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Vertical, horizontal and angulation positioning control in guided implant surgery: accuracy of available systems

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Vertical, horizontal and angulation positioning control in guided implant surgery: accuracy of available systems

Fifth year of Dentistry

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List of used abbreviations

RCT: Randomized Clinical Trial

CT: Clinical Trial

IV: In Vitro

FG: Full Guided

HG: Half Guided

MD: Mesio-Distal

BL: Bucco-Lingual

N.M: Not Mentioned

SD: Standard Deviation

I. Introduction

Throughout the history, rehabilitation of partially or fully edentulous areas of the mouth has never stopped to evolve. As of today, the future of dental implant surgery seems to be shifting to guided surgery as its superiority to free hand surgery has clearly been demonstrated (1,2).

Guided surgery allows us to visualize, plan implant position digitally as well as reproduce those results in vivo with a narrow margin of error. This is particularly advantageous in cases with bone resorption where implant placement is possible but difficult because of limited bone thickness for example (3,4). It offers in some cases a more minimally invasive treatment option avoiding the need of previous bone regeneration reducing treatment time and complications (2,4).

Not only is guided surgery anatomically driven but it is also prosthetically driven which is ultimately the most ideal approach (2–4). Indeed, allowing one to predeterminate several prosthetic parameters such as insertion angle; pre-surgical personalized abutment and others (4). Thanks to its predictability, guided surgery can be considered an option in aesthetic cases where immediate loading is required (4). The digital design of implant abutments and provisional crowns and their manufacturing is possible before surgery which facilitate this approach especially for complex cases such as full arch rehabilitation (4,5).

Various methods of transferring the digital spatial information to the operating site exist. It involves most of the time the use of static surgical guides complemented by additional tools increasing or decreasing control over the surgery that we will mention later. Most recently, dynamic navigation systems have enabled an innovative three-dimensional and real time control of the drill without the need of a surgical guide (1). Static surgical guides are classed depending on their support (bone, teeth, mucosa) or on the visibility which they allow (closed or opened) (1,3,4). Each of these types of guides possess their own advantages and disadvantages, therefore the choice of selection should be individualized and based on the clinical situation.

The respect of three-dimensional accuracy is critical for a successful treatment. Any incorrect positioning on any axis of the bone can result in aesthetical, prosthetic and anatomic complications (4,6). Patient chair-time and discontentment, treatment cost as well as clinician stress therefore increases. Incorrect implant placement, especially in the vertical axis, can result in the occurrence of anatomical lesions to critical structures such as the inferior alveolar nerve, branches of the lingual arteries or the maxillary sinus (4,6,7). Software planning and the use of surgical guides does minimize errors often associated with the freehand method (7).

The mechanisms of implant positioning control in the three dimensions are diverse and depends on the type of surgery performed. Indeed, the protocols and the surgery kits vary depending on the level of guidance of the surgery: full guided, half guided or free hand.

Full guided surgery requires a 3D exploration, usually a CBCT in order to plan the surgery. Software skills are needed in order to allow the fabrication of an accurate CADCAM template. Patient chair time can be significantly reduced when compared to other systems. Accuracy remains its principal advantage (1). Indeed, it facilitate the realization of flapless surgeries and pain, swelling, bleeding and morbidity are therefore significantly reduced (1–3). Patient satisfaction reaches higher levels than HG or FH surgeries (1). However, FG surgeries usually require the use of closed guide to obtain the best stability which has two main consequences: firstly, it forbids any peri-operative spatial modification of drilling or implant placement and secondly it complicates the surgical site irrigation resulting in higher bone heating (1,2). High cost remains a limitation to wide FG surgery use (1,2).

Half guided surgery can be divided in 3 sub-categories: drilling guided, pilot-guided and non-computed guided (1). In drilling guided surgery, the guide is used in all the drill steps and removed only when the implant is placed. The drilling is thus guided, and implant placement is done manually, however accuracy is comparable to FG surgeries. Open guides can be used in drilling guided surgeries. Direct vision of surgical site during drilling and implant placement becomes possible as well as better irrigation and cooling of the bone and the main inconvenience is the absence of guidance in the vertical axis (1).

Pilot drill surgery only requires guide use during pilot drilling. Implant placement is consequently performed manually. Bone drilling modifications are therefore possible and mispositioned implants can be avoided. Once again, the absence of vertical control is the main disadvantage. It has been demonstrated less accurate than FG surgery (1,2).

Finally, the non-computer guided surgery provides the surgeon with a more accessible and economical solution. The template is non-computer manufactured can be utilised during drilling and/or implant placement. A 3D planning is performed using CBCT, wax up and cast models. A radiographic guide is produced and then used as the surgical guide. It is the least accurate of all existing guided systems, but it remains however more accurate than free hand surgery (1).

In order to compare implants placement precision, it is essential to define its concept. Accuracy assessment in guided implant surgery is defined as the deviation between the virtual implant planning and the postoperative implant position. The deviation is usually estimated radiographically by superposition of preoperative and postoperative CBCT images (6,8).

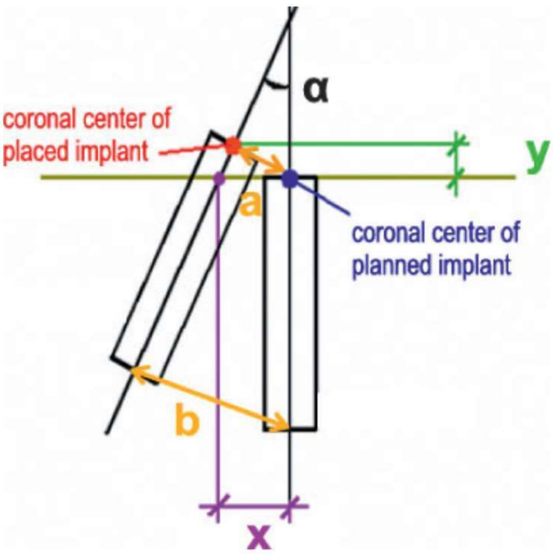


Figure 1: Parameters used to analyse implant placement accuracy (8)

Depending on the clinical study method, different parameters are described as in the following illustration (Fig 1). Some authors measured the horizontal (x) and vertical (y) deviation between the coronal centres of the implants as well as the deviation at the implant entry (a) and/or apex (b). However, other studies only reported the distance between the centre of the implants (8).

It is important to mention that this radiographic method is subject to limitations such as insufficient resolution, radiographic distortion, metal artefacts, patient movement and exposure to radiation.(9–11)

Figure 2: Patient movement during a pre-surgical CT scan is evidenced by the presence of "double contours" (9) (cf. arrow)

New digital non-radiographic methods to estimate implant position have been emerging including the use of intraoral scanners (11) or more recently of scan bodies (9). However, these studies are experimental and to our knowledge haven't been used yet in clinical trials.

Dimensional control in guided surgery is acquired with specially designed tools. Guiding sleeves are metallic cylinders that are inserted in the surgical template allowing guidance of direction and orientation of the drilling (12). They are placed on the surgical template accordingly to pre-surgery planification. It is well known that the cause of deviation in the position of planned and placed implants is multifactorial: scanning, processing, surgery and prosthetics have all been incriminated (13–15). Recent studies aimed to assess the role of sleeve inserts in this deviation (8,13,16). Specific clinical situations such as posterior surgical sites and limited mouth opening can force the clinician to incline the drill so that it fits inside the sleeve decreasing therefore the accuracy (13). The position of the drill within the guide should be parallel and in a centric position for an accurate drilling (13,16). The variety of possible clinical situations that can be encountered justifies the different types of sleeves (shapes, height and diameter) that can be found in all the available systems (17).

Figure 3: Colour guided sleeves system with different diameters. They fit in the guide sleeve of the template. (18)

Virtual abutment design allows the determination of ideal implant position associated with the usual attention to anatomical factors. Once the ideal abutment position is obtained, it needs to be transferred to the template. Usually, a pilot drill in the template is used to "transfer" the abutment position allowing implants to be positioned in 3 dimensions according to prosthetic restoration. The adequate guiding sleeve is then placed into the template (18). The method presented is one of many, in fact, the fabrication process of the surgical template and the guiding sleeve placement differs depending on the manufacturer and are not always documented.

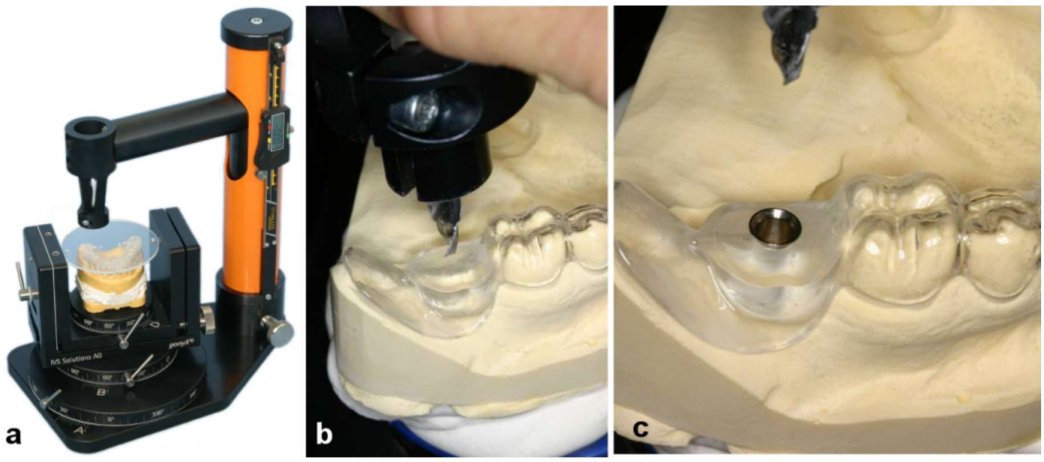


Figure 4: Creation of drill guides using a gonyX table; Transfer of computer-assisted implant planning to the surgical template (18).

The mechanisms of control of drilling and implant placement on the vertical axis are abundant (15). Control of this axis is often problematic, especially in half guided surgeries (1). In an attempt to clarify this multitude of systems, we decided to divide them as follow: visual depth indicators and physical depth stops. The latter exists under various forms, but one is often found in various brands: the drill handle systems (cf. fig 5). A variation of this would be the "Pick & go" systems using detachable drill stops (cf fig 7). Another common version uses non-removable, metallic circular depth stop present on the bur at specific depths lengths. (cf fig 6) The desired drilling depth is obtained when the metallic sleeve of the surgical template and the metallic bur depth stop contacts with each other. Visual depth indicators consist mainly in two systems: visible lines all around the bur indicating the depth reached at each line and the use of a depth probe. Often, depth stops systems use both visual and physical depth control.

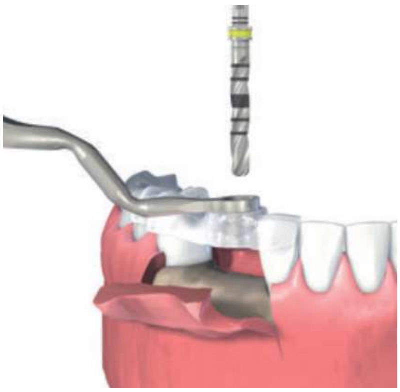


Figure 5: Drill handle system (Straumman™)

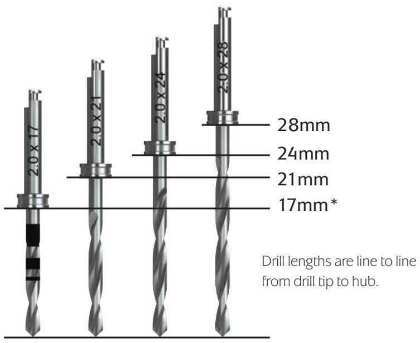


Figure 6: Bur built-in depth stop system (Biohorizons™)

Figure 7: Removable drill stop system (Zimmer™)

The literature about these tools and their mode of operation, sometimes unique and sometimes similar depending on the commercial brand is scarce. However, the increasing number of brands, with each having their own system and instruments sometimes makes the system choice complicated to the clinician. Since these mechanisms could eventually impact system accuracy and overall the treatment success, this systematic review aims to identify, describe then classify the different three-dimensional positioning control mechanisms of the most used systems available on the market. The secondary objective is to evaluate the influence of those systems on the accuracy of the final implant position and to rank the most precise if the current literature allows it.

II. Material and methods

1. Protocol

1.1 PICOC table

The focus question was developed according to the PICOC approach presented in Table 1.

Population (P)	Partial or complete edentulous patients without major systemic diseases who underwent guided surgical implant surgery.
Intervention (I)	Semi or fully guided implant placement.
Control group (C)	Comparison workflow or/and of pre-operative planning implant position with post-operative implant position.
Objectives (O)	Describe 3D control mechanisms of the different market available guided implant surgery systems and identify factors responsible of deviation. Assess the accuracy of each of these systems.
Context (C)	Emergence of new dimensional control mechanisms of implant placement and multitude of available systems leading to unclear indications of each system.
Focus question	How do each guided implant systems allows three-dimensional control of implant positioning and which one is the most accurate?

Table 1: PICOC table

1.2 Inclusion criterias

- Prospective studies
- Randomized and non-randomized control trials
- In vitro studies
- Animal studies
- Article available in English
- Intervention of the study: guided dental implant placement and accuracy assessment

1.3 Exclusion criterias

- Studies older than 10 years
- Guided surgery not concerning dental implants
- Unpublished documents
- Case series
- Reviews
- Insufficient precise information regarding pre- and post-operative implant positioning matching
- Studies published in other languages rather than English

1.4 Objectives

The primary objective of this study was to compare the accuracy of the different guided implant surgery systems available on the market. The secondary objective was to identify the factors influencing the accuracy and to describe the 3D control mechanisms of each of these systems.

1.5 Hypothesis

Null hypothesis Ho: "There are no significant differences of accuracy between the different implants systems and their 3D positioning control mechanisms" or:

$$\mu_{accuracy\ drill\ key\ systems} - \mu_{accuracy\ keyless} = 0$$

Alternative hypothesis Ha: "There are significant differences of accuracy between the different implants systems and their 3D positioning control mechanisms" or:

$$\mu_{accuracy\ drill\ key\ systems} - \mu_{accuracy\ keyless} \neq 0$$

To test our hypothesis, we aim to summarize the relevant data and to statistically compare them in order to demonstrate an eventual pattern.

2. Data collection and analysis

2.1 Information source

The principal information source was the PUBMED database. Additional search in Google Scholars database was performed. Articles bibliography and cross-references were used for further potential article identification.

