX® | P (52) | Mx (39) Md (21) | FH (30) FG (30) | SIngle | T | Straumann | MDS | DK |
| 10 | Cristache et al. (10.1155/2017/4292081) | 2017 | 65 | OS, prospective | R2GATE | P (25) | Mx (32) Md (33) | FG | Multiple | T | Clear Guide M + Megagen Anyridge | MDS | MD |
| 11 | Kaewsiri et al. (10.1111/clr.13435) | 2019 | 60 | RCT | coDiagnostiX® | P (60) | Mx (37) Md (23) | FG | SIngle | T | VisiJet MP200 + Straumann | MDS | DK |
| 12 | Pettersson et al. (10.1111/j.1708-8208.2010.00285.x) | 2012 | 139 | OS, prospective | Procera | F (25 jaws) | Mx(15) Md (10) | FG | Multiple | M+P | Nobel Biocare | MDS | MD |
| 13 | D'haese et al. (10.1111/j.1708-8208.2009.00255.x) | 2012 | 78 | OS, prospective | Mimics 9.0, Materialise N.V | F (13 patients) | Mx (78) | FG | Multiple | M+P | Osseospeed (Astratech) implants | MDS | DK |
| 14 | Fürhauser et al. (10.1111/cid.12264) | 2014 | 27 | OS, retrospective | NobelClinician™ | P (27 patients) | Mx (27) | FG | Single | T | Nobel Biocare | MDS | MD |
| 15 | Arisan et al. (10.1111/j.1708-8208.2011.00435.x) | 2012 | 108 | OS, prospective | Simplant | F (11 patients, 18 jaws) | Mx (64) Md (44) | FG | Multiple | M+P | Simplant SAFEguide + Thommen implants | MDS | DS |
| 16 | Derksen et al. (10.1111/clr.13514) | 2019 | 146 | OS, prospective | coDIagnostix | P | Mx (66) Md (79) | FG | Multiple | T | Straumann | MDS | DK |
| 17 | Van de Wiele et al. (10.1111/clr.12494) | 2014 | 75 | OS, prospective | SImplant | F (17) | B | FG | Multiple | M+P | Simplant SAFEguide + Osseospeed (Astratech) | MDS | DK |
| 18 | Skjerven et al. (10.1111/clr.13438) | 2019 | 28 | OS, prospective | coDIagnostix | P | Mx (15) Md (13) | FG | - | T | Straumann | MDS | DK |
| 19 | Arisan et al. (10.1902/jop.2009.090348) | 2010 | 294 | OS, prospective | Aytarim | B | N.G. | HG | - | B, T, M+P | Aytasarim + Catia, Dassault Systems | - | DK |
| | | | | | Simplant | | | FG | | T, M+P | Simplant | | DS |
| | | | | | Simplant | | | HG | | B | Simplant | | DS |
| 20 | Cassetta et al. (10.1016/j.ijom.2011.09.009) | 2011b | 111 | OS, retrospective | Simplant | B | Mx(68) Md(43) | FG | | M(85) B(18) T(8) | Materialise + P1H implants | MDS | DK |

TABLE 4 Data extraction from individual studies.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | Cassetta et al. (10.1016/j. ijom.2012.06.010) | 2013a | 129 | OS, retrospective | Simplant | F (112impl) P (17) | Mx(78) Md(51) | FG | | M(103) B(18) T(8) | Materialise + P1H implants | MDS | DK |
| 22 | Cassetta et al. (10.1111/ cid.12120) | 2013b | 137 | OS, retrospective | Simplant | F (137impl) | Mx(40) Md(26) Mx (48) Md(23) | FG | Multiple | M+P | Materialise | MDS | DK |
| 23 | Stübinger et al. (10.1111/ cid.12019) | 2012 | 44 | OS, prospective | FacilitateTM | F (44 impl) | | FG | Multiple | B+P | Osseospeed | MDS | MD |
| 24 | Cassetta et al. (10.1111/j.1708-8208.2011.00369.x) | 2011a | 227 | OS, retrospective | Simplant | B | Mx (135) Md (92) | HG<br>FG<br>FG | Multiple | T<br>M+P<br>B | SAFEguide/Materialise + P1H implants | MDS | DK |
| 25 | Sun et al. (10.1111/cid.12189) | 2013 | 80 | OS, retrospective | Procera | F | Mx (10 jaws) Md (8 jaws) | FG | Multiple | M+P | NobelBiocare | MDS | MD |
| 26 | Verhamme et al. (10.1111/ cid.12112) | 2013 | 104 | OS, prospective | Procera | F | Mx (30 jaws) | FG | Multiple | M, M+P | NobelGuide + Branemark Groovy (NobelBiocare) | MDS | MD |
| 27 | Verhamme et al. (10.1111/ cid.12230) | 2014 | 150 | OS, prospective | Clinical Design® software (Nobel Biocare®) | F | Mx (25 jaws) | FG | Multiple | M, M+P | NobelGuide + Branemark Groovy (NobelBiocare) | MDS | MD |
| 28 | Behneke et al. (10.1111/j.1600-0501.2011.02176.x) | 2011 | 132 | OS, prospective | 3D (med3D GmbH) | P | Mx (87) Md (45) | FG, HG, PDG | Both | T | Stramann/Nobel Replace | MDS | N.G |
| 29 | Geng et al. (PMID: 26309497) | 2015 | 111 | OS, prospective | SImplant | B | Mx (69 ) Md (42) | HG, FG | Both | M, T | Straumann | MDS | DK |
| 30 | Lee et al. (10.4047/ jap.2016.8.3.207) | 2016 | 21 | OS, prospective | R2GATE | P | Mx (9) Md (12) | FG | N.G. | T | Megagen AnyOne | MDS | MD |
| 31 | Vieira et al. (10.11607/ jomi.3156) | 2013 | 62 | OS, retrospective | Dental Slice, Biopars | F | N.G. | FG/HG | multiple | M+P | NobelGuide | MDS | MD |
| 32 | Ozan et al. (10.1016/j. joms.2008.09.033.) | 2009 | 110 | OS, retrospective | 3D-software (Rhinoceros 4.0, McNeel Ins) | B | Mx (58) Md (52) | HG | Both | T, B, M | Ay-Tasarim, Kos-gep + SwissPlus, Zimmer | LM | N.G. |
| 33 | Lee et al. (10.4047/ jap.2013.5.4.440) | 2013 | 102 | OS, retrospective | OnDemand3D; Cybermed Co. | B | Mx (62) Md (40) | N. G. | N. G. | T, M+P | Osstem, Superline (Dentium), Branemark MKIII Groovy (Nobel Biocare) | MDS | MD |
| 34 | Ochi et al. (10.1016/j. compbiomed.2013.07.029) | 2013 | 30 | OS, prospective | Procera | F | Mandible | FG | Multiple | M+P | Nobel Speedy Groovy | MDS | MD |
| 35 | Testori et al. (10.11607/ prd.1279) | 2014 | 118 | OS, prospective | Simplant | B | N.G | FG | N.G. | T, B, M | Navigator System, Biomet 3i | MDS | MD |
| 36 | Farley et al. (10.11607/ jomi.3025) | 2013 | 20 | OS, prospective | Implant Master | P | B | FG | Single | T | Biomet 3I Osseotite Certain | LM | DK |

**: B – both; F – fully; P – partially; N.G. – Not given; †: Mx – Maxilla; Md – Mandible; ‡: FG – Fully guided; HG – Half guided; PDG - Pilot drill guided; §: M – Mucosa; T – Teeth; B – Bone; P – Pins; ||: MDS – Mounted drill stopper, LM – laser marking; ¶: DK – drill key, MD – mounted drill, DS – double sleeve; **: RCT – Randomizedcontrolled trial; OS – Observational Study.*

TABLE 4 Data extraction from individual studies.