2.2 Literature search

The search terms were inspired by the PICOC table: ((((computer assisted surgery) OR (guided implant surgery) OR (computer guided surgery))) AND ((dental implant*) OR (dental) OR (implant*))) AND ((accuracy) OR (precision)) AND (systematic[sb] OR Randomized Controlled Trial[ptyp] OR Comparative Study[ptyp] OR Meta-Analysis[ptyp] OR Observational Study[ptyp]) AND full text[sb] AND "last 10 years"[PDat] AND English[lang]. A flow chart of the search has been made to illustrate better and more in detail the literature selection process. (cf. III.A)

2.3 Data extraction

When available, data was extracted from included studies and classified according to the study design and type: randomized controlled trials *(Table 3)*, clinical trials in humans *(Table 4)*, in-vitro studies *(Table 5)*. The variables of interest were: implant system used, accuracy (coronal deviation in mm, apical deviation in mm, vertical deviation in mm and angular deviation in degrees) and guiding method (guidance level, brand, mechanism, flap/flapless, surgical and planning protocol, surgeon experience, software used, type of guide, guide support, guide fixation and guide fabrication), patient population, number of implants placed (total and per arch). We also extracted data concerning the study location, funding, objectives and the article conclusion. For in-vitro studies, we also registered data about the models used. All study groups were concerned by data extraction, however groups who were not of relevance for this study were not used in the statistical analysis (such as free hand surgery groups). All numerical data were recorded in *Table 6*. Associated variation was always recorded: standard deviation for means and range for medians (only when mean/SD were not available). Data was then divided according to the guidance level and system used: FG surgeries with drill key system *(Table 7)*, FG surgeries with keyless systems *(Table 8)*, mixed guidance levels: FG/HG surgeries with keyless and drill key systems respectively *(Table 9)*.

2.4 Dealing with missing or incomplete data

When data of interest was absent, N.M as for "Non-Mentioned" was put down. Vertical deviation can be measured at the apex level or at the platform level. If both were mentioned, the one with the highest deviation value was registered. Studies using different accuracy variables other than coronal horizontal, apical horizontal, vertical and angle deviation were excluded. Coronal horizontal deviation is sometimes reported as mesio-distal and bucco-lingual deviation individually. In that case, the highest value between the two was recorded. Studies that reported only the MD or BL deviation were included and the available data was recorded. About the vertical deviation, some studies prefer to use negative values when implants were inserted below the reference line and positive values when implants were not inserted deep enough. In such cases, we used the absolute value only for the statistical analysis in order not to increase the study heterogeneity without justification.

2.5 Statistical analysis

Continuous variables from the included studies were analysed with RStudio Desktop software (version 1.2.5042) as a single arm meta-analysis of means. Values expressed as mean and standard deviations were preferred. However, when median and range only were available, we used an online calculator put at disposal by statistic researchers, to estimate the mean and standard deviation.(19) In order to visualize better the results, a forest-plot was generated for each deviation (coronal, apical, vertical and angulation deviation). This process was repeated for each dataset (FG, HG) and for each level of evidence (RCT, CT, IV). Both groups data (keyless systems and drill key systems) could be displayed and compared in each forest plot for comparison. Nevertheless, if required data was missing, inter-group comparison resulted impossible. Most of the time, the keyless group was the most affected and was in this case excluded from the analysis. Used data sets can be seen in Tables 11 and 12.

2.6 Assessment of heterogeneity

The heterogeneity was measured by the I^2 index that quantifies it as a percentage: inferior to 25% (low), up to 50% (medium), superior to 75% (high). If low heterogeneity was observed, the results corresponding to the fixed effect model were accepted, while if heterogeneity was high, results corresponding to the random effect model were considered. The statistical significance level was set at $\alpha < 0.05$. Confidence intervals overlaps were considered as sign of statistically significant effects.

III. Results

1. Flow chart of the literature search

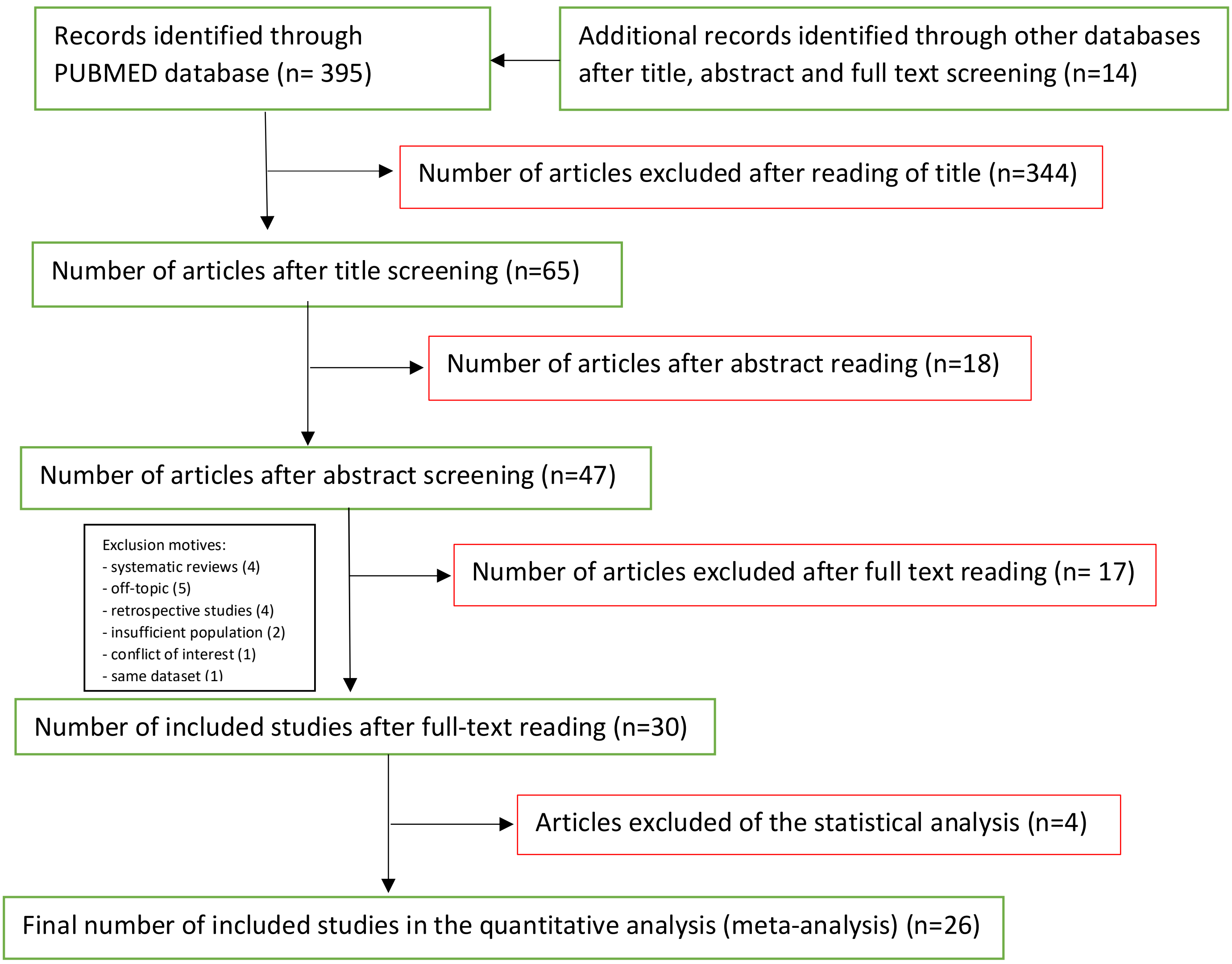


Figure 8: Flow chart

2. Description of the study population

2.1 Characteristics of the studies included

Ten randomized clinical trials, eight non-randomized prospective clinical trials and eleven in vitro studies were included. However, one randomized clinical trial had to be excluded from the statistical analysis as it measured solely the coronal deviation on mesio-distal and bucco-lingual axis only (20). Similarly, one clinical trial has also been excluded as the unique deviation given was the total deviation of all implants placed without distinction of the different systems used in the study (18). One in-vitro study was excluded from the statistical analysis as it aimed to demonstrate the influence of specific factors on the final implant deviation, its values tended to be exaggerated and therefore provoked an excessive heterogeneity (21). Only one randomized clinical trial (22) eventually compared the deviations generated by two different guided surgery systems, however both were FG systems with drill keys, only one system used physical depth stops while the other did not and relied only on visual depth assessment. No significant differences were found. Also, one recent in-vitro study (23) assessed the accuracy of 3 implants systems however results could not be compared with the rest of the data as it was not expressed as our inclusions criteria required. Those studies were excluded from the statistical analysis but were still used in our discussion.

A total of 2095 implants were placed with a system using a drill key in 428 patients while only 305 implants were placed with a keyless system in 94 patients. More detailed numbers are displayed in the following table.

		Implants placed with a drill key system	Number of patients	Implants placed with a keyless system	Number of patients
FG	RCT	375	187	147	50
	CT	455	148	119	39
	IV	1121		20	
	Sub-total	**1951**	**335**	**286**	**89**
HG	RCT	115	93	0	0
	CT	29	N.M	19	5
	Sub-total	**144**	**93**	**19**	**5**
	Total	***2095***	***428***	***305***	***94***

Table 2. Numerical recount of study populations

Often, in-vitro studies aimed to evaluate the impact of potential factors on accuracy whether they are extrinsic to the system implant (experience of the operator, method of evaluation…) or intrinsic (type of guide, sleeve height…) The characteristics of all the included studies are summarized in Table 8, 9 and 10.

2.2 Implant systems

The most used guided implant surgery system functioning with a drill key was the Straumann Guided Surgery system, while the most used keyless system was the Osstem OneGuide system. Other brands were used but they shared similar 3D control mechanisms. Depth stops and depth indicators were present on the burs of most FG systems allowing a physical control of depth drilling as well as a visual assessment of the depth. However, a minority of FG systems did not have any depth stop and only remained on the surgeon visual control of depth drilling. Only one system presented an exclusively physical depth control and did not allow any visualization of the depth drilling (24). It could be mentioned that a group of clinical study did use a unique keyless system that relied on drills of increased length and diameter (Camlog), nevertheless when compared to other FG systems, no statistical difference of accuracy was found.

2.3 Dental status

Most RCTs included single or partially edentulous patients. One RCT (22) included patients in need of at least 4 to 6 implants. In control trials however, almost all included patients were fully edentulous, except for two clinical trials that included both partial and total edentulous patients (24,25). In the keyless group, only one patient was fully edentulous (24) the remaining patients were partially or single edentulous.

2.4 Surgical guides

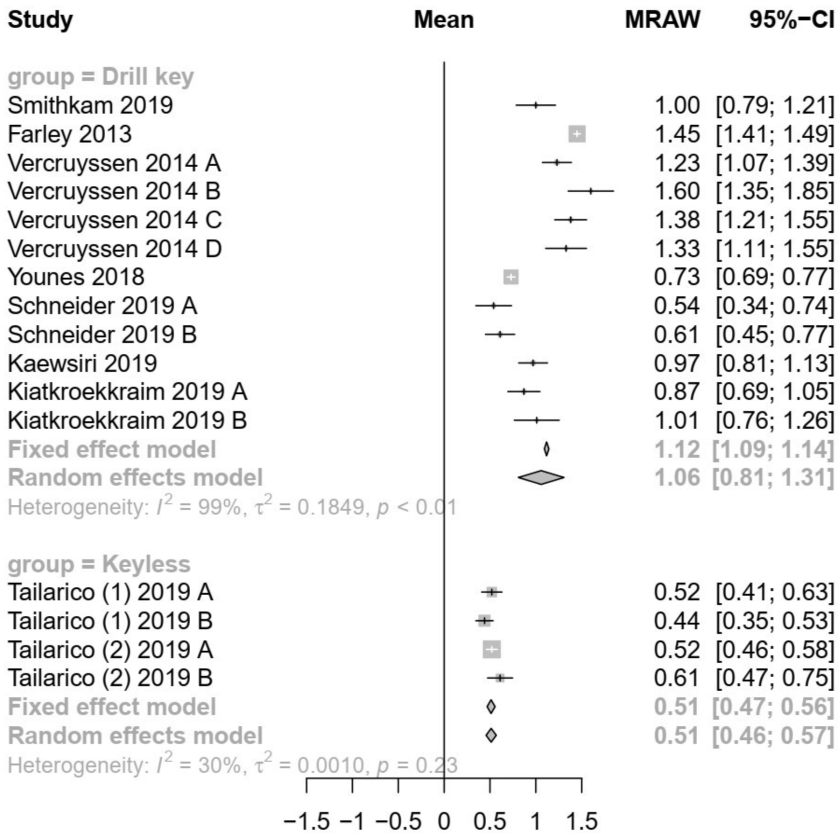
In the drill key group, the surgical guide was usually tooth-supported when patient was single or partially edentulous. Totally edentulous patients required the use of fixed mucosa supported surgical guides. Bone supported surgical guide was used only in one study (22). This same study was the only RCT in this group to use surgical guide fixation with pins. In the keyless group, surgical guides were all tooth-supported and fixed with 2 to 4 pins.

3. Accuracy

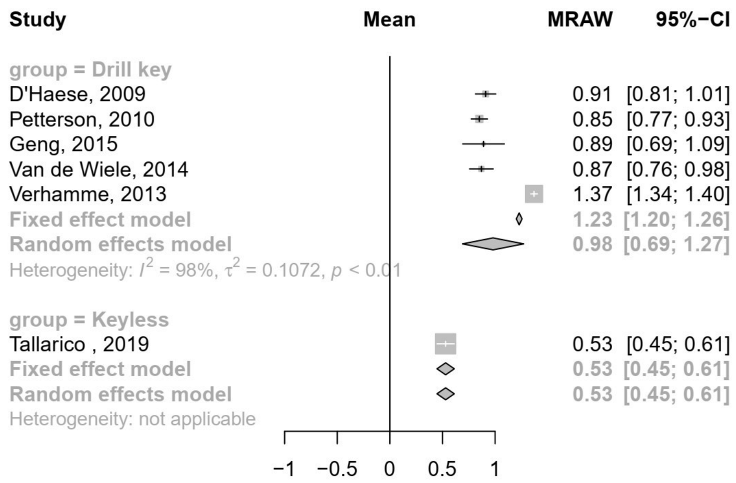
3.1 Coronal deviation

The coronal horizontal deviation could be compared between the drill key group and the keyless group with the FG surgery data set. The keyless systems have shown to be significantly more accurate with a mean coronal deviation of 0.51mm (0.46; 0.57) only while the drill key group averaged 1.06mm (0.81;1.31). The range of the confidence interval of the keyless group is significantly smaller than the drill key group which could suppose a higher predictability and reproducibility of the keyless systems. This is illustrated heterogeneity scores: low for the keyless group (30%) and high for the drill key group (>99%). The lower range value for the drill key group was of 0.34mm (Schneider, 2019) while the highest was of 1.85mm (Vercryussen, B, 2014). For the keyless group, the lower range value was of 0.35mm (Tallarico (1)B, 2019) and the highest of 0.75mm (Tallarico (2)B, 2019). Hence, although more unpredictable, drill key systems can reach similar accuracy levels than keyless systems. This tendency was also visible in the CT dataset. Keyless systems averaged 0.53mm (0.45; 0.61) of coronal horizontal deviation while drill key systems averaged 0.98mm (0.69;1.27). In-vitro deviation results present a high heterogeneity but are significantly lower than the deviation of the RCT group. Finally, the HG dataset demonstrated that the drill systems had a significantly higher coronal deviation compared to the keyless group deviation.

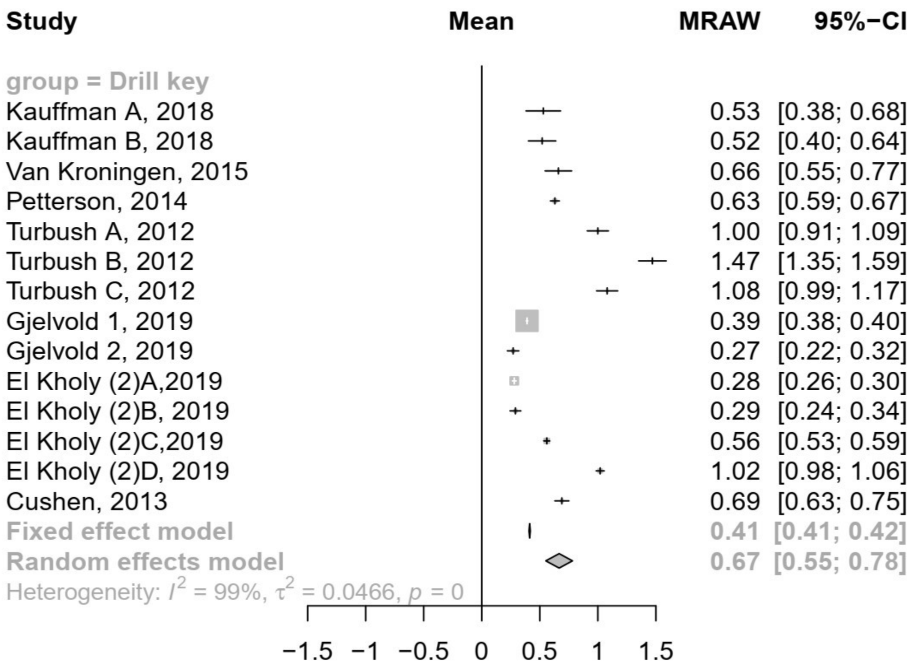
Forest-plots (coronal deviation):



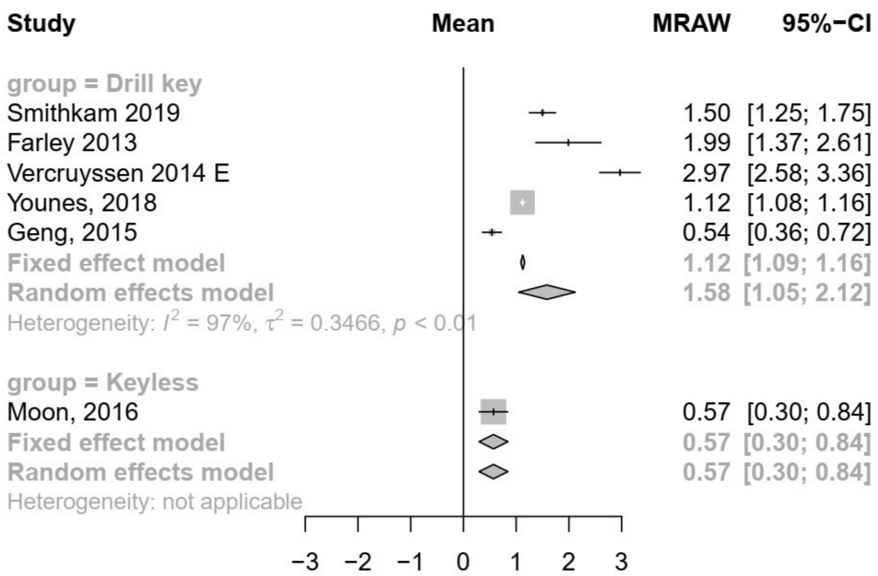
Forest plot 1.A: FG group – RCT evidence



Forest plot 1.B: FG group – CT evidence



Forest plot: 1.C – IV evidence

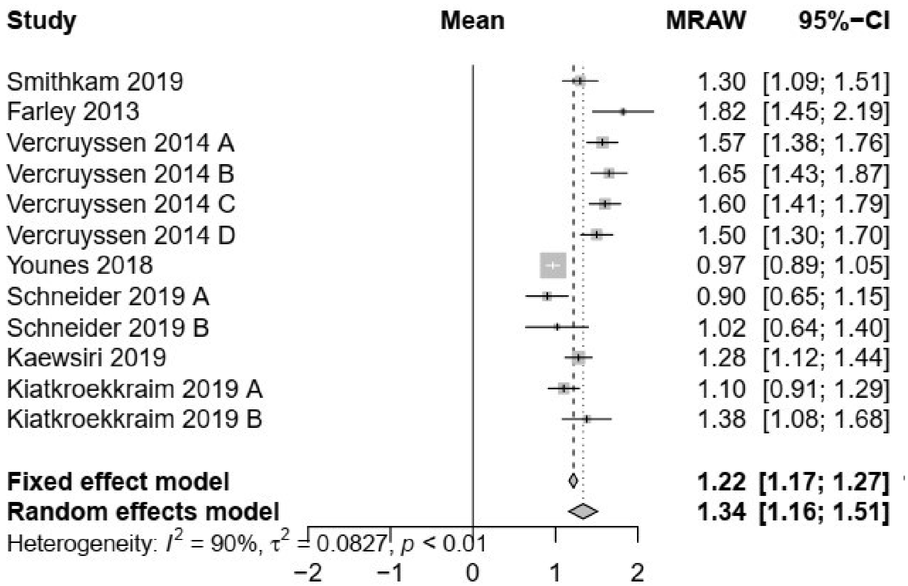


Forest plot: 1.D – HG group – RCT, CT evidence

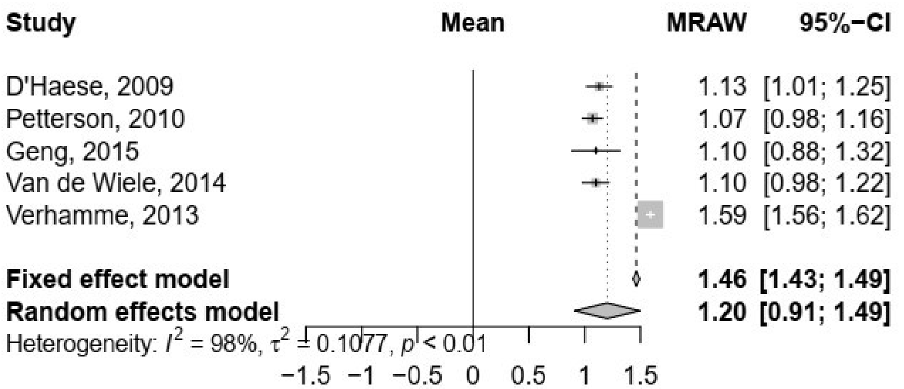
3.2 Apical deviation

Inter-group comparison of the apical deviation was impossible as data was missing in the keyless group. However, the mean apical implant deviation could be calculated in the drill key group 1.34mm (1.16;1.51) [RCT], 1.20mm (0.90;1.49) [CT] and of 0.87mm (0.65; 1.09) [IV]. The highest and the lowest range value of apical deviation belong to the RCT dataset with respectively 2.19mm (Farley, 2013) and 0.90mm (Schneider, 2019 A). Inter-group deviation comparison could be performed with the HG dataset and showed keyless system statistically significant superiority. Indeed, drill key systems averaged 1.91mm (1.32; 2.49) of apical deviation while the keyless system averaged 0.79 mm (0.51; 1.07).

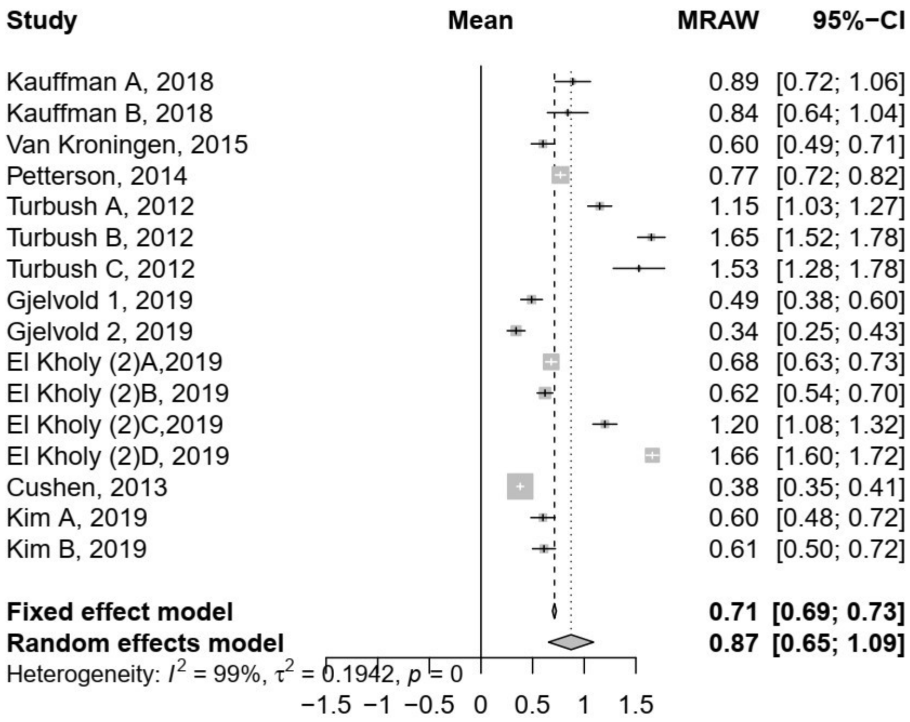
Forest-plots (apical deviation):



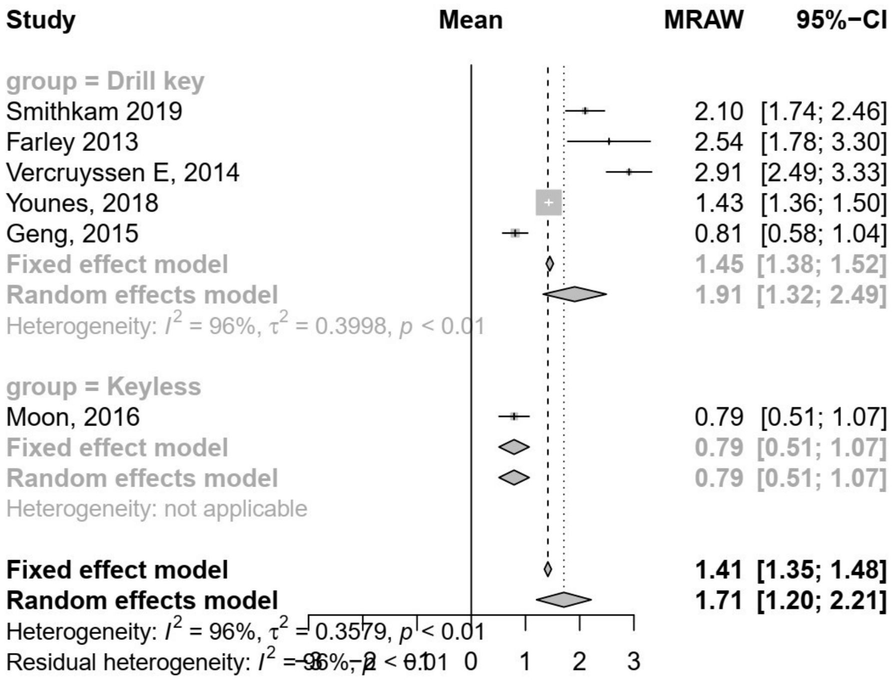
Forest plot 2.A: FG group – RCT evidence



Forest plot 2.B: FG group – CT evidence



Forest plot: 2.C – IV evidence

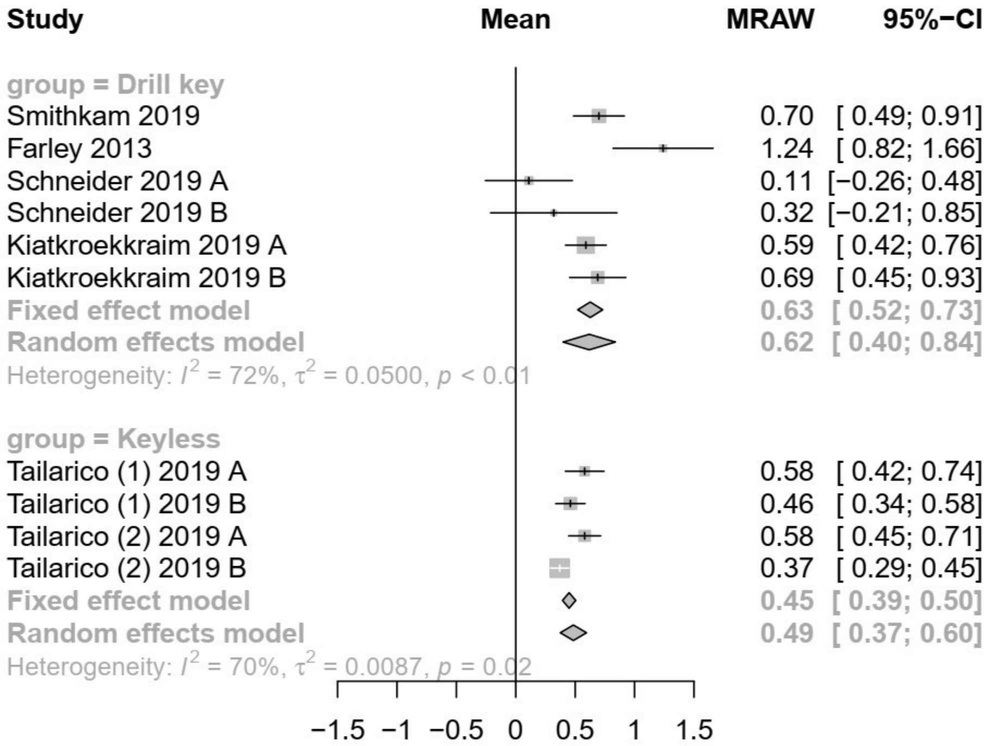


Forest plot: 2.D – HG group – RCT, CT evidence

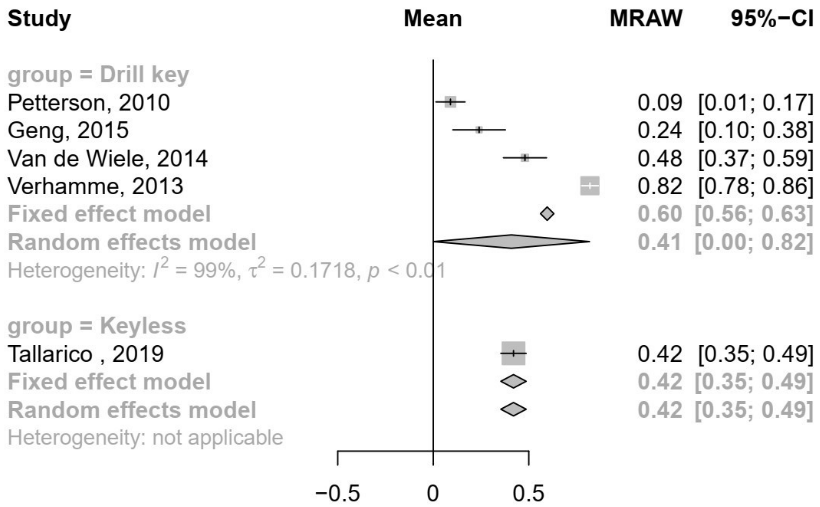
3.3 Vertical deviation

The RCT dataset allowed the inter-group comparison in acceptable conditions; the heterogeneity was inferior to 75% and therefore the fixed effect model was reliable. The mean vertical deviation of the drill key group averaged 0.63mm (0.52;0.73) while the keyless group averaged 0.45mm (0.39;0.50). Since both confidence interval do not overlap, we can deduce that there is a statistically significant lower vertical deviation in favour of keyless systems. The CT dataset showed a higher non-significant vertical deviation for the drill key group of 0.41mm (0.00;0.82) when compared to the keyless group 0.42mm (0.35;0.49). The IV dataset evidenced a mean vertical deviation of 0.49mm (0.37;0.60). The HG dataset however demonstrated a higher mean vertical deviation in the drill key group: 0.91mm (0.26; 1.55) when compared to keyless group: 0.64mm (0.38; 0.90).