- guided implant placement vs. free-hand 0.978 mm±0.051 vs. 1.274 mm±0.101; I2: 96.95; p=0.009;
- fully guided vs. half-guided vs. pilot drill guides 1.009 mm±0.090 vs. 1.169 mm±0.183 vs. 1.501 mm±0.423; I2: 96.57;
- teeth supported vs. bone-supported vs. mucosa supported highest 0.877 mm±0.126 vs. 1.465 mm±0.28 vs. 1.151 mm±0.233; I2: 99.17;
- double sleeve design vs. drill key vs. mounted drill 0.861 mm±0.205 vs. 1.058 mm±0.091 vs. 1.192 mm±0.128; I2:98.89.

Results are summarized in Table 5.

## 3D deviation at apex

Of the 36 publications, 33 indicated a deviation at the implant apex. In total deviations at implant apex of 3264 implants were included. Mean deviation of 1.42 mm (95% CI: 1.275, 1.575, SE: 0.072) was determined (Fig. 3). Mean deviations between included studies ranged from 0.37 mm (95% CI: 0.305, 0.435, SE: 0.033) (52) to 2.86 mm (95% CI: 2.213, 2.587, SE: 0.095) (53). The highest deviation of the implant apex was 8.73 mm (50).

Results showed high heterogeneity ($I^2$ = 99.43, p <0.01). Subgroup analysis of clinical factors revealed the following deviations:

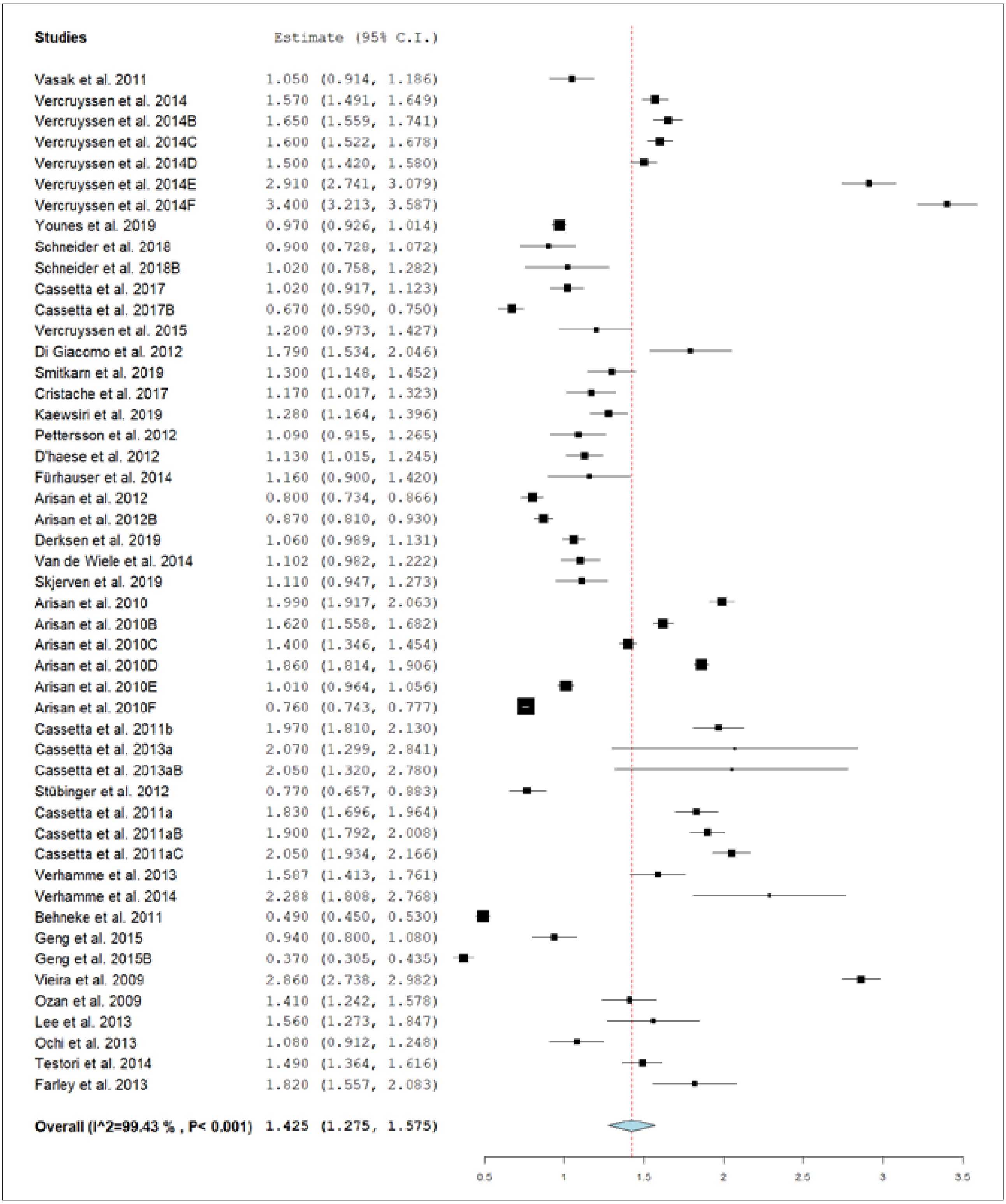


FIG. 2 Mean deviation at implant apex.

- open gap area (Kennedy Class I or II) vs. closed gap area (Kennedy Class III or IV) 1.269 mm±0.200 vs. 1.273 mm±0.129, I2:88.8;
- implantation in the anterior segment vs. posterior segment 1.139 mm±0.248 vs. 1.295 mm±0.265, I2:95.1;
- mandible vs. maxilla 1.357 mm±0.075 vs. 1.307 mm±0.090, I2:87.2;
- partially edentulous jaws vs. fully edentulous 1.042 mm±0.144 vs. 1.338 mm±0.118, I2:97.7;
- flapless approach vs. open-flap 1.270 mm±0.103 vs.