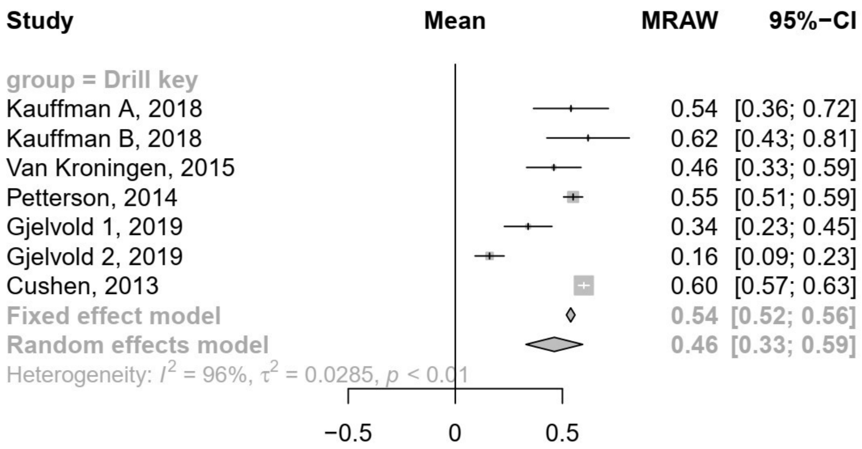
Forest-plots (vertical deviation)



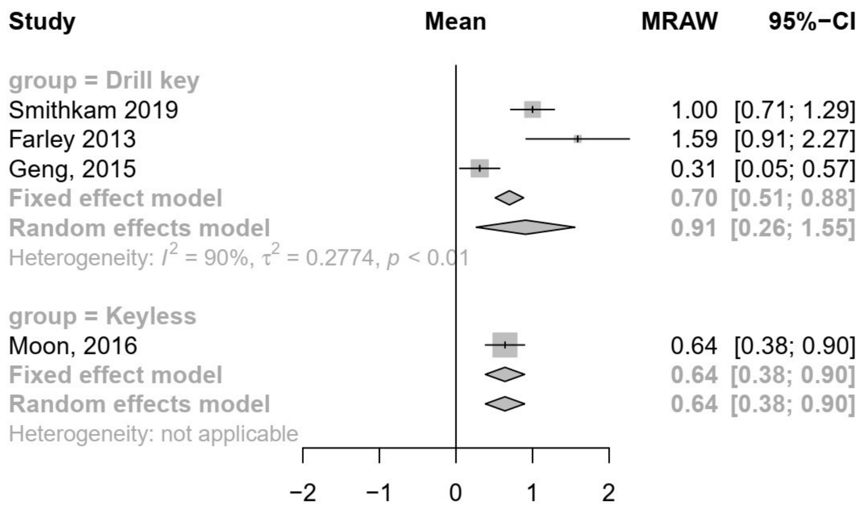
Forest plot 3.A: FG group – RCT evidence



Forest plot 3.B: FG group – CT evidence



Forest plot: 3.C – IV evidence

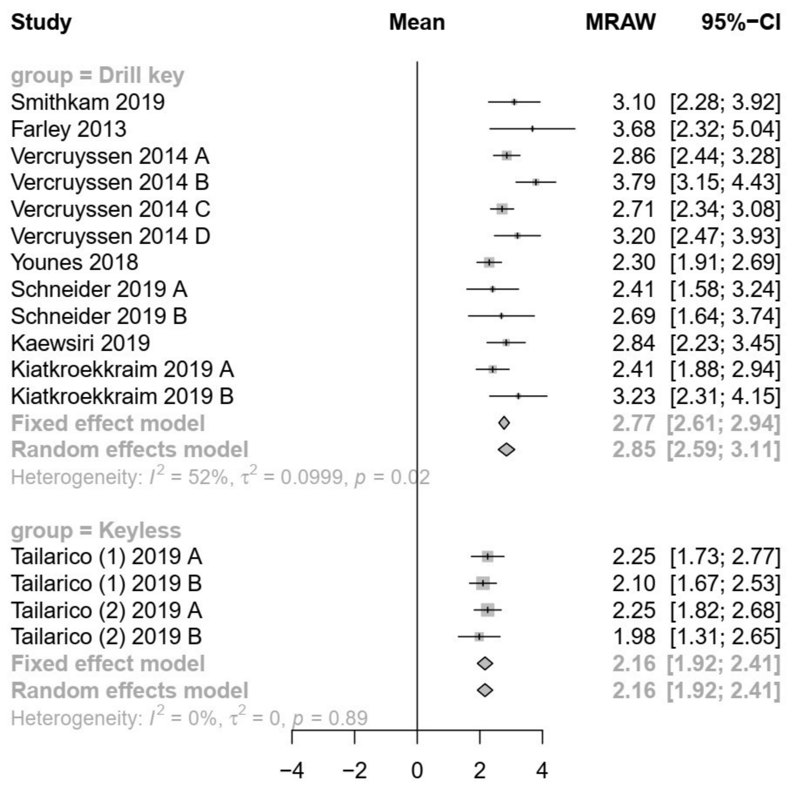


Forest plot: 3.D – HG group – RCT, CT evidence

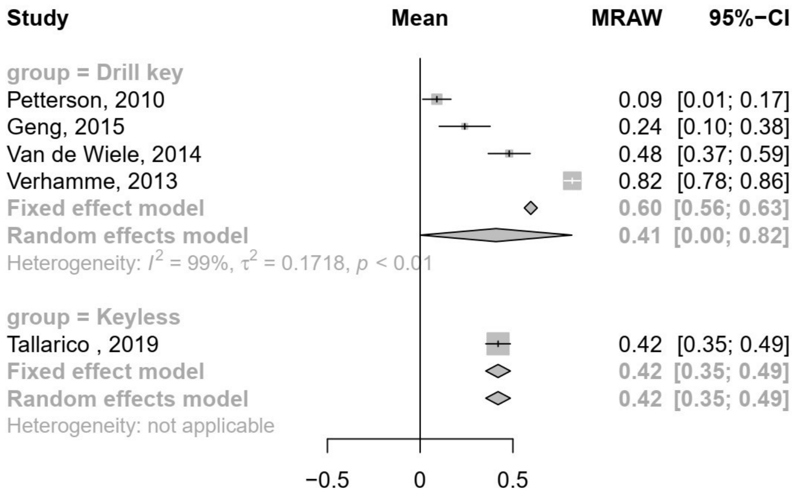
3.4 Angulation deviation

The RCT dataset allowed inter-group comparison of the angulation deviation, the fixed effect model results were accepted as heterogeneity was moderate. The drill key group averaged 2.77 degrees of angulation deviation (2.61;2.94) meanwhile the keyless group averaged 2.16 degrees (1.92; 2.41). The keyless systems angulation deviation is therefore significantly lower than drill key systems. The CT dataset illustrates a higher angulation deviation for the keyless group, however non-significant 0.42 (0.35;0.49) when compared to the drill key group: 0.41 (0.00;0.82). The IV dataset showed a higher angular mean deviation for the drill key group than the keyless group: 3.09 (2.08;4.10) versus 1.93 (1.66;2.21). Finally, the HG surgery dataset established a lower angulation deviation average of the drill key group: 6.22 (4.10; 8.34) when compared to the keyless group: 3.84 (3.17;4.51).

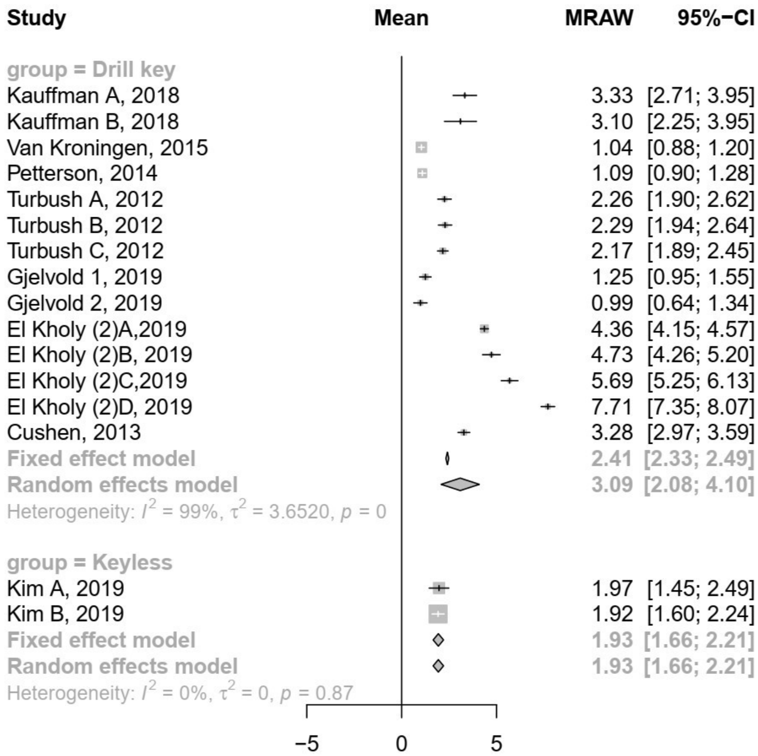
Forest-plots (angulation deviation):



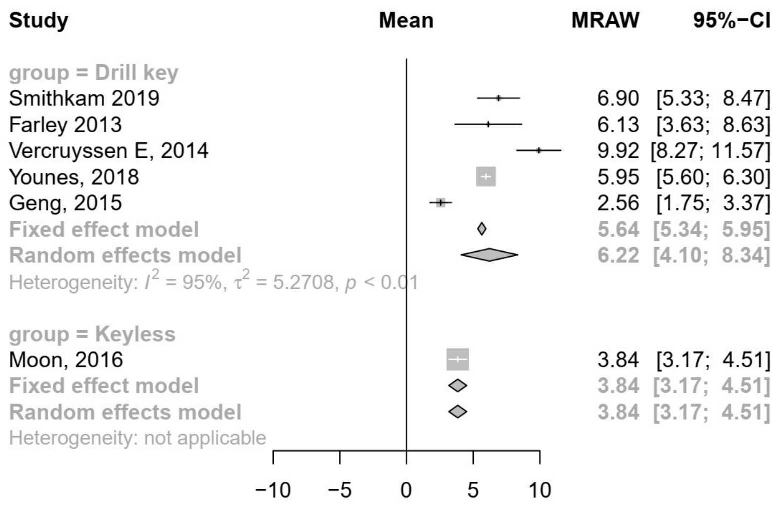
Forest plot 4.A: FG group – RCT evidence



Forest plot 4.B: FG group – CT evidence



Forest plot: 4.C – IV evidence



Forest plot: 4.D – HG group – RCT, CT evidence

4. Potential deviation factors extrinsic to the implant system

Investigation recently focused on the potential deviation factors generated by SLA guides. It has been demonstrated that bone and mucosa supported guide provide less precision than teeth supported guides (3). This conclusion is consistent with the results of our study, for the coronal and apical deviation. Angulation deviation seemed however to be less impacted by the type of guide used. A conclusion that is in line with in-vitro investigation (26). However, we could observe a tendency of bone-supported guides to generate higher deviation values (22). Patient movement during the scan is known to exaggerate the angulation deviation values. Some of the included studies encountered the same issue and the authors had to perform two different statistical analysis, one of which including the movement factor (27). In the same line, a recent in-vitro study aimed to verify if two different CBCT scanners would respectively measure the same discrepancies. No significant influence of the CBCT scanner on the deviation measurement was found, however the authors reminds that caution is needed when extrapolating the results to the clinical environment (28).

Mucosal thickness is also a potential factor of deviation particularly in smoker population. Indeed, oral mucosa resilience is higher in such patients resulting in a higher degree of freedom when positioning the surgical guide or even a scanning device. Significant errors along the entire planning and surgical process could be produced (29). Yet, investigators do not systematically exclude smokers from their clinical trials even though they are prone to more deviation (30). Some authors excluded heavy smokers (>10 cigarettes a day) (20,31) while others excluded patient with any kind of smoking habits (32).

Also, the use of flapless surgery was not consistent among the investigators even when the level of guidance was maximum and conditions seemed to allow such procedure (2,33). The fact that the use of flapless surgery was arbitrarily distributed among the included studies of this meta-analysis could influence its results.

Most common ways to reduce the chances of mispositioning of the surgical templates are the use of a bite index and of fixation pins (34,35). A recent in-vitro study compared the accuracy of guided implant surgery in totally edentulous patients when the surgical template was either hand-fixed or screw-fixed. Results were non-significant although indicating a better depth control (36). The authors have been making the hypothesis that drilling in a posterior site and contra-lateral to the side where the guide is held by hand could lift the guide without the operator noticing it and therefore generate incorrect implant positioning. However, they concluded that the use of fixation pins was still recommended in order to reach better precision levels while exhorting for more in vivo investigation (36).

It is interesting to mention that all the patients of the keyless group had their surgical guide stabilized by bite index and two to four fixation pins even if the template was tooth-supported and patient only single or partially edentulous (17,37,38). In some cases, it was placed without the use of a bit index but manually with a fit checking material (37). This could be one of the explanations for the lower deviation values found for this group. In the drill key group, none of the clinical trials (in partially or single edentulous patients) followed such meticulous protocol. Indeed, surgical template fit was in this case manually checked only.

As well, in the keyless group all of the surgical guides were tooth-supported. Hopeless prognosis teeth were extracted before the surgery. The surgical templates were designed to lean on all the residual teeth in order to improve the guide stability including the contra-lateral side of the operating site (38). A recent and well powered in-vitro study written by El Kholy et al (39) demonstrated that number and location of teeth supporting the surgical guide significantly improve the accuracy. Full-arch and four teeth supported guides assured the most minimal deviation. Once again, since the template were designed to be supported by all the remaining teeth, we can assume that this way the deviation could be reduced to a minimum.