| Study characteristics | | Entry Deviation | | | | |
|---|---|---|---|---|---|---|
| | | Mean Deviation | 95% CI lower limit | 95% CI upper limit | P value | |
| Gap | Free-end | 0.959 | 0.605 | 1.314 | 0.885 | |
| | Interdental | 0.928 | 0.699 | 1.158 | | |
| Stopper | Laser marking | 1.365 | 0.925 | 1.805 | 0.170 | |
| | Mounted Stopper | 1.030 | 0.840 | 1.219 | | |
| Sleeve design | Double Sleeve | 0.849 | 0.563 | 1.136 | 0.232 | 0.378 |
| | Drill Key | 1.041 | 0.913 | 1.168 | | |
| | Double Sleeve | 0.868 | 0.309 | 1.427 | 0.276 | |
| | Mounted Drill | 1.238 | 0.876 | 1.600 | | |
| | Drill Key | 1.059 | 0.878 | 1.239 | 0.283 | |
| | Mounted Drill | 1.234 | 0.970 | 1.498 | | |
| Location | Anterior | 0.970 | 0.581 | 1.358 | 0.769 | |
| | Posterior | 1.054 | 0.648 | 1.460 | | |
| Jaw | Maxilla | 1.017 | 0.837 | 1.198 | 0.757 | |
| | Mandible | 1.065 | 0.825 | 1.305 | | |
| Edentulism | Full | 1.112 | 0.887 | 1.337 | 0.089 | |
| | Partial | 0.806 | 0.533 | 1.078 | | |
| Support | Bone | 1.449 | 1.285 | 1.613 | 0.986 | 0.311 |
| | Bone+Pins | 1.453 | 1.062 | 1.843 | | |
| | Bone | 1.459 | 1.190 | 1.727 | 0.064 | |
| | Mucosa | 1.118 | 0.878 | 1.358 | | |
| | Bone | 1.466 | 0.807 | 2.125 | 0.267 | |
| | Mucosa+Pins | 1.049 | 0.721 | 1.377 | | |
| | Bone | 1.460 | 1.167 | 1.752 | 0.000 | |
| | Teeth | 0.867 | 0.718 | 1.016 | | |
| | Bone+Pins | 1.459 | 0.914 | 2.004 | 0.294 | |
| | Mucosa | 1.130 | 0.846 | 1.414 | | |
| | Bone+Pins | 1.463 | 0.460 | 2.467 | 0.443 | |
| | Mucosa+Pins | 1.049 | 0.713 | 1.385 | | |
| | Bone+Pins | 1.458 | 0.932 | 1.984 | 0.035 | |
| | Teeth | 0.868 | 0.715 | 1.021 | | |
| | Mucosa | 1.157 | 0.568 | 1.746 | 0.754 | |
| | Mucosa+Pins | 1.049 | 0.722 | 1.377 | | |
| | Mucosa | 1.127 | 0.855 | 1.400 | 0.106 | |
| | Teeth | 0.869 | 0.714 | 1.024 | | |
| | Mucosa+Pins | 1.048 | 0.768 | 1.329 | 0.440 | |
| | Teeth | 0.889 | 0.598 | 1.180 | | |
| Implant Placement | Guided | 0.978 | 0.878 | 1.078 | 0.009 | |
| | Free-hand | 1.274 | 1.077 | 1.471 | | |
| Guide Type | Fully guided | 1.009 | 0.832 | 1.186 | 0.378 | |
| | Half guided | 1.169 | 0.810 | 1.529 | | |
| | Pilot drill guided | 1.501 | 0.673 | 2.330 | | |
| Flap | Flapless | 1.027 | 0.803 | 1.251 | 0.847 | |
| | Open Flap | 1.069 | 0.707 | 1.430 | | |
| Fixation | Fixed | 1.127 | 0.863 | 1.392 | 0.860 | |
| | Not Fixed | 1.092 | 0.806 | 1.378 | | |
| Defect | Multiple | 1.132 | 0.996 | 1.269 | 0.460 | |
| | Single | 1.017 | 0.742 | 1.291 | | |

TABLE 5 Mean implant deviations at entry point.

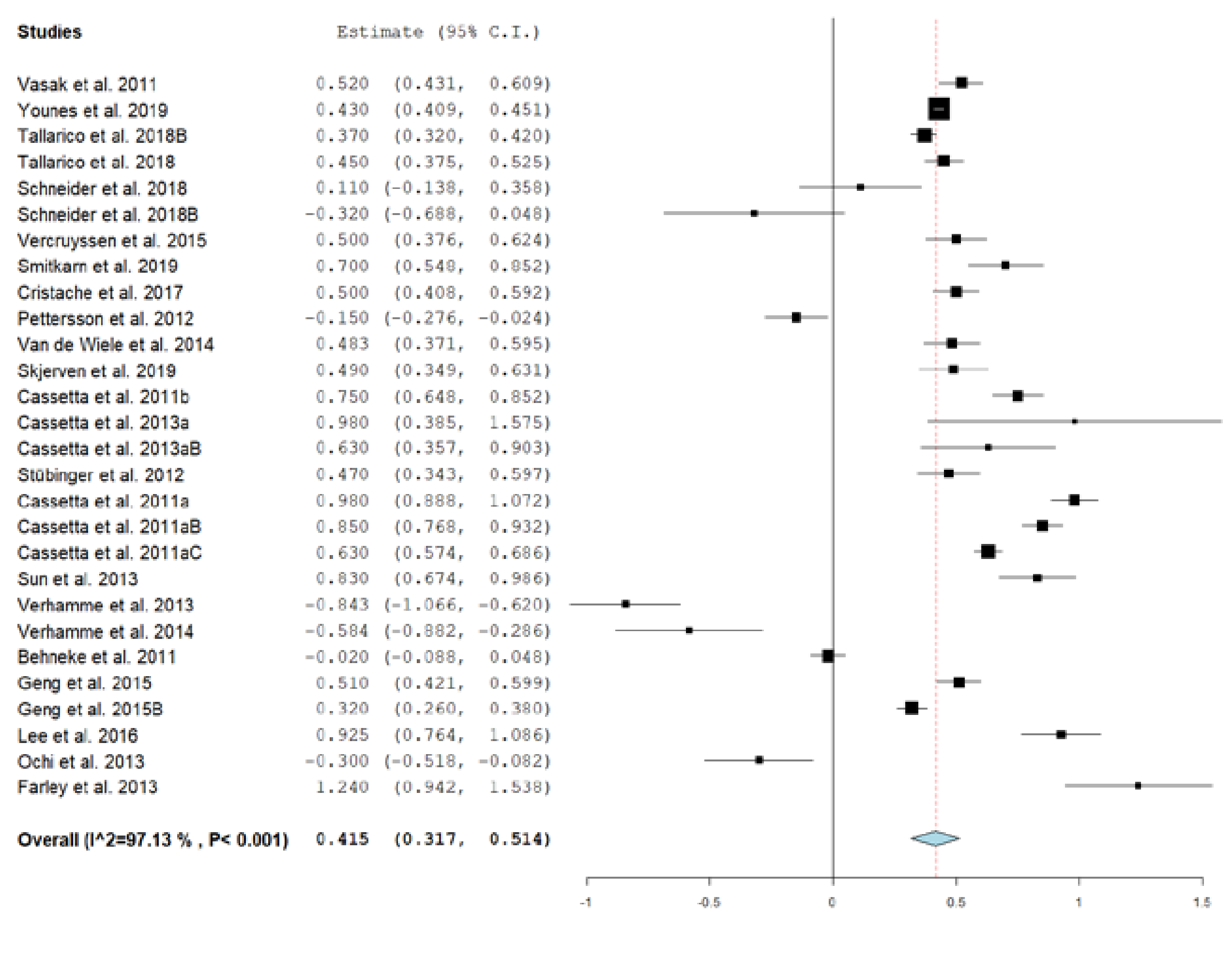


FIG. 3 Mean implant depth deviation.

1.309 mm±0.174, I2:97.5;

- single implantation per guide vs. multiple 1.300 mm±0.245; 1.401 mm±0.108, I2:97.5.

None of the results were statistically significant.

Results are summarized in Table 6.