Interocclusal opening and drill lengths should be thoroughly evaluated for each patient before accepting guided surgery as an adequate treatment plan. A minimum of 35mm of mouth opening is recommended to allow an adequate drill placement (40). An insufficient opening can result in an exaggerated deviation (22) or in the impossibility to use of the surgical guide (18,24). However, most recent clinical trials include now in their inclusion criteria a minimum interocclusal distance: 30mm (31), 40mm (30) but it remains sometimes unspecified (25,41). Another relevant information regarding the surgical guides used in the keyless group is that part of the guides used had non-metallic and opened sleeves (laterally) like illustrated below. (cf. figure 9)

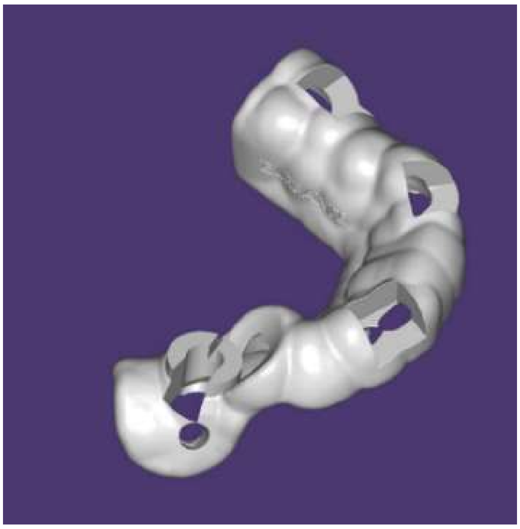


Figure 9: Surgical template without metallic sleeves

These built-in sleeves feature a lateral opening that aim to facilitate the drill insertion in posterior sites. The conclusion of one of the included RCT comparing conventional sleeves to open sleeves were that the latter were more accurate in the vertical plane and angle. This is another potential advantage that the keyless group has over the drill key group which could explain the lesser mean deviations.

The influence of experience on the accuracy of guided implant surgery has been subject to a lot of debate in the last years. Yet, to our knowledge there is still no uninanimous answer to that interrogation. The existence of a learning curve still remains unclear. However, Casetta et al (35)(42) concluded lately that guide positioning errors were significantly higher for inexperienced surgeons also when an occlusal index was used. Main consequences of such mistake is the significant increase of implant depth, coronal and apical deviation (especially in the bucco-lingual plane) while angulation was not significantly influenced. Even if most of the studies mentionned the operator experience, it was not systematic and this variable is unknown for some of the included studies.

Among other eventual variables known to affect accuracy we could point out bone density, implant length, surgical site location and the diversity of the surgical and planning protocols.

5. Potential deviation factors intrinsic to the implant system

In vitro investigation is helpful in order to determine potential deviation factors directly related to the surgical kit design. Indeed, in vitro design allows the standardization of the procedures and therefore the reduction of eventual bias that we encounter in a clinical environment. The drill key systems have been thoroughly studied but few information about keyless systems was found.

Drill guidance and drill related deviation are known to significantly impact the accuracy (21,43). The role of drill key height (16,21) and free drilling distance has recently been acknowledged while the sleeve height has been rejected. The free drilling distance can be defined as the linear measurement from the bottom of the guided sleeve to the tip of the surgical drill (bottom of the osteotomy). (cf. figure 10 below)

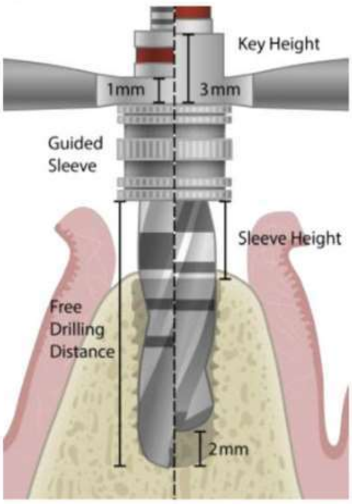


Figure 10. Illustration of Free Drilling Distance and key height (21)

Increasing the drill key height allows a higher guidance and control of the drill in a centric position within the sleeve and therefore a more precise drilling. As well, the increase of drill length is associated with a higher drill lateral movement and shattering (44). Schneider et al (43) established that the drill lateral movement can be reduced by increasing the key height and decreasing the drill length. Results that are in line with the most recent investigation (21). Clinical trials whose surgical protocol involves a shorter drill, a lower sleeve height and a longer drill key can have more precise results.

A gap between the sleeve and the drill is necessary in order to avoid contact and consequent heating of the metal but it inevitably produces a certain amount of tolerance (16,44). Koop et al (44) evaluated in vitro the maximal deviations that can be generated exploiting the tolerance of drill key and keyless systems. The use of a drill key seemed to be preventing deviation better than keyless systems. There was a correlation between the amount of deviation and the increase of the free drilling distance. This correlation was stronger for the keyless system used than for the drill key system. However, the system used in that study (ExpertEase) although keyless had major differences compared to the one used in the keyless group of our meta-analysis (Osstem One Guide) and therefore those results cannot be extrapolated. Indeed, the first system the sleeve insert was drill-held and could move vertically along the axis of the drill while realizing the osteotomy. Such system, to our knowledge remains barely used nowadays and seem unreliable. In the second system however, the sleeve although drill-held was built-in and could not move along the drill as illustrated in the follow images. (Osstem) In vitro investigation dedicated to this system is lacking.

Figures 11 (left) and 12 (right): Illustration of the contact between drill and surgical guide (Images provided by Osstem)

Guided implant placement has also been incriminated by the authors of the clinical trials included in our study as a possible source of deviation. In fact, when access is particularly difficult, the implant mount driver can be angulated and thus prematurely contact with the guide impeding proper surface matching (17).

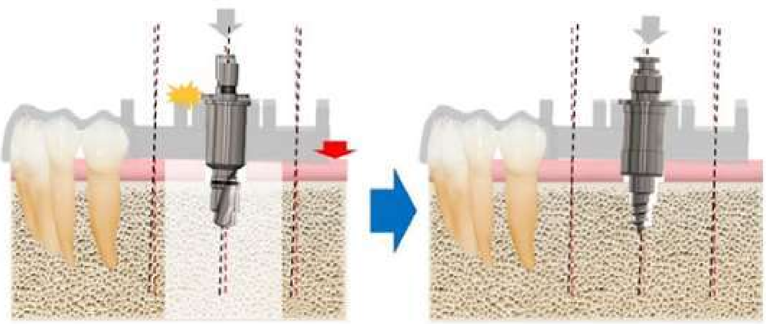


Figure 13: Complication of guided implant insertion when implant mount driver pressure on the guide and reduce final implant accuracy. (17)

As to guided insertion in drill key systems, Cassetta et al (42) mentioned that despite the tolerance between the sleeves and drills or the implant holder, excessive friction between these components was a frequent issue. Such phenomenon could also be a source of deviation.

Finally, it has been established that simplified drilling protocols tended to improve the accuracy of guided surgery. In fact, the reduction of the number of drilling steps lead to a reduction to a reduction of potential source of errors (45). We could mention that the keyless system here investigated claims a reduction in the number of drilling steps depending on patient's bone density (between 2 and 4 drilling steps maximum). For a 4 mm diameter implant for example, the drilling sequence of this keyless system requires between 2 (soft bone) to 3 drilling steps (hard bone) before implant placement. On an indicative basis, for an equivalent implant placed with a common drill key system, the drilling sequence requires at least 5 drilling steps. It is relevant to mention that the belief that single-drill techniques would be related to a prejudicial increase of temperature has been rejected by the literature (45). This fact could as well explain the better accuracy results obtained by the keyless group.

Potential factors of deviation originated by the implant systems flaws exist. In vitro investigation is still on the process of identifying such factors which could later be confirmed by in vivo trials.

IV. Discussion

1. Study design

A key concept to keep in mind for the reader is that the deviation isn't exclusively generated by the surgical procedure. It has been demonstrated that reasons for deviation are multifactorial and results from the cumulation of errors in various aspects of the whole process such as planning, scanning and guide fabrication. In other words, analyse of accuracy of guided implant surgery should only be performed when acknowledging the influence of external factors. Minimizing such influence making up ideal datasets only with data from studies with a similar protocol or inclusion criterias would not only be problematic but also results in groups with sample size too small to allow any comparison. Therefore, our dataset solely includes data based on the surgical system used in the included studies ignoring in a relative extent this external source of bias of the deviation values. This approach results in an inevitable high heterogeneity of the datasets, especially for the FG group as more literature and variety of study parameters were available. To our knowledge, all the meta-analysis performed on guided implant surgery accuracy faced the same conditions (46,47). The use of adapted statistical tools such as a regression analysis to search for correlations between external factors and implant accuracy could eventually have provided more information on this effect.

2. Limited data of the keyless group

Clinical trials evaluating keyless systems and simultaneously suitable to inclusion in this meta-analysis were rare. Nevertheless, 3 suitable clinical trials including one randomized were recently published (17,37,38). They allow the constitution of a correct sample size, but they presented certain limitations. Particularly the fact that these three clinical trials were conducted by the same investigation team and that the first author is a consultant for the implant brand used in the trials. However, they were self-funded and the authors denied any conflict of interest. They mention that the data belonged to the authors and by no means did the companies interfere with the conduct of the trial or the publication of the results.

The main feature that fortified the validation and the inclusion of these trials in our study was the rigorous and transparent methodology employed.

3. Study results

The comparison between the results of our study (RCT dataset, drill key system) with the results of two other meta-analysis revealed a stable amount of coronal, apical and vertical deviation along the years.

Indeed, Van Assche et al (8) in 2012 averaged 1.0mm (0.74; 1.31) coronal deviation and Bover-Ramos et al (47) in 2018 averaged 1.10mm (0.91; 1.29) while we estimated a mean coronal deviation of 1.06mm (0.81; 1.31). Regarding the apical deviation, Bover-Ramos et al (47) and Van Assche et al (8) both found identical mean apical deviations with respectively: 1.40mm (1.16; 1.64) and 1.4mm (1.06; 1.70) while we calculated a mean of 1.34mm (1.16; 1.51). The vertical deviation also remained stable, we estimated a mean of 0.63mm (0.52; 0.73) while Van Assche et al (8) found 0.6mm (0.17; 0.95). Bover-Ramos et al (47) values are equivalent even if slightly higher with 0.74mm (0.54; 0.95) of mean vertical deviation.

Nevertheless, our results evidenced a significant improvement of the angulation over time. We calculated a mean of 2.77° (2.61; 2.94) of angulation deviation while Bover-Ramos et al (47) estimated a mean of 3.98° (3.31; 4.64) and Van Assche et al (8) a mean of 4.2° (3.59; 4.96). This reduction is statistically significant.

From this data, we could suggest that the drill key system is predictable and allows results reproducibility. More time and investigation are necessary to make the same assumption about keyless systems. One could think that the similarities are the results of a similar dataset and included studies, however only one RCT was also included in our study and in Bover-Ramos et al meta-analysis (47). None of the included studies by Van Assche et al (8) were included in our study.

4. The confusion around coronal deviation

Little data about the distribution of the deviation on the transversal plane is available. Our work has put forward the variability of the data reported for the coronal deviation. Some articles published the global deviation (22) that is defined as the 3D distance between the coronal centers of the planned and placed implants. While others, for example the authors of the clinical trials of the keyless group provided the mesio-distal deviation only (17,37,38) or lateral linear deviation depending on the author. However, such approach can be limited as it doesn't include the bucco-lingual deviation which is capital for an adequate evaluation of treatment clinical success and precision (33). A concerning issue with this lack of uniformity is that lateral linear deviations values are usually smaller than the global deviation values (22). Van Assche et al (8) in their meta-analysis on the accuracy of guided surgery included any study reporting coronal implant deviation as a unique distance or as two individual vectors: horizontal (x) or vertical distance (y). More recently, Bover-Ramos et al (47), mentions horizontal coronal deviation suggesting the inclusion of mesio-distal datas only. If a consensus of the definition of coronal implant deviation was to be reached it would avoid misinterpretations and facilitate the data comparison process.

5. Absence of clinical success indicator

Also, most of the time, a range of implant positions are compatible with clinical success fulfilling the functional, aesthetics, phonetic and hygienic requirements. Therefore, such numerical values of deviation could have a relative validity and care should be taken as to its interpretation. It could be judicious to incorporate to analysis clinically oriented variables to judge better of the treatment success. (33)

V. Conclusion

The results of our study revealed the superiority of keyless systems concerning coronal, apical, vertical and angulation deviations and therefore we rejected our null hypothesis and accepted our alternative hypothesis. We have seen the influence of external and internal factors to the surgical instrumentation on the accuracy. Surgeons knowledge about these factors is capital in order to successfully and safely carry out guided dental implant surgeries.

VI. Prospect for the future

Investigation regarding deviation factors in guided surgery must carry on. In vitro research is convenient for the identification of deviation factors related to surgical instruments. However, in vivo studies should provide result confirmation. More studies measuring the accuracy of keyless systems are needed. Eventually, a randomized clinical trial comparing the accuracy different systems would be optimal. The split-mouth design is an interesting concept to reduce the risk of bias. Also, more detailed information regarding the surgical kit used and treatment success should be provided. Finally, a consensus on the assessment of coronal deviation would be useful in order to facilitate future research and meta-analysis.

VII. ANNEXES

Annex 1: Work acceptation letter (carta de aceptación del trabajo)

Annex 2: Tables

Annex 1: Work acceptation letter (carta de aceptación del trabajo)

uic barcelona

FACULTAT DE ODONTOLOGÍA
Trabajo Final de Grado

Nº ID TFG: TFG-87/2019-A57

Sr/a. GOURDACHE , Ilyès

Desde la Coordinación de Trabajos de Final de Grado se le comunica que se ha aceptado que realice el trabajo que lleva por título ”Vertical, horizontal and angulation positioning control in guided implant surgery: accuracy of available systems“, una vez superados sus estudios lo pueda defender ante un tribunal previa aprobación de su tutor y de la coordinación de TFG.

La persona encargada de tutorizarle durante este período de tiempo será el Dr/Dra. JORDI GARGALLO

Adicionalmente, se le informa que la normativa de la UIC establece que hace falta obtener una evaluación favorable del Comité de Ética en la Recerca (CER) o del Comité de Ética de Estudios Clínicos (CEIC), antes de iniciar la investigación. Deberá aportar este informe cuando lo obtenga.

Le saluda cordialmente

Dr. Oscar Salomó
Coordinador Trabajo Final de Grado Odontología

Sant Cugat del Vallés a 29 de Noviembre 2019

Annex 2: Tables

Randomized Clinical Trials | Table 4 | Prospective randomized studies

Article, year, ref.	Location	Funding	Objectives	Implant system used (brand) and guiding method	Flap	$n_{patients}$	$n_{implants}$	$n_{implants}$ per arch	Conclusion
Smitkarn, 2019 (35)	Faculty of Dentistry, Chulalongkorn University, Thailand	University funds	Compare accuracy of FG and FH surgery in single edentulous spaces	FG - drill keys (Straumann) Closed SLA guide	Yes	26	30	20 (Md) 10 (Mx)	Static CAIS: > accuracy but < primary stability than FH
				HG – non computer guided (Straumann) Laboratory produced guide (wax-up)		26	30	11 (Md) 19 (Mx)	
Farley, 2013 (36)	The Ohio State University College of Dentistry, USA	Biomet 3i support - no conflicts of interest reported	Compare accuracy of FG and conventional HG surgery in a split mouth design (symmetric edentulous areas)	FG – drill keys (Biomet 3i) Closed SLA guide	No	5	10	7 (Md) 3(Mx)	Single implants placed with CAD/CAM guides usually closer to planned position vs HG (especially in coronal-horizontal distances – more consistent deviations)
				HG – non computer guided (Biomet 3i) Laboratory produced guide (wax up)	Yes	5	10	7 (Md) 3 (Mx)	
Marei, 2019 (20)	College of Dentistry, Imam Abdulrahman Bin Faisal University, Dammam, Saudi Arabia	N.M	Measure the influence of surgeon experience on theaccuracy of implant placement in partially edentulous	HG (drilling guided) - drill keys + FH Guided drilling until 3.2 mm Ø (Universal Surgical Simplant Kit - Dentsply) For 3.7mm implants +1 FH drill (3.4mm) For 4.1mm implants + 2 FH drills (3.4 and 3.8 mm) For 4.7mm implants + 3 FH drills (3.4, 3.8, and 4.4 mm) FH osteotomy with Zimmer Kit (physical stops for depth control) and FH implant placement Closed SLA guide (Dentsply Implants NV, Kessel-Lo, Belgium) – teeth supported + fixation pins in case of posterior free end saddles.	No	10 (Control group: experienced surgeons)	25	N.M	Experience does affect implants accuracy especially in the bucco-lingual direction. The use of HG surgery doesn't completely compensate for the level of operator experience, but it might be of use for novice surgeons.
						10 (Test group: inexperienced surgeons)	15		

Article, year, ref.	Location	Funding	Objectives	Implant system used (brand) and guiding method	Flap	$n_{patients}$	$n_{implants}$	$n_{implants}$ per arch	Conclusion
Vercruyssen, 2014 (22)	Catholic University Leuven (Belgium)	No conflicts of interest. Material delivered free of charge: Implants (Astra Tech Company – Sweden) SLA guides (Materialise Dental Company - Leuven, Belgium)	Assess the accuracy of guided surgery compared to free hand surgery or the use of a surgical template in fully edentulous jaw.	FG group 1: Materialise Universal® (Mat Uni) - drill keys No drilling physical stop : visual assessment + non guided implant placement	No	12 (Mat Uni Mucosa)	55	6* (Mx) 6 (Md)	Inaccuracy of guided surgery is clearly less than for non-guided surgery (in particular at entry point, implant apex and of angular deviation) Guided surgery has an added value, but at each step awareness for possible errors in deviation is crucial for treatment success. Accuracy difference between the two FG systems isn't statistically nor clinically relevant *NB: 4 to 6 implants are placed in each jaw
				Closed SLA guide : fixation by 3-4 anchor pins	Yes	12 (Mat Uni Bone)	53	9 (Mx) 3 (Md)	
				FG group 2: Facilitate system™ (Fac) – drill keys Built-in physical stops on the drills + guided implant insertion	No	14 (FacMucosa)	52	7 (Mx) 5 (Md)	
				Closed SLA guide : fixation by 3-4 anchor pins	Yes	12 (FacBone)	52	6 (Mx) 6 (Md)	
				HG group: pilot-drill Laboratory produced guide (wax-up)	Yes	12 (Pilot drill)	51	3 (Mx) 9 (Md)	
				FH group: software planning was allowed and visualized during surgery	Yes	12 (Mental)	51	8 (Mx) 4 (Md)	
						Total : 74	Total: 314	N(Mx) = 39 N (Md)= 33	

Article, year, ref.	Location	Funding	Objectives	Implant system used (brand) and guiding method	Flap	$n_{patients}$	$n_{implants}$	$n_{implants}$ per arch	Conclusion
Younes, 2018 (2)	Vrije Universiteit Brussel (VUB), Faculty of Medicine and Pharmacy	No conflicts of interest. Material delivered free of charge: Implants, surgical guides and prosthetic component: Dentsply One author has collaboration agreements with Nobel Biocare and Straumann	Compare the effectiveness of FH, HG (pilot guided) and FG implant surgery in partially edentulous patients (at least 2 teeth distal of the canine) by means of the Apical Global Deviation (AGD). Study the relation to the additional financial cost and time spent.	FH group: no guidance	Yes	11	26	N.M	The extra operational cost for guided implant surgery is acceptable and clinically justified since cementation can be avoided. FG surgery is the most efficient surgical approach, even though the absolute operational cost is higher when compared to PG and FH surgery.
				HG group: pilot-drill guided 1st osteotomy guided using a surgical guide and a 1.95mm pilot drill (built-in depth stop). No drill keys were used. Following osteotomies were performed FH using corresponding visual depths markers on the bur. Tooth supported guide	No	11	24		
				FG group: drill keys Visual depth control (marking on the drill) Tooth supported guide	No	10	21		

Article, year, ref.	Location	Funding	Objectives	Implant system used (brand) and guiding method	Flap	$n_{patients}$	$n_{implants}$	$n_{implants}$ per arch	Conclusion
Schneider, 2019 (37)	University of Zurich, Zurich, Switzerland	University funds	Compare conventional and computer-assisted implant planning and placement (CAIPP) protocols regarding surgical planning predictability, intraoperative complications, and patient-centered outcomes in partially edentulous patients	FH group: osteotomy orientation was strictly monitored intraoperatively using direction indicators, the surgical guide, and opposing teeth) Tooth supported guide Astra Tech Implant System, Dentsply Sirona Implants, or Straumann (randomized)	Yes	16 (Control group – FH) *10 cases excluded (final casts did not allow a reliable file overlapping)*	16	Not mentioned = said to have no influence on the results differences between groups	CAIPP protocols showed a higher diagnostic potential than conventional protocols regarding predictability of bony defects, GBR procedures, and implant dimension. The rate of complications and unexpected events was high for both protocols. Therefore, a strict intraoperative implant position monitoring is mandatory for both conventional and CAIPP protocols. Despite the complications, the final prosthetic and biologic outcomes were not significantly impaired.
				FG group (T1): CBCT + Rx guide (based on diagnostic wax-up) Planning: Simplant, Dentsply, Sirona Surgery: Straumann Guided Surgery kit or Facilitate (Dentsply Sirona Implants) = drill keys (Sleeve-in-sleeve concept) OPG + Rx guide (from wax-up) later converted into Qx guide. SLA closed tooth-supported surgical guide with metalic sleeves (Simplant Guide, Dentsply Sirona).	Yes	11/24 *Cases exclusion: 3 (final casts did not allow a reliable file overlapping) + 11 (partial or complete impossibility to use the surgical splint/guided surgery)*	11		
				FG group (T2): CBCT (patient only) + optic scan of diagnostic cast Planning: CBCT and model scan merged together by the clinician (SMOP, SwissMeda) Closed surgical guide with non-metallic sleeves designed by the software planning company (SwissMed) and printed in-house using a 3D printer (Objet Eden 260V, Stratasys).	Yes	11/23 *Cases exclusion: 3 (final casts did not allow a reliable file overlapping) + 11 (partial or complete impossibility to use the surgical splint/guided surgery*	11		

Article, year, ref.	Location	Funding	Objectives	Implant system used (brand) and guiding method	Flap	$n_{patients}$	$n_{implants}$	$n_{implants}$ per arch	Conclusion
Kaewsiri, 2019 (34)	Chulalongkorn University, Thailand	University funds	Compare the accuracy of implant placement between static and dynamic computer assisted implant surgery (CAIS) systems in single tooth space.	Static CAIS group: FG group Planning: coDiagnostiX software version 9.7 (Dental Wings Inc, GmbH) SLA surgical guide – tooth supported (VisiJet MP200, VisiJet M3 Stone Plast, 3D Systems, Inc.) 5mm diameter T-sleeve from Straumann was embedded in the guide to allow guided drilling and implant placement Surgery: Straumman Guided Surgery Straumman Guided Surgery protocol - drill key system	No (25) Yes (5)	Static CAIS group (n=30)	30	21 (Mx) 9 (Md	Implant placement accuracy in single tooth space using dynamic CAIS appear to be the same to that of static CAIS.
				Dynamic CAIS group: DN group Planning: Iris–100 software (EPED Inc.) Surgery: Implant navigation system machine (IRIS-100, EPED Inc.)	No (25) Yes (5)	Dynamic CAIS group (n=30)	30	16 Mx 14 Md	

Article, year, ref.	Location	Funding	Objectives	Implant system used (brand) and guiding method	Flap	$n_{patients}$	$n_{implants}$	$n_{implants}$ per arch	Conclusion
Kiatkroekkraim, 2019 (43)	Faculty of Dentistry, Chulalongkorn University, Thailand	University funds	Compare the accuracy of implant position when placed by static CAIS technique using surgical guides produced by the two different optical surface scan acquisition techniques: intraoral vs. extraoral	Intraoral scan group FG : Straumann Guided Surgery - drill key Guided implant placement Full arch intraoral scan + bite scan (3Shape) merged with CBCT to allow digital planification Printing: SLA guides (MAX UV 3D printer; Asiga, Erfurt, Germany) with VisiJet MP200 preparation and VisiJet M3 StonePlast acrylic mixture material (3D Systems, Inc., Rock Hill, SC, USA).	No Yes (both)	n= 20	30	19 (Mx) 11 (Md)	There was no statistically significant difference between the groups. CAIS conducted with stereolithographic guides manufactured by means of intraoral or extraoral scans appears to result in equal accuracy of implant positioning.
				Extraoral (model) scan group FG : Straumann Guided Surgery - drill key Guided implant placement Patient laboratory model scan (3shape) merged with CBCT to allow digital planification Printing: SLA guides (MAX UV 3D printer; Asiga, Erfurt, Germany) with VisiJet MP200 preparation and VisiJet M3 StonePlast acrylic mixture material (3D Systems, Inc., Rock Hill, SC, USA).		n=22	30	21 (Mx) 9 (Md	

Article, year, ref.	Location	Funding	Objectives	Implant system used (brand) and guiding method	Flap	$n_{patients}$	$n_{implants}$	$n_{implants}$ per arch	Conclusion
Tallarico (2), 2019 (28)	Private center	Self-funded No conflict of interested stated One author is a consultant for Osstem	compare virtual planning accuracy and template-related complications of computer-assisted template-based implant placement using conventional impression and scan of a physical stone cast or intraoral scanning	Fully digital group: intraoral digital impression FG surgery: Osstem Guide Taper Kit, Osstem, Korea - keyless system Software: Exocad DentalCAD, Exocad GmbH, Darmstadt, Germany and 3Diagnosys v. 4.2, 3DIEMME, Cantù, Italy SLA template: Rapid prototyping technology (New Ancorvis, Bargellino, Italy) - teeth or mucosa supported Implants: Osstem TSIII, Osstem, Seoul, South Korea	No or tissue punch	10	28	33 (Mx) 24 (Md)	Despite the limitations of the present trial, intraoral scanning may be a viable option for the rehabilitation of partially edentulous patients when computer-guided template-assisted implant placement is used. In both groups, the maximum 3D deviations (angular, horizontal and vertical) did not exceed the safe offset of the software
				Conventional group: traditional impression FG surgery: Osstem Guide Taper Kit, Osstem Software: Exocad DentalCAD, Exocad GmbH, Darmstadt, Germany and 3Diagnosys v. 4.2, 3DIEMME, Cantù, Italy SLA template: Rapid prototyping technology (New Ancorvis, Bargellino, Italy) - teeth or mucosa supported Implants: Osstem TSIII, Osstem, Seoul, South Korea		10	29		

Article, year, ref.	Location	Funding	Objectives	Implant system used (brand) and guiding method	Flap	$n_{patients}$	$n_{implants}$	$n_{implants}$ per arch	Conclusion
Tallarico (3), 2019 (29)	Private center	Self-funded No conflict of interested stated One author is a consultant for Osstem	Compare virtual planning accuracy of novel computer-assisted, template-based implant placement techniques, which make use of CAD/CAM SLA surgical templates with or without metallic sleeves	Control group: conventional SLA template with metalic sleeves FG surgery: Osstem Guide (Taper), Korea - keyless system (visual depth gauge) Software: Exocad DentalCAD, Exocad GmbH, Darmstadt, Germany and 3Diagnosys v. 4.2, 3DIEMME, Cantù, Italy Printing: independant certified center (New Ancorvis srl, Bargellino, Italy)	No *(if possible)*	15	41	N.M	With the limitation of the present randomized controlled trial, the surgical templates designed without metallic sleeves were more accurate in the vertical plan and angle compared to the conventional template with metallic sleeves. Open sleeves should be used with caution in the molar region only in case of reduced interarch space. Nevertheless, in both groups, the maximum tridimensional deviations (angular, horizontal, vertical) did not exceed the safe offset of the software. Further research with a higher sample size and longer follow-up are needed to confirm these preliminary results
				Experimental group: SLA template without metalic sleeve (open/closed sleeve design) FG surgery: OneGuide Kit, Osstem, Korea - keyless system Software: Exocad DentalCAD, Exocad GmbH, Darmstadt, Germany and 3Diagnosys v. 4.2, 3DIEMME, Cantù, Italy Printing: independant certified center (New Ancorvis srl, Bargellino, Italy)		15	49 *(16: open sleeve, 33: closed sleeve)*		

Clinical Trials

Table 5

Article, year, ref.	Type of study	Location	Funding	Objectives	Implant system	Flap	$n_{patients}$	$n_{implants}$	$n_{implants}$ per arch	Conclusion
Petterson, 2012 (10)	Prospective clinical trial	Karolinska Institutet, Sweden	N.M Impression coping provided free of charge by Nobel	Verify the position of virtually planned implants compared with implants placed with a surgical template in edentate patients	FG: drill keys (Nobel Guide) Guided drilling + implant placement Mucosa supported SLA guide with embedded sleeves (produced by Nobel)	No	25	139	89 (Mx) 50 (Md)	There were significant differences between virtually planned implants position and the final position of implants placed clinically.
D'haese, 2009 (33)	Prospective clinical trial	University of Ghent, Ghent, Belgium	N.M	Evaluate the accuracy of mucosal-supported stereolithographic guides in the edentulous maxillae	FG – drill keys (AstraTech AB) Guided drilling + implant placement Mucosa supported SLA guide – fixation with 4 screws Scanning software: Materialise (Materialise N.V., Leuven, Belgium) Planning software: Facilitate software system (Astra Tech AB)	No	13	78	13 Mx	Clinicians should be warned that angular and linear deviations are to be expected. Short implants show significantly lower apical deviations compared with longer ones. Reasons for implant deviations are multifactorial; however, it is unlikely that the production process of the guide has a major impact on the total accuracy of a mucosal-supported SLA guide.
Tallarico, 2019 (17)	Multicenter single cohort prospective study	Private practices (S. Korea and Italy)	N.M	Investigate the accuracy of a newly developed sleeve-designed template and to evaluate differences between maxillary and mandibular implants as well as anterior versus posterior area	FG – keyless system (OsstemGuide Kit, Osstem) Planning: Center 1: 3Diagnosys ver. 4.2, 3DIEMME, Cantù, Italy Center 2: Implant studio, 3Shape A/S, Copenhagen, Denmark	No	Center 1: n=16 Center 2: n=23 n(total)= 39	119	Center 1: 32 Mx 16 Md Center 2: 33 Mx 38 Md	This study showed good precision in all the parameters measured. The results were thus in a range equal to or better than the mean precision found in numerous clinical trials described in the literature. Posterior implants were less accurate because of the use of open sleeves template.