Subgroup analysis of technical factors revealed the following results:

- mechanical vs. visual control 1.656 mm±0.207; 1.302 mm±0.093; I2: 97.63;
- double sleeve subgroup vs. drill key vs. mounted drill 0.989 mm±0.179 vs. 1.373 mm±0.084 vs. 1.462 mm±0.147; I2: 97.63;
- guided implant placement vs. free-hand implantation 1.235 mm±0.068 vs. 1.526 mm±0.126; I2: 96.39; p=0.042;
- fully guided implantation vs. half vs. pilot-drill guided 1.283 mm±0.093 vs. 1.583 mm±0.177 vs. 1.796 mm±0.421; I2: 97.06;
- fixed vs. non-fixed 1.317 mm±0.124 vs. 1.400 mm±0.134; I2: 97.27;
- teeth vs. bone vs. mucosa supported were the most accurate 1.109 mm±0.128 vs. 1.695 mm±0.259 vs. 1.525 mm±0.234; I2: 98.05.

Results are summarized in Table 6.

## 3D implant depth deviation

Of the 36 works 22 provided results of implant depth deviation. A total of 1915 implants' depth deviations were analyzed. The overall mean deviation of the implant depth was 0.415 mm (95% CI: 0.317, 0.514, SE: 0.096) (Fig. 4). Depth deviation ranged from -0.32 mm (95% CI: -0.688, 0.048, SE: 0.188) (28) to 1.24 mm (95% CI: 0.942, 1.538, SE: 0.152) (58). The maximum individual deviation of the implant depth was 4.70 mm (48). The results were heterogeneous ($I^2 = 97.13$, p <0.001).

Subgroups analysis of clinical factors revealed following results:

- implantation in the anterior segment vs. posterior 0.360 mm±0.051 vs. 0.485 mm±0.074, I2:3.9;
- maxilla vs. mandible 0.104 mm±0.182 vs. 0.216 mm±0.243, I2:97.4;
- fully vs. partially edentulous 0.225 mm±0.106 vs.

| Study characteristics | | Apex Deviation | | | | |
|---|---|---|---|---|---|---|
| Study characteristics | | Mean Deviation | 95% CI lower limit | 95% CI upper limit | P value | |
| Gap | Free-end | 1.269 | 0.877 | 1.660 | 0.986 | |
| | Interdental | 1.273 | 1.021 | 1.525 | | |
| Stopper | Laser marking | 1.656 | 1.251 | 2.062 | 0.119 | |
| | Mounted Stopper | 1.302 | 1.120 | 1.485 | | |
| Sleeve design | Double Sleeve | 0.989 | 0.639 | 1.339 | 0.051 | 0.209 |
| | Drill Key | 1.373 | 1.208 | 1.538 | | |
| | Double Sleeve | 1.001 | 0.467 | 1.536 | 0.154 | |
| | Mounted Drill | 1.466 | 1.117 | 1.814 | | |
| | Drill Key | 1.390 | 1.170 | 1.611 | 0.706 | |
| | Mounted Drill | 1.463 | 1.155 | 1.771 | | |
| Location | Anterior | 1.139 | 0.652 | 1.626 | 0.667 | |
| | Posterior | 1.295 | 0.776 | 1.814 | | |
| Jaw | Maxilla | 1.357 | 1.209 | 1.504 | 0.675 | |
| | Mandible | 1.307 | 1.130 | 1.484 | | |
| Edentulism | Full | 1.338 | 1.107 | 1.568 | 0.112 | |
| | Partial | 1.042 | 0.759 | 1.324 | | |
| Support | Bone | 1.686 | 1.327 | 2.046 | 0.124 | 0.240 |
| | Bone+Pins | 1.244 | 0.810 | 1.678 | | |
| | Bone | 1.683 | 1.353 | 2.013 | 0.405 | |
| | Mucosa | 1.493 | 1.193 | 1.794 | | |
| | Bone | 1.628 | 1.096 | 2.300 | 0.201 | |
| | Mucosa+Pins | 1.257 | 0.949 | 1.565 | | |
| | Bone | 1.687 | 1.315 | 2.060 | 0.011 | |
| | Teeth | 1.145 | 0.955 | 1.335 | | |
| | Bone+Pins | 1.258 | 0.768 | 1.748 | 0.419 | |
| | Mucosa | 1.511 | 1.140 | 1.882 | | |
| | Bone+Pins | 1.285 | 0.558 | 2.013 | 0.945 | |
| | Mucosa+Pins | 1.257 | 1.941 | 1.574 | | |
| | Bone+Pins | 1.253 | 0.785 | 1.721 | 0.681 | |
| | Teeth | 1.146 | 0.947 | 1.346 | | |
| | Mucosa | 1.533 | 0.991 | 2.074 | 0.385 | |
| | Mucosa+Pins | 1.257 | 0.950 | 1.565 | | |
| | Mucosa | 1.506 | 1.160 | 1.851 | 0.075 | |
| | Teeth | 1.146 | 0.952 | 1.340 | | |
| | Mucosa+Pins | 1.256 | 0.982 | 1.529 | 0.604 | |
| | Teeth | 1.153 | 0.878 | 1.428 | | |
| Implant Placement | Guided | 1.235 | 1.101 | 1.369 | 0.042 | |
| | Free-hand | 1.526 | 1.280 | 1.773 | | |
| Guide Type | Fully guided | 1.283 | 1.102 | 1.465 | 0.150 | |
| | Half guided | 1.583 | 1.237 | 1.929 | | |
| | Pilot drill guided | 1.796 | 0.971 | 2.620 | | |
| Flap | Flapless | 1.269 | 1.064 | 1.474 | 0.842 | |
| | Open Flap | 1.308 | 0.985 | 1.632 | | |
| Fixation | Fixed | 1.317 | 1.075 | 1.559 | 0.650 | |
| | Not Fixed | 1.400 | 1.137 | 1.663 | | |
| Defect | Multiple | 1.401 | 1.189 | 1.613 | 0.706 | |
| | Single | 1.300 | 0.820 | 1.781 | | |

TABLE 6
Mean implant deviations at apex.

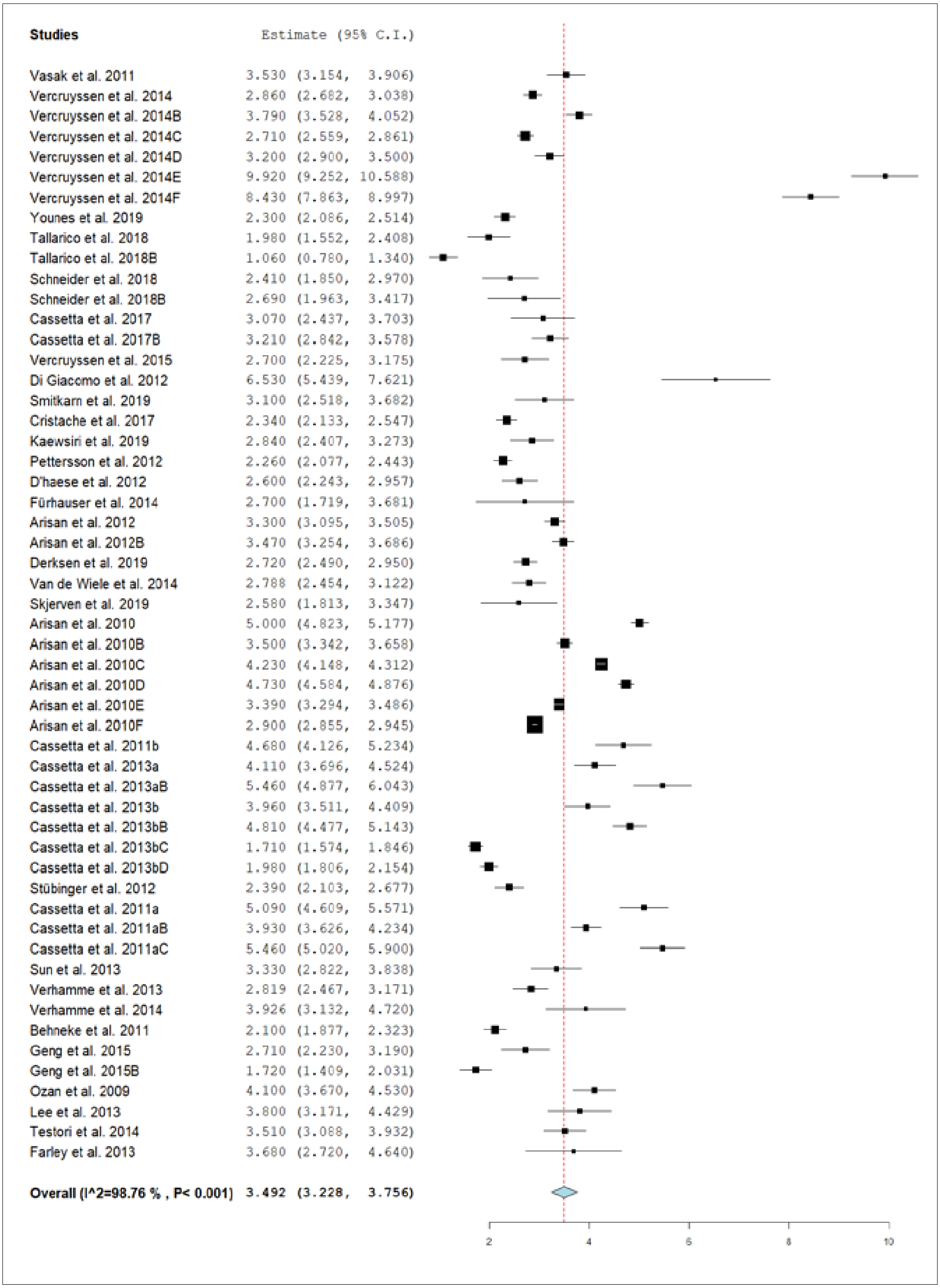


FIG. 4 Mean implant angular deviation.

| Study characteristics | | Angle Deviation: Mean Deviation | 95% CI lower limit | 95% CI upper limit | P value | |
|---|---|---|---|---|---|---|
| Gap | Free-end | 2.679 | 2.087 | 3.270 | 0.912 | |
| | Interdental | 2.718 | 2.353 | 3.083 | | |
| Stopper | Laser marking | 4.037 | 3.338 | 4.737 | 0.012 | |
| | Mounted Stopper | 3.069 | 2.787 | 3.351 | | |
| Sleeve design | Double Sleeve | 3.301 | 2.454 | 4.148 | 0.989 | 0.526 |
| | Drill Key | 3.295 | 2.942 | 3.647 | | |
| | Double Sleeve | 3.277 | 2.828 | 3.726 | 0.936 | |
| | Mounted Drill | 3.002 | 2.670 | 3.333 | | |
| | Drill Key | 3.291 | 2.947 | 3.636 | 0.428 | |
| | Mounted Drill | 3.017 | 2.432 | 3.602 | | |
| Location | Anterior | 3.023 | 1.679 | 4.367 | 0.715 | |
| | Posterior | 3.389 | 1.961 | 4.816 | | |
| Jaw | Maxilla | 2.910 | 2.551 | 3.270 | 0.826 | |
| | Mandible | 2.974 | 2.533 | 3.415 | | |
| Edentulism | Full | 3.168 | 2.883 | 3.454 | 0.001 | |
| | Partial | 2.465 | 2.143 | 2.979 | | |
| Support | Bone | 4.338 | 3.479 | 5.198 | 0.053 | 0.001 |
| | Bone+Pins | 2.980 | 1.907 | 4.053 | | |
| | Bone | 4.338 | 3.483 | 5.193 | 0.182 | |
| | Mucosa | 3.565 | 2.820 | 4.310 | | |
| | Bone | 4.337 | 3.491 | 5.183 | 0.013 | |
| | Mucosa+Pins | 3.168 | 2.790 | 3.546 | | |
| | Bone | 4.317 | 3.599 | 5.035 | 0.000 | |
| | Teeth | 2.602 | 2.264 | 2.939 | | |
| | Bone+Pins | 2.965 | 1.941 | 3.988 | 0.348 | |
| | Mucosa | 3.561 | 2.851 | 4.272 | | |
| | Bone+Pins | 2.974 | 1.922 | 4.026 | 0.734 | |
| | Mucosa+Pins | 3.167 | 2.791 | 3.544 | | |
| | Bone+Pins | 2.910 | 2.024 | 3.796 | 0.520 | |
| | Teeth | 2.600 | 2.270 | 2.929 | | |
| | Mucosa | 3.564 | 2.830 | 4.298 | 0.346 | |
| | Mucosa+Pins | 3.167 | 2.791 | 3.544 | | |
| | Mucosa | 3.547 | 2.936 | 4.168 | 0.009 | |
| | Teeth | 2.602 | 2.264 | 2.940 | | |
| | Mucosa+Pins | 3.158 | 2.806 | 3.510 | 0.037 | |
| | Teeth | 2.610 | 2.234 | 2.986 | | |
| Implant Placement | Guided | 3.104 | 2.828 | 3.379 | 0.003 | |
| | Free-hand | 4.037 | 3.497 | 4.578 | | |
| Guide Type | Fully guided | 3.064 | 2.781 | 3.347 | 0.001 | |
| | Half guided | 4.259 | 3.670 | 4.848 | | |
| | Pilot drill guided | 3.778 | 2.210 | 5.346 | | |
| Flap | Flapless | 2.959 | 2.685 | 3.234 | 0.347 | |
| | Open Flap | 3.222 | 2.750 | 3.693 | | |
| Fixation | Fixed | 3.090 | 2.734 | 3.445 | 0.146 | |
| | Not Fixed | 3.514 | 3.066 | 3.961 | | |
| Defect | Multiple | 3.323 | 3.022 | 3.624 | 0.478 | |
| | Single | 3.032 | 2.290 | 3.775 | | |

TABLE 7 Mean implant angular deviations.

0.439 mm±0.089, I2:91.5;
- open-flap vs. flapless 0.135 mm±0.178 vs. 0.349 mm±0.076, I2:93.7;
- multiple implantations per guide vs. single 0.349 mm±0.105 vs. 0.960 mm±0.271, I2:95.8, p=0.035.

Statistical significance was determined in number of implants per guide (single/multiple) subgroup.
Subgroup analysis revealed the following results:
- mechanical vs. visual control 0.792 mm±0.230 vs. 0.370 mm±0.073; I2: 95.29;
- mounted drill vs. drill keys vs. double sleeve 0.147 mm±0.087 vs. 0.589 mm±0.069; I2: 94.92; p<0.001;
- fixed vs. non-fixed 0.415 mm±0.094 vs. 0.557 mm±0.095 I2: 93.87;
- guided implant insertion vs. free-hand 0.395 mm±0.070 vs. 0.670 mm±0.198; I2: 95.71;
- pilot drill guide vs. fully guided vs. half guided 0.110 mm±0.296 vs. 0.501±0.055 vs. 0.68±0.178; I2: 91.54;
- mucosa supported vs. bone-supported vs. teeth supported -0.184 mm±0.227 vs. 0,47 mm±0.298 vs. 0.438±0.1; I2: 95.47.