Table 5

Article, year, ref.	Type of study	Location	Funding	Objectives	Implant system	Flap	$n_{patients}$	$n_{implants}$	$n_{implants}$ per arch	Conclusion
Naziri, 2016 (18)	Prospective clinical trial	Department of Oral and Plastic Maxillofacial Surgery, Military Hospital Ulm, Germany	N.M No competiting interests	Assess the accuracy of computer-assisted implant insertion based on computed tomography and template-guided implant placement	Group I: HG – keyless pilot drill (Astra) – first two drills guided (until mm) Guided implant placement (for 4.0mm ⌀ implants) and non-guided implant placement - Astra Tech Osseospeed (Dentsply Implants, Mölndal, Sweden) Replaceable Steco titanium sleeves (steco-system-technik GmbH & Co.KG, Hamburg, Ger- many)	Yes	N.M	50	N.M	A very good transfer ac- curacy when using surgical templates for implant placement after 3D implant planning. The technique allows surgeons to protect important anatomical structures and facilitates implant positioning in relation to the intended superstructure so that the prosthetic restoration can be analyzed in advance. However, more clinical studies should be initiated to substantiate the promising results of the present study.
					Group II: FG – keyless (Astra) Guided implant placement (> or = 5mm ⌀ ? non guided) - Astra Tech Osseospeed (Dentsply Implants, Mölndal, Sweden		N.M	50	N.M	
					Group III: FG – drills of increased length (Camlog Guide) Guided implant placement - Camlog Promote Plus (Camlog Biotechnologies AG, Basel, Switzerland)		N.M	50	N.M	
					Group IV: FG – drill keys (Straumann Guided surgery system) Guided implant placement - Straumann ITI Bone Level (Straumann AG, Basel, Switzerland)		N.M	40	N.M	
					Group V: HG - keyless pilot drill (Straumann Steco) First two drills guided - 2.2 and 2.8mm - with Steco sleeves of identical diameter. FH implant placement - Straumann ITI Bone Leve		N.M	46	N.M	
					Laboratory made guides from wax-up		Total: 181	Total included: 236	Total: 98 (Mx) 138 (Md)	

Clinical Trials

Table 5

Article, year, ref.	Type of study	Location	Funding	Objectives	Implant system	Flap	$n_{patients}$	$n_{implants}$	$n_{implants}$ per arch	Conclusion
Geng, 2015 (25)	Prospective clinical trial	Department of Dental Implantology , Centre of Beijing Stomatological Hospital, China	Specialized Research Fund for the Doctoral Program of Higher Education of China	Evaluate the clinical outcomes of implants placed using different types of CAD/CAM surgical guides, including partially guided and totally guided templates, and to determine the accuracy of the different guides in partially and totally edentulous patients	Group 1: HG - pilot drill guided (single) Mucosa or teeth supported guide Planning software: Simplant Implants brand: Straumann	No	24	29	N.M	CAD/ CAM surgical guides can improve the precision of dental implant placement. Tooth-supported surgical guides may be more accurate than mucosa-supported guides, while partially guided templates can provide the same outcomes as totally guided templates, thus simplifying the surgical procedure.
					Group 2: FG - drill key (Straumann Guided Surgery) + guided implant placement Mucosa or teeth supported guide			30		
Moon, 2016 (24)	Prospective clinical trial	Chosun University Dental Hospital	University research funds	Present the clinical issues in actual guided surgeries through the examination of the cases of patients that were treated with computer-guided implant surgery and confirm the accuracy of guided surgery by analyzing whether the positions before and after the placement matched.	Partial edentulous group: HG surgery (Dentis surgical guide drill set) - keyless system SLA-RP tooth supported surgical guide	N.M	4	11	9 (Md) 2 (Mx)	Our results were considered favorable compared to the free hand method, but various limitations were still observed. It is important to be able to utilize these methods in actual clinical settings by improving the various problems, including the considerations of patient mouth opening range, surgical guide shape, length of metal sleeve and surgical drill, template supporting problem, and scanning method.
					Full edentulous group: HG surgery (Dentis surgical guide drill set) - keyless system SLA-RP mucosa supported surgical guide	N.M	1	8	8 (Mx)	

Table 5

Article, year, ref.	Type of study	Location	Funding	Objectives	Implant system	Flap	$n_{patients}$	$n_{implants}$	$n_{implants}$ per arch	Conclusion
Van de Wiele, 2014 (38)	Prospective clinical trial	KU Leuven, Belgium	Oral implants and stereolithographic guides were delivered free of charge by DENTSPLY Implants	Analyze accuracy of implant placement with mucosa- supported stereolithographic guides, executed by inexperienced surgeons supervised by an experienced colleague.	Inexperienced surgeon group : one student of Periodontology master - supervised in all steps by an experienced surgeon Closed SLA guide : fixation by 3-4 anchor pin by a experienced surgeon) FG surgery: drill key system (Facilitate, DENTSPLY Implants) Implant brand: AstraTech OsseoSpeed Tx implants (DENTSPLY Implants) Mucosa supported SLA guide Matching software: Mimics (Materialise, Leuven, Belgium)	No	16	75	N.M	Within the limitations of this study and for the above-mentioned surgical protocol, inexperience of the surgeon had no influence on the accuracy of implant placement in fully edentulous jaws, when all steps needed for the procedure are supervised by experienced dentists.
					Experienced surgeon group: same as FG group 2 (FacMucosa) in Vercryussen et al (2014) - cf RCT table. FG surgery: drill key system (Facilitate, DENTSPLY Implants) SLA mucosa supported guide (fixed by 3 anchors pins)	No	12	52	N.M	
Verhamme, 2013 (48)	Prospective clinical trial	Radboud University Nijmegen Medical Centre, Netherlands	N.M One author is a product specialist of Nobel Biocare	Evaluate accuracy of flapless placement of two or four implants in the maxilla of fully edentulous patients using a mucosa-supported surgical template in a clinically relevant manner.	FG surgery: drill key system (Nobel Guide) SLA template (produced by Nobel) Randomized use of fixation pins or manual pression	No	30	104	104 (Mx)	Computer-aided implant planning showed to be a clinically relevant tool for the placement of two or four implants in the maxilla of fully edentulous patients. Exact positioning of the surgical template in anterior/posterior direction is crucial in reducing implant deviations both in buccal and mesial direction.

In Vitro studies

Table 6

Article, year, ref.	Location	Funding	Objectives	Implant system and guiding method	Models	Groups	Nimplants	Conclusion
El Kholy, 2019 (21)	University of Bern, Switzerland	Grant to the author through the Foundation of Dental Research and Education	Evaluate the effect of guided sleeve height, drilling distance, and guided key height on accuracy of static Computer-Assisted Implant Surgery (sCAIS).	FG - Drill key (Straumann) Tooth supported closed SLA guide Planning: CoDiagnostiX 3D printed using the Rapid Shape P30 printer (Rapid Shape GmbH, Heimsheim, Germany) Material: SHERAprint transparent resin Implants: 4.1 × 10mm and 4.1 × 16 mm bone level implants (Straumann Ag, Basel, Switzerland)	30 duplicate acrylic models (Bonemodels, Castellon, Spain) simulating human bone with 6 potential sites for implant placement corresponding to FDI positions 12, 15, 21, 23, 25, and 26	Group 1a: implants placed using a combination of 2 mm sleeve height and 1 mm key height.	20	Decreasing the drilling distance below the guided sleeve, by using shorter sleeve heights or shorter implants can significantly increase the accuracy of sCAIS
						Group 1b: implants placed using a combination of 2 mm sleeve height and 3 mm key height.	20	
						Group 2a: implants placed using a combination of 4 mm sleeve height and 1 mm key height.	20	
						Group 2b: implants placed using a combination of 4 mm sleeve height and 3 mm key height.	20	
						Group 3a: implants placed using a combination of 6 mm sleeve height and 1 mm key height.	20	
						Group 3b: implants placed using a combination of 6 mm sleeve height and 3 mm key height.	20	

In Vitro studies

Table 6

Article, year, ref.	Location	Funding	Objectives	Implant system and guiding method	Models	Groups	Nimplants	Conclusion
Kauffman, 2018 (40)	N.M	N.M No conflicts of interests reported	Determine the transmission accuracy of surgical guides in edentulous arches with hand fixation and surgical guides with intermediary screw fixation.	FG - drill key (BEGO Guide System) Planning software: Implant3D Matching software: med3D *Osteotomy protocol:* *1st drilling: Pilot Drill Ø 1.6 mm, length 24 mm / Dilatation drilling: TriSpade Ø 2.5 mm, length 20 mm / Final drilling for implants S 3.75: TriSpade Ø 3.25 mm, length 20 mm* Guided implant placement. Mucosa based template (scarce information)	4 edentulous mandible models (GOS Mandibula Type 1 - slightly atrophic mandible or bone quality D II) A mucosa mask represents the resilient mucosa.	Control group: HFG = hand-fixed template group	20	The use of CT-based implant planning succeeds in fixed and hand fixed surgical procedures with high precision in the atrophic, edentulous mandible model. According to the results of this study, in cases demanding high depth precision, screw fixation of the template can be helpful
						Experimental group: FG = screw-fixed template group 3 screws (9mm length, 1.5mm diameter): L and R 1st molar and R central incisor.	20	
Van Groningen, 2015 (32)	Academic Centre for Dentistry Amsterdam (ACTA), Amsterdam, The Netherlands	ACTA funding fund No conflict of interests	Assess the accuracy of a model-based guided surgery system in terms of linear deviations at entry point and apex and angular discrepancies between 2 CBCT scanners (AccuiTomo 170; Morita Inc., Kyoto, Japan; NewTom 5G; QR, Verona, Italy)	FG: drill key (Straumann Guided Surgery) Planning: CoDiagnostiX Implants: Straumann Regular Standard Plus (length of 10mm) at the position of the 1st premolar and 1st molar, bilaterally Tooth supported surgical guide (laboratory made)	8 duplicated industrial acrylic partially edentulous master models of the lower jaw (Kennedy III classification)	Group 1: NewTom 5G; QR, Verona, Italy Group 2 : AccuiTomo 170; Morita Inc., Kyoto, Japan	32	Within the limitations of this in vitro study, there was no significant influence of CBCT device selection (NewTom 5G and Accuitomo 170) on transfer accuracy of a laboratory-based surgical guide implant system. Caution should be exercised when extrapolating the results of this in vitro investigation to the clinical environment.

In Vitro studies

Table 6

Article, year, ref.	Location	Funding	Objectives	Implant system and guiding method	Models	Groups	Nimplants	Conclusion
Petterson, 2014 (31)	Karolinska Institutet, Sweden	Nobel Biocare	Evaluate any deviation between virtually planned and actually placed implants by 5 surgeons performing CAD/CAM guided implant surgery on duplicate plastic models	FG - drill key (Nobel Guide) SLA closed mucosa supported surgical stents (Drill Model, Fully Edentulous Maxilla; Nobel Biocare AB) - 3 anchors pins (Guided Anchor Pin, ⌀1.5 mm; Nobel Biocare AB) 6 implants (Groovy RP ⌀3.75, 13 mm; Nobel Biocare AB) in each model were placed	25 plastic maxillary jaw models (5 per surgeon)	Surgeon 1	30	Statistically significant differences were found for 3 out of 4 outcome parameters between all virtually planned and actually placed implant positions and for 3 out of 4 outcome parameters between the surgeons. It could be questioned whether this is clinically significant. The results from this study may clarify the variations that occur between surgeons.
						Surgeon 2	30	
						Surgeon 3	30	
						Surgeon 4	30	
						Surgeon 5	30	
						Total	150	
Turbush, 2012 (30)	N.M	N.M No conflicts of interests reported	Compare the accuracy of implant placement by using 3 different types of surgical guide: bone-supported, tooth-supported, and mucosa-supported	FG - drill key (Nobel Guide) Planning: Mimic Materialise SLA surgical guide 5 implants (Nobel Replace Straight Groovy, RP, 4×13 mm) were placed in each mandible. A total of 150 implants were placed (Nobel Replace Straight Groovy, RP, 4×13 mm)	10: SLA made edentulous mandible (based on patient CBCT) 10: addition of teeth (canines and 1st molars) 10: addition of soft acrylic resin of 2mm to simulate mucosa. Total: 30	Group 1: Tooth-supported group (n=10)	50	The results of this study show that stereolithographic surgical guides may be reliable in implant place- ment and that: 1) there was no statistically significant difference among the 3 types of guide when comparing angular deviation and 2) mucosa-supported guides were less accurate than both tooth-supported and bone-supported guides for linear deviation at the implant neck and apex
						Group 2: Bone-supported group (n=10)	50	
						Group 3: Mucosa-supported group (n=10)	50	

Table 6

Article, year, ref.	Location	Funding	Objectives	Implant system and guiding method	Models	Groups	Nimplants	Conclusion
Hinckfuss, 2012 (27)	University of Minnesota, Minneapolis ,Minn, USA	American Academy of Implant Dentistry Material donation: Zimmer Dental	Evaluate the effect of surgical guide design, surgeon's experience, and size of the edentulous site on the accuracy of implant placement.	4 different surgical guide designs: all are tooth-supported guides 1st design (HG): "pilot-sleeve" – only a 2.2-mm metal tube (Stent Guide Tubes, Biomet 3i, Palm Beach Garden, Fla) which is wide enough for a 2-mm surgical drill to fit through 2nd design (FG 1): Unique sleeve wide enough for all the drills to fit. 3rd design (FG 2): Several sleeves insert that precisely fit each drill to guide the drill position, angulation, and drilling depth. Implant placement is also guided. (Guided surgery system, Dental Crafters, Marshfield, Wis) 4th design (FH): no surgical guide was used 3 dummy implants of 3.7x13 mm (Zimmer Dental, Carlsbad, Calif) in each typodont using 1 of 4 surgical guide techniques.	84 duplicate maxillary typodonts (Models Plus, Kingsford Heights, Ind) – 4 per surgeon (1 design for each typodont) Edentulous space: - Right canine (single site) - Right and left central incisors (double site) - 8 dimples (5 on the sides of the typodont, 1 on the labial surface of the right 1st premolar and left lateral incisors as positioning references for future measurement	Group 1: Novice group – no clinical surgical experience (n=7)	84	The results of this research found that surgical guide design, surgeon's experience, and size of edentulous site all statistically significantly affect the accuracy of implant placement. An angulation error in the buccal-lingual direction (Dyz) was shown to be less likely to occur in the experienced group. Overall, use of guided surgery does not improve accuracy of implant placement compared with simple guides or no guide in single or double implant situations.
						Group 2: Intermediate group – between 20 to 80 implants placed (n=7)	84	
						Group 3: Experienced group – more than 300 implants placed (n=7)	84	
						Total: 21	Total: 252	