Results are summarized in Table 7.

### Angular deviation

33 of the 36 publications reported the angular deviation of the implant axes. A total of 3508 implants' axial deviations were included. The overall mean angular deviation was 3.49 ° (95% CI: 3.228, 3.756, SE: 0.135), (Fig. 5), and ranged from 1.06° (95% CI: 1.028, 3.756, SE: 0.143) (60) to 6.53° (95% CI: 4.252, 7.588, SE: 0.341) between studies (31). The maximum recorded individual angular axis deviation was 21.16° (43).
The obtained results were heterogeneous: $I^2$ = 98.762, p <0.02.
Results of subgroup analysis are as follows:
- guided implantation in open gap area (Kennedy Class I or II) vs. interdental (Kennedy Class III or IV) 2.679°±0.302 vs. 2.718°±SE: 0.186, I2:54.7;
- anterior segment vs. posterior 3.023°±0.686 vs. 3.389°±0.728, I2:98.1;
- maxilla vs. mandible 2.910°±0.183 vs. 2.974°±0.728, I2:94;
- partially vs. fully edentulous 2.465°±0.164 vs. 3.168°±0.146, I2:87.6, p=0.001;
- open-flap vs. flapless 2.963°±0.138 vs. 3.232°±0.251, I2:91.8;
- single vs. multiple implantations per guide (3.032°±0.379 vs. 3.323°±0.154, I2:92.

Statistical significance was determined in differences of accuracy in type of edentulism subgroup.
Subgroup analysis revealed the following results:
- mechanical vs. visual control 3.069°±0.144 vs. 4.037°±0.357; I2: 92.45; p=0.012;
- mounted drills vs. drill key vs. double sleeve systems 2.976°±0.279 vs. 3.336°±0.167 vs. 3.357°±0.49; I2: 93.11;
- guided implant placement vs. free-hand 3.104°±0.141 vs. 4.037°±0.276; I2: 93.15; p=0.003;
- fully guided implantation vs. half guided vs. pilot drill guided 3.064°±0.144 vs. 4.037°±0.276; I2: 93.15; p=0.001;
- fixed vs. non-fixed 3.090°±0.181 vs. 3.514°±0.228; I2: 93.16;
- teeth-supported vs. mucosa supported vs. bone supported (2.574°±0.181 vs. 3.556°±0.343 vs. 4.327°±0.396; I2: 91.49; p=0.001.

Results are summarized in Table 8.

## DISCUSSION

### Overall findings

The purpose of this review was to systematically assess up to date clinical studies regarding accuracy of individual static guided surgery and evaluate the influence of clinical and technical factors.
Mean overall 3D deviation of guided implant position was 1.14 mm (95% CI: 1.016, 1.268, SE: 0.064) at implant neck and 1.42 mm (95% CI: 1.275, 1.575, SE: 0.072) at implant apex, mean angular deviation - 3.49° (95% CI: 3.228, 3.756, SE: 0.135) and vertical - 0.415 mm (95% CI: 0.317, 0.514, SE: 0.096). These results correspond with previously published reviews (13, 15-17). However, most of the preceding reviews have included results of clinical, preclinical and cadaver studies while this review focused on clinical studies only. These results indicate that ~2 mm safety margin should be considered while planning implant position to avoid the damage of surrounding anatomical structures and unplanned prosthetic solutions in esthetic areas. Besides, the high deviations reported are noteworthy. Verhamme et al. reported maximum of 7.812 mm implant position error at implant neck and 8.73 mm at apex, Cassetta et al. reported a maximum of 21.16° angular deviation and Sun et al. the highest vertical deviations (4.7 mm). Despite reported deviations of guided implantation the accuracy of guided implant placement was more accurate than freehand placement in angular and 3D deviations at entry and apical points with statistical significance (p<0.05).

### Influence of clinical factors

Subgroup analysis of clinical factors included comparisons between types, locations, sizes of defects and flap status. To the best of our knowledge this is a first meta-analysis that compared influence of defect type (interdental or free-end gap) on accuracy of guided surgery. Statistically significant differences of implant accuracy in one or more measurement points were determined in subgroups comparing number of implantations per single guide (single vs. multiple) and type of edentulism (full vs. partial) (p<0.05). Subgroup of multiple guided implantations included both fully edentulous and partially edentulous cases with more than one implantation per guide. Individual studies of Derksen et al. and Behneke et

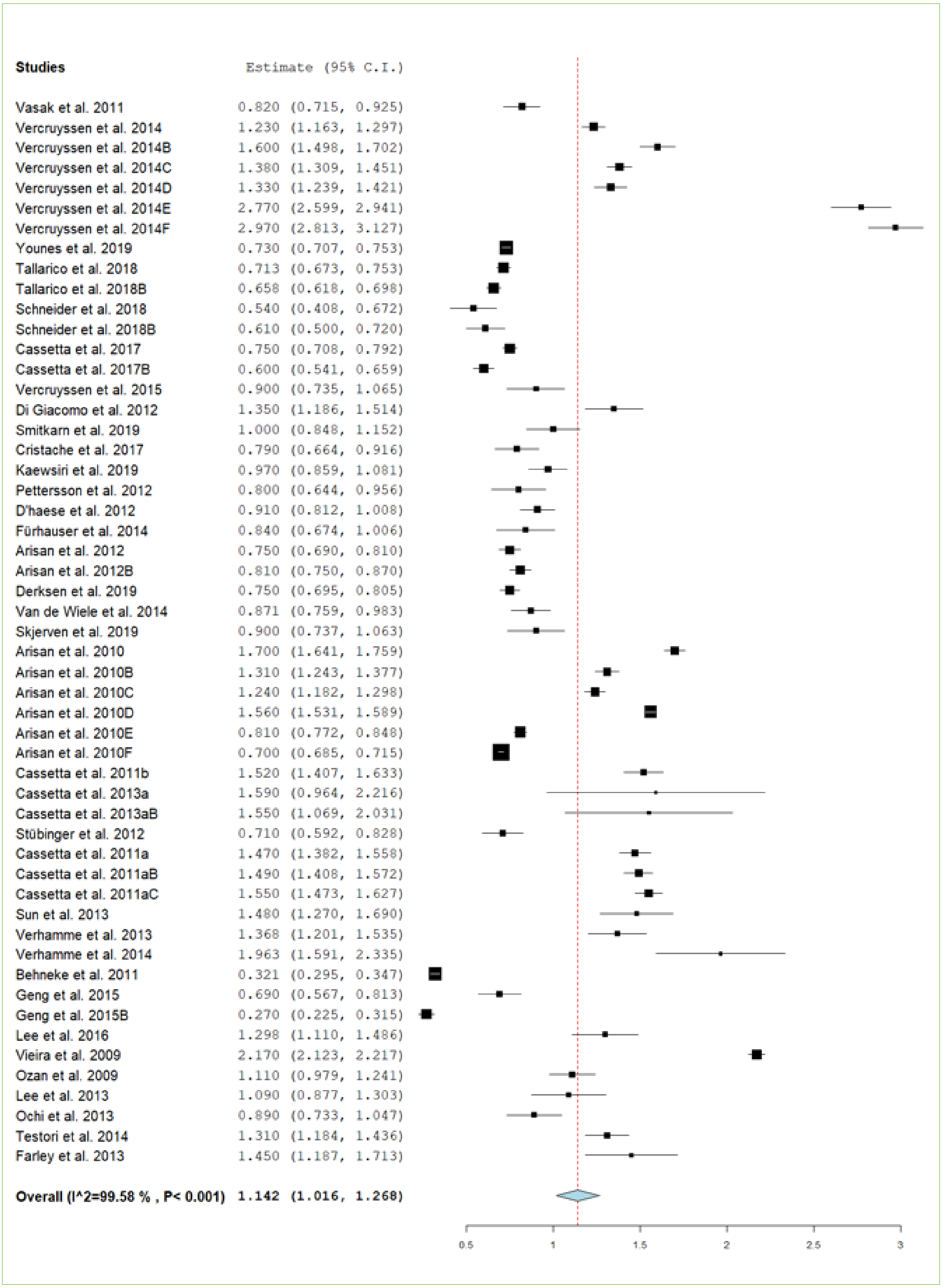


FIG. 5 Mean deviation at implant entry point.

| Study characteristics | | Depth Deviation Mean Deviation | 95% CI lower limit | 95% CI upper limit | P value | |
|---|---|---|---|---|---|---|
| Stopper | Laser marking | 0.792 | 0.342 | 1.242 | 0.080 | |
| | Mounted Stopper | 0.370 | 0.228 | 0.513 | | |
| Sleeve design | Drill Key | 0.589 | 0.454 | 0.725 | **0.000** | |
| | Mounted Drill | 0.147 | -0.024 | 0.318 | | |
| Location | Anterior | 0.360 | 0.260 | 0.460 | 0.162 | |
| | Posterior | 0.485 | 0.341 | 0.629 | | |
| Jaw | Mandible | 0.216 | -0.261 | 0.693 | 0.712 | |
| | Maxilla | 0.104 | -0.254 | 0.461 | | |
| Edentulism | Full | 0.225 | 0.018 | 0.432 | 0.121 | |
| | Partial | 0.439 | 0.265 | 0.613 | | |
| Support | Bone+Pins | 0.470 | -1.306 | 2.246 | 0.476 | 0.085 |
| | Mucosa | -0.283 | -1.344 | 0.777 | | |
| | Bone+Pins | 0.470 | -0.353 | 1.293 | 0.675 | |
| | Mucosa+Pins | 0.277 | -0.093 | 0.647 | | |
| | Bone+Pins | 0.470 | 0.123 | 0.817 | 0.890 | |
| | Teeth | 0.444 | 0.327 | 0.562 | | |
| | Mucosa | -0.235 | -0.826 | 0.357 | 0.167 | |
| | Mucosa+Pins | 0.276 | -0.142 | 0.694 | | |
| | Mucosa | -0.103 | -0.437 | 0.230 | 0.004 | |
| | Teeth | 0.442 | 0.288 | 0.595 | | |
| | Mucosa+Pins | 0.282 | 0.045 | 0.519 | 0.291 | |
| | Teeth | 0.440 | 0.268 | 0.613 | | |
| Implant Placement | Guided | 0.395 | 0.257 | 0.532 | 0.190 | |
| | Free-hand | 0.670 | 0.282 | 1.057 | | |
| Guide Type | Fully guided | 0.500 | 0.400 | 0.610 | 0.252 | |
| | Half guided | 0.660 | 0.004 | 1.310 | | |
| | Pilot drill guided | 0.110 | -0.260 | 0.480 | | |
| Flap | Flapless | 0.324 | 0.169 | 0.479 | 0.817 | |
| | Open Flap | 0.284 | -0.015 | 0.583 | | |
| Fixation | Fixed | 0.415 | 0.232 | 0.599 | 0.290 | |
| | Not Fixed | 0.557 | 0.369 | 0.744 | | |
| Defect | Multiple | 0.349 | 0.143 | 0.554 | 0.035 | |
| | Single | 0.960 | 0.429 | 1.491 | | |

TABLE 8 Mean implant depth deviations.

al. reported statistically significantly higher accuracies in interdental gap cases compared to free-end gap cases. The movement of the guide due to lack of support or fixation has been already reported as an important factor (15).

Anterior localization of guided implantation was statistically more accurate in clinical studies of Di Giacomo et al. (31), Vasak et al. (27), D'Haese et al. (36). Furthermore, Vercruyssen et al. (79) and Tahmaseb et al. (15) reached same conclusion in their reviews. These authors indicated as a possible explanation that surgical manipulation in the anterior segment is easier and less compromised by the anatomic or physiologic obstacles such as tongue, cheeks or limited mouth opening.

Flapless surgery is appealing because of easier post-operative healing and less morbidity (12). Decreased resorption of alveolar bone and soft tissue is also reported around implants screwed in flapless approach (82, 83). Preservation of intact periosteum is the main reason for these advantages. Intact periosteum maintains the conditions for blood supply and osteogenic potential. These biological advantages must be accompanied by accurate implant positioning. Authors agree that flapless implantation cannot be universally applied. Minimum of 4-4.5 mm remaining alveolar bone height and 5 mm of keratinized gingiva is recommended for successful flapless implantation (13, 17). Besides, flapless approach requires special skills, thus it is more sensitive to clinical experience (82). Our meta-analysis did not provide significant differences in accuracy between the two approaches.

Individual studies have reported significant differences in implant position accuracy in favor of mandible but only at single evaluation points (16, 27, 35).

Zhou et al. meta-analysis was the only review that reported statistically significantly higher accuracy of guided implantations in the mandible (16); the authors explained these findings with differences in ridge anatomy and bone density. This meta-analysis did not find differences between the groups.

Both reviewed and present findings highlight the importance of guide stabilization and fixation for overall accuracy. In addition, the need for different protocols of guide support and fixation according to the types of edentulism, remaining teeth, size and location of the defect could be considered in the future clinical studies.

## Influence of technical factors

The set of technical factors analyzed is as follows: type of guide support, status of fixation, type of guidance, sleeve design and type of vertical control. To our knowledge this is the first review that evaluated the influence of ~~latter~~ mechanical properties on overall accuracy of static guided implantation.

According to the European Association of Osseointegration static guides are divided into fully, half guided and pilot drill guides. This division is based on the amount of free-hand stages in their protocol. In this review overall results of guided implantation accuracy include all three types of guides (13). In addition, subgroup analysis between these three groups was conducted too. Subgroup analysis revealed that fully guided systems have better angular accuracy than half or pilot-drill guided ($p<0.05$). These results are in concordance with previous studies of D'Haese et al, (12) and Zhou et al. (16). The first RCT comparing fully guided, pilot-drill guided and freehand implantation by Younes et al. concluded that the fully guided protocol should be considered the gold standard in individual static guided implantation.

Additionally, guiding systems can be divided into three subgroups according to their sleeve-drill relation: double sleeve, drill key and mounted drill. Manufacturers try to address the problem of tolerance between drill and sleeve. Tolerance gap is important to avoid overheating due to excess friction (84). Exposure of alveolar bone to temperature higher than 47°C leads to irreversible damage and causes unpredictable resorption. Despite this, tolerance gap also leads to possibility of drill deviations, especially in surgical locations with compromised range of movement. Thus, the optimization of drill-sleeve relation should address minimizing drill movement tolerance and subsequent damage to bone by debris and overheating.

Static guide consists of a plastic prototype with incorporated sleeves that can be either metallic or of the same material as the guide. Incorporated sleeve becomes specific to every implantation drill with changeable sleeves that are either put into it in double sleeve system or are applied with carriers in drill key systems (Fig. 6, 7). The two systems are similar regarding drill-sleeve relation and differ from mounted drill systems (Fig. 8). The latter achieve fitting of the drill to the sleeve via mounted coronal part on the drill and do not require changeable sleeves. This results in elimination of the tolerance gap in the mounted drill systems as the mounted part of the drill tightly fits the sleeve in the guide, whereas double sleeve systems have determined tolerance gap between the drill and the sleeve.

The specifics of drill key design additionally require the surgeon to hold the drill key with his/her spare hand. Therefore, the surgeon is obliged to ensure the proper position of both drill key and drill, whereas using other sleeve systems he/she can focus on position of the drill only. Statistically lower mean deviation was recorded with mounted-drill systems at vertical deviation measurement point.

Depth control of implantation in guiding systems is achieved either using drills with mounted stoppers (mounted stopper systems) or using laser markings for visual depth control (laser stopper systems) (Fig. 9). Systems with mechanical vertical control were significantly more accurate that laser marking subgroup according to the results ($p=0.012$). This marks the importance of mechanical vertical control in guided surgery.

Mean deviations of teeth supported guides were lower at coronal, apical and angular measurement points. This is in accordance with lower deviations in partially edentulous patients over fully edentulous ones determined by the analysis of clinical factor of the present review. The fact that teeth-supported guides show the highest accuracy while bone-supported one the lowest is also reported in previous studies (3, 13, 14, 16, 79). In the review of Raico et al. (17), it is concluded that guide support influences

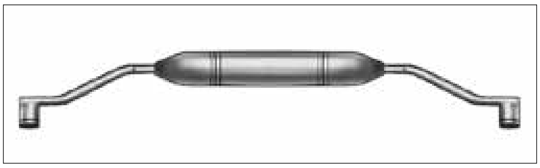

FIG. 6 Double sleeve.
FIG. 7 Drill key.
FIG. 8 Mounted drill.

FIG. 9 Left: mounted drill with mechanical vertical stopper; Right: mounted drill with laser marking.

the accuracy of guided implantation.
Improper stabilization of the guide is a source for deviations. For instance, application of bone-supported guide requires extensive flap elevation. On the other hand, thickness of gingival tissue, inaccurate digitalization of gingival surface, mobility of soft tissue and changes after anesthetic injection may influence higher deviations for mucosa-supported, flapless guided implantation (15, 82). It can be concluded that remaining teeth have substantial influence on overall stability of the guide and accuracy of guided implantation. Therefore, the problem emerges in fully edentulous cases. The absence of teeth as guide support elements highlights the need of additional stabilization and fixation elements and optimization of the guide support protocol in edentulous cases.
Possibility of stabilization of guide with surgical pins on vestibular side is suggested as the solution to this problem (15). Location of surgical pins can be planned pre-surgically. Pins are used in both open-flap and flapless surgeries. Studies included to this subgroup analysis used three to four fixation pins. This meta-analysis did not find statistically significant differences between the subgroups. However, results of guided implantation being more accurate with fixed guides can be seen in other reviews (3, 12, 82). Meta-analysis of Zhou et al. (16) resulted in statistically significant higher accuracies of fixed guide subgroup. The advantages of guide fixation, especially in edentulous patients can be perceived as obvious, but authors see the sense of research in optimizing the protocols for number, locations of the pins according to the classes of alveolar bone resorption and gingival thickness.

## Limitations

Authors acknowledge the limitations of this review. Meta-analysis showed high heterogeneity ($I^2$>98%) among included clinical studies. This was expected due to differences between RCT's and observational studies, study designs, methodologies and clinical aspects. Combined evaluation of RCTs and observational studies could also be the source of bias. However, authors decided to accept the risk due to lack of RCTs. High heterogeneity was observed in previous meta-analyses on this topic too (15-17).
Furthermore, sources of possible errors in assessment and processing patient's data, guide planning, manufacturing and processing, clinical execution and post-operative evaluation contribute to cumulative deviations and mask the influence of factors of interest.
This review included only studies on patients and excluded cadaver and preclinical studies on anatomical models. Cadaver studies have shown significant differences in results compared to clinical studies due to formalin-induced bone demineralization (73). Studies on models are exposed to additional errors that are absent in clinical studies, such as errors in model manufacturing, matching and model mobility during simulation of surgery (36, 71, 72). In addition, implantations on models do not simulate clinical obstacles such as limited mouth opening, cheeks, tongue or floor of the mouth (64).
Type of CTs used was a factor ignored in this review. Recently, Arisan et al. (74), Poeschl et al. (75), have shown no significant differences in accuracy of implantation between groups that used either cone-bean CT (CBCT) or multi-slice CT (MSCT). This statement agrees with the results of a meta-analysis performed by Zhou et al. (21). The risk of errors because of patient movements during CT scan, beam hardening, image segmentation or radiological artefacts remains, but it can be reduced, as authors reported, by the experience of professionals in executing CT, processing and matching data and if these steps were performed by the same person.

Use of intraoral surface scanning (IOS) in clinical practice has increased. Accuracy of IOS depends on the distance between scanner and scanned surface and different IOS devices and software vary in precision. Besides, mobile tissues often are not captured precisely. Thus, extensive edentulous segments still require digitalization of analog impression. Furthermore, possible sources of errors remain in stages of superimposition and processing of IOS and CT data. Misalignment of the CT and IOS data can occur due to lack of common identifiable reference points. This can happen because of the radiographic artefacts. Fluge et al. reported that manual segmentation of the raw data is preferred to default segmentation and it has major significance for proper alignment of the data (76). In addition, some studies used post-operative IOS instead of CT to compare implant positions. This alternate evaluation method reduces exposure to radiation, but it is not informative in evaluation of implant position within bone. Besides, differences in deviations between two evaluation methods have been reported. Thus, comparability of the two measurement methods is not confirmed (15, 39).

Planning, manufacturing and post-processing stages of guide fabrication can also contribute to cumulative errors. Digital methods for guide fabrication include both additive and subtractive methods, the former is more cost-efficient. Possible sources of manufacturing errors are inherent in 3D printers, and often specified in technical specifications, and influence of variable offset size that can lead to decreased stability of the guide.

The clinical execution stage could lead to major errors as well. Authors suggest the importance of experience in conventional implantation prior to switching to guided implantation. However, the reports on the importance of clinical experience of the surgeon on accuracy of guided implant placement are inconsistent (29, 40, 67, 78).

Methods of measurement of deviations are similar with several exceptions. In some publications x, y and z axes did not represent mesiodistal, buccolingual and apicocoronal directions, respectively. In some cases, it was not clear whether the deviations were evaluated in 2D or 3D. In order to eliminate these discrepancies inquiries were sent to the authors for specifications. If authors did not answer to the inquires on their studies, the works were excluded from subgroup analysis. The rest of the results were standardized and included in the analysis.

## CONCLUSIONS

Mean deviations of static individual guided implantation require considering a 2 mm safety margin. Guided implant placement and fully guided protocol are more accurate than free-hand placement. The results of this review suggest that technical parameters of guide and guiding protocols influence the accuracy of individual static guided implantation. Additionally, static guides perform better in some clinical situations than other oness. Future research should focus on analyzing advantages of computer assisted guided implantation in particular edentulism classes as well as the advantages of different guide design.

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