Table 6

Article, year, ref.	Location	Funding	Objectives	Implant system and guiding method	Models	Groups	Nimplants	Conclusion
Gjelvold, 2019 (49)	University of Malmö, Malmö, Sweden	Oral Health Related Research Grant from Odontologisk Forskning i Region Skåne Material donated free of charge by BioHorizons	Evaluate the degree of deviation in the final dental implant position after the use of surgical guides fabricated from 2 different desktop 3D printers using a digital workflow	Surgery: FG - Drill key system (BioHorizons Guided Surgery Kit) Planning: Implant Studio; 3Shape) Implants: Tapered Internal; BioHorizons; 12 mm x 3.8 mm ⌀ 2 tyes of 3D printer used: DLP (Digital Light Processing): photopolymer resin (E-Guide; EnvisionTEC) using a DLP printer (Vida; EnvisionTEC) SLA (stereolithography): different photopolymer resin (Dental SG Resin; Formlabs) using an SLA printer (Form 2; Formlabs)	20 duplicates of a maxillary typodont (1st left premolar was removed)	Group 1: SLA printed guides (n=10)	10	1. The tested desktop 3D printers proved capable of producing surgical guides with similar deviations to definitive implant position. 2. The DLP printer proved more accurate concerning deviations at the entry point and vertical implant position.
						Group 2: DLP printed guides (n=10)	10	
Kim, 2019 (9)	Kyungpook National University, Daegu, S. Korea	National funds (Ministry of Trade, Industry & Energy)	Evaluation of the accuracy of computer-assisted implant surgical guides, which were designed and fabricated with personal 3D printers (in-office)	Planning: Deltanine (Daesung, Seoul, Republic of Korea) and R2gate (Megagen, Daegu, Republic of Korea) FG - keyless (Guided Surgical Kit, Osstem, Busan, Korea) Teeth supported guide Guide made with Deltanine (n=10) Guide made with R2gate (n=10)	20 partially edentulous resin study models were produced using a 3D printer (ZENITH, Dentis, Daegu, Korea) from a patient randomly selected; Digital scan of soft tissue (diagnostic model) + patient CBCT scan for hard tissues	Group 1: Guide designed with Deltanine software	10	1. The surgical guide fabricated according to the two software programs shows no difference in the positioning accuracy of the implants. 2. The accuracy of the personal 3D printed implant surgical guides is in the average range allowed by the dental clinician. 3. The surgical guide fabricated by the method presented in this study can be utilized in dental clinical practice.
						Group 2: Guides designed with R2gate software	10	

In Vitro studies

Table 6

Article, year, ref.	Location	Funding	Objectives	Implant system and guiding method	Models	Groups	Nimplants	Conclusion
El Kholy, (2) 2019 (41)	School of Dental Medicine, University of Bern	Grant to the author from the Foundation of Dental Research and Education	Investigate the effect of surgical guide support and implant site location on the accuracy of static Computer-Assisted Implant Surgery (sCAIS) in partially edentulous patients.	Model scan with 3shape trios, digital wax up, digital implant planning, surgical guide design and production (all steps performed with Dental Wing Operating System) Matching: scan bodies, full arch, intraoral scan, CoDiagnostiX Surgery: FG - drill key (Straumann) Full arch supported guides or partial supported guides by 4, 3 or 2 teeth Implants: 4.1 × 10 mm implant tissue level (TL) or bone level (BL) Straumann implant replica. 3D printer (Rapidshape P30) Material: SHERAprint-sg by SHERA Werkstoff- Technologie GmbH & Co. KG, material thickness (3 mm)	85 duplicate acrylic dental model (Bonemodels) 6 potential sites for implant placement per model: - 21 (simulating fresh extraction socket) - 25 y 26 (simulating distal extension) - 15, 12, 23 (simulating single tooth gap)	Group 1: Full-arch-supported guides (n=40)	240	The number and location of teeth supporting the surgical guide can significantly influence the accuracy of sCAIS, with 4 teeth providing equal accuracy to full-arch guides in (STG) situations
						Group 2a. Guides supported by 4 teeth (nmodels=15, nguides=40)	45	
						Group 2b: Guides supported by 3 teeth (nmodels=15, nguides=45)	45	
						Group 2c: Guides supported by 2 teeth (nmodels=15, nguides=45)	45	
						Group 2 (total): nmodels=45, nguides=135	135	

In Vitro studies

Table 6

Article, year, ref.	Location	Funding	Objectives	Implant system and guiding method	Models	Groups	Nimplants	Conclusion
Cushen, 2013 (50)	University of Texas Health Science Center San Antonio, Texas	Academy of Prosthodontics Foundation / United States Air Force Wilford Hall Medical Center Clinical Research Division, San Antonio, Texas	Measure the accuracy of dental implant placement with a bone- supported stereolithographic surgical template created from a virtual implant plan and to determine the effect of operator experience on implant placement accuracy.	FG surgery - drill key (Facilitate; Astra Tech AB) Planning: Mimics Materialise; Materialise Medical, Leuven, Belgium Bone-supported SLA surgical template Implants: 4 mm × 11 mm parallel-walled demonstration	20 resin mandibles were fabricated from CBCT scan of an unknown edentulous patient with an in-house Viper SLA system (3D Systems, Rock Hill, SC)	Highly experienced surgeons: over 100 implant placement experience (n=2)	50	The results of this investigation revealed that under ideal conditions, bone-level SLA surgical templates made from CBCT scans and a virtual implant plan can result in implant placement to within 8 degrees angular error, 1.5 mm horizontal error, and 1.0 mm vertical error. Also, the more experienced the clinician placing the implants, the more accurate the implant placement.
						Little experienced surgeons: < 10 implants placed (n=2)	50	
Yeung, 2019 (23)	Virginia Commonwealth University, Richmond, Va	Dental Student Research Fellowship (American Association of Dental Research Student / Virginal Commonwealth association) + Zimmer Biomet partial funding One author (S.B) is a lecturer for Zimmer Biomet Institure. BioHorizon, Nobel Biocare, and Zimmer Biomet provided implant fixtures used for this study	Measure the accuracy and precision of 3 implant systems, Tapered Internal implant system (BioHorizons), NobelReplace Conical (Nobel Biocare), and Tapered Screw-Vent (Zimmer Biomet) when in-office fabricated surgical guides were used.	Three FG surgery implant systems were chosen: - Tapered Internal implant system (BioHorizons, BH) - drill key Implants: 4.6×12 mm (guided implant placement) - NobelReplace Conical (Nobel Biocare, NB) - drill key Implants: 4.3×13 mm (guided implant placement) - Tapered Screw-Vent (Zimmer Biomet, ZB) - drill key Implants: 3.7×13 mm (non guided implant placement) Intraoral scan performed with TRIOS scanner (3Shape). Planning: Implant Studio 2017 (3Shape)	30 SLA maxillary models from patient CBCT with the maxillary right central incisor missing. Printing: PreForm (Formlabs)	BioHorizons system	10	1. When guide fabrication is performed in office by using a desktop stereolithographic printer, clinicians should recognize the limitations of the guide, such as the guide fit and depth of placement. 2. When performing fully or partially guided surgery, clinicians need to be aware of potential vertical and palatal displacements. 3. When a long drill is used with a surgical stopper, clinicians should recognize that the implant placement may have less precision and that the fit of all surgical components is essential during osteotomy preparation.
						Nobel Guide system	10	
						Zimmer Biomet system	10	

Numerical data

Table 7

Randomized Controlled Trials						
First author, date, reference	Groups	Coronal implant deviation in mm (SD)	Apical implant deviation in mm (SD)	Vertical implant deviation in mm (SD)	Apical angle deviation in ° (SD)	Operator experience
Smithkarn, 2019	Static CAIS group	1.0 (0.6)	1.3 (0.6)	0.7 (0.6)	3.1 (2.3)	Significantly experienced
	HG group	1.5 (0.7)	2.1 (1.0)	1.0 (0.8)	6.9 (4.4)	
Farley, 2013	CAD CAM group	1.45 (0.06)	1.82 (0.60)	−1.24 (0.68)	3.68 (2.19)	Not mentionned
	Conventional group	1.99 (1.00)	2.54 (1.23)	−1.59 (1.09)	6.13 (4.04)	
Marei, 2019	*Invalid data*					Experienced
						Inexperienced
Vercruyssen, 2014	Mat Mucosa	1.23 (0.60)	1.57 (0.71)	Not mentioned	2.86 (1.6)	Not mentioned
	Mat Bone	1.60 (0.92)	1.65 (0.82)	Not mentioned	3.79 (2.36)	
	Fac Mucosa	1.38 (0.64)	1.60 (0.70)	Not mentioned	2.71 (1.36)	
	Fac Bone	1.33 (0.82)	1.50 (0.72)	Not mentioned	3.20 (2.70)	
	Pilot-drill	2.97 (1.41)	2.91 (1.52)	Not mentioned	9.92 (6.01)	
	Free hand	2.77 (1.54)	3.40 (1.68)	Not mentioned	8.43 (5.10)	
Younes, 2018	FG surgery	0.73 (0.10)	0.97 (0.19)	Not mentioned	2.30 (0.92)	Experienced
	PG surgery	1.12 (0.10)	1.43 (0.18)	Not mentioned	5.95 (0.87)	
	FH surgery	1.45 (0.10)	2.11 (0.18)	Not mentioned	6.99 (0.87)	
Schneider, 2019	Control	1.25 (0.62)	2.32 (1.24)	0.28 (1.01)	7.36 (3.36)	Not mentioned
	T1 (FG surgery)	0.54 (0.33)	0.9 (0.43)	0.11 (0.62)	2.41 (1.4)	
	T2 (FG surgery)	0.61 (0.27)	1.02 0.64	−0.32 (0.9)	2.69 (1.78)	
Kaewsiri, 2019	Static CAIS group	0.97 (0.44)	1.28 (0.46)	Not mentioned	2.84 (1.71)	Experienced (> 500 implants using conventional method and > 50 implants using each static and dynamic CAIS system)
	Dynamic CAIS group	1.05 (0.44)	1.29 (0.50)	Not mentioned	3.06 (1.37)	
Kiatkroekkraim, 2019	Intraoral scan group	0.87 (0.49)	1.10 (0.53)	0.59 (0.48)	2.41 (1.47)	Experienced (15 years)
	Extraoral scan group	1.01 (0.56)	1.38 (0.68)	0.69 (0.54)	3.23 (2.09)	

Table 7

Tallarico (2), 2019	Fully digital group	0.52 (0.30)	Not mentioned	0.58 (0.44)	2.25 (1.41)	Experienced
	Conventional group	0.44 (0.26)	Not mentioned	0.46 (0.34)	2.10 (1.18)	
Tallarico (3), 2019	Control group	0.52 (0.30)	Not mentioned	0.58 (0.44)	2.25 (1.41)	Experienced
	Experimental group	0.61 (0.49)	Not mentioned	0.37 (0.28)	1.98 (2.38)	
	Open sleeve (subgroup)	0.87 (0.62)	Not mentioned	0.42 (0.33)	3.3 (3.1)	
	Closed sleeve (supgroup)	0.51 (0.38)	Not mentioned	0.32 (0.24)	1.35 (1.57)	
Clinical Trials						
D'haese, 2009	Mean deviation values	0.91 (0.44)	1.13 (0.52)	Not mentioned	2.60 (1.61)	Not mentioned
Pettersson, 2010	Without any movement	0.85	1.07	-0.09	2	Not mentioned
	With movement	1.12	1.75	-0.57	4.27	
Tallarico, 2019	Center 1	0.61 (0.49)	Not mentioned	0.37 (0.28)	1.98 (2.38)	Experienced
	Center 1 (only closed holes)	0.50 (0.37)	Not mentioned	0.33 (0.25)	1.30 (1.56)	
	Center 2	0.48 (0.44)	Not mentioned	0.45 (0.42)	1.06 (1.56)	
Naziri, 2016 (median/range)	All groups deviation	1.0 (0.2-4.3)	1.4 (0.3-5.5)	0.6 (0,0-4.0)	3.6 (0,0-16.6)	N.M
Geng, 2015	Tooth supported guides	0.27 (0.24)	0.37 ± 0.35	0.32 (0.32)	1.72 (1.67)	N.M
	Mucosa supported guides	0.69 (0.66)	0.94 ± 0.75	0.51 (0.48)	2.71 (2.58)	
	PG surgery (pilot guided)	0.54 (0.50)	0.81 (0.64)	0.31 (0.72)	2.56 (2.23)	
	FG surgery	0.89 (0.78)	1.10 (0.85)	0.24 (0.54)	2.9 (3.0)	
Moon, 2016	Mean deviation (both types of guides)	3.84 (1.49)	0.45 (0.48)	0.70 (0.63)	0.64 (0.57)	N.M
Van de Wiele, 2014	Inexperienced	0.871 (0.495)	1.102 (0.531)	0.483 (0.495)	2.788 (1.475)	N.M
	Experienced	1.384 (0.643)	1.598 (0.701)	0.748 (0.654)	2.705 (1.358)	
Verhamme, 2013 (mean/CI95)	Mean deviations	1.368 (0.170)	1.587 (0.178)	-0.843 (0.227)	2.819 (0.362)	N.M

Numerical data

Table 7

In vitro						
El Kholy, 2019	Deviation measurements in relation to the drilling distance apical to the sleeve (free drilling distance)	14mm	0.494 (0.142)	0.344 (0.078)	Not mentioned	1.855 (0.322)
		16mm	0.838 (0.121)	0.418 (0.051)		2.570 (0.409)
		18mm	1.264 (0.163)	0.606 (0.063)		2.615 (0.571)
	Deviation measurements in relation to the drilling key height above the sleeve	1mm	0.961 (0.345)	0.498 (0.117)		2.680 (0.458)
		3mm	0.769 (0.328)	0.413 (0.126)		2.033 (0.442)
Kauffman, 2018 (Median/range)	FG group (screw-fixed template)		0.47 (0.05-1.31)	0.86 (0.21–1.68)	0.44 (0.03-1.54)	3.41 (0.48–5.79)
	HFG group (hand-fixed template)		0.49 (0.10-1.11)	0.77 (0.16-1.86)	0.52 (0.06-1.69)	2.76 (0.32–7.54)
Van Kroningen, 2015	CBCT 1 (NewTom)		0.53 (0.18)	0.43 (0.16)	0.27 (0.18)	0.96 (0.41)
	CBCT 2 (AccuiTomo)		0.66 (0.35)	0.60 (0.35)	0.46 (0.39)	1.04 (0.48)
Petterson, 2014	Surgeon 1		0.53 (0.33 – 0.73)	0.69 (0.32 – 1.14)	- 0.49 (-0.71/-0.28)	1.57 (0.32-3.73)
	Surgeon 2		0.64 (0.27 – 1.19)	0.72 (0.27 – 1.46)	- 0.63 (-1.17 - 0.22)	0.86 (0.06-3.73)
	Surgeon 3		0.58 (0.33 – 0.82)	0.69 (0.39 – 1.10)	- 0.48 (-0.78 – 0.12)	0.95 (0.15-2.63)
	Surgeon 4		0.62 (0.30 – 0.94)	0.69 (0.28 – 1.19)	- 0.53 (- 0.84/-0.27)	0.89 (0.08-3.56)
	Surgeon 5		0.57 (0.32 – 0.84)	0.89 (0.51- 1.33)	- 0.42 (-0.65/0.00)	1.67 (0.84-4.39)
	Deviation for all implants		0.59 (0.27 – 1.19)	0.73 (0.27-1.46)	- 0.51 (0.12 /-1.17)	0.61 (0.06-4.39)
Turbush, 2012	Group 1 (tooth-supported guide)		1.00 (0.33)	1.15 (0.42)	Not mentioned	2.26 (1.30)
	Group 2 (mucosa-supported guide)		1.47 (0.43)	1.65 (0.48)	Not mentioned	2.29 (1.28)
	Group 3 (bone-supported guide)		1.08 (0.33)	1.53 (0.90)	Not mentioned	2.17 (1.02)
Gjelvold, 2019	SLA group		0.39 (0.01)	0.49 (0.17)	0.34 (0.18)	1.25 (0.49)
	DLP group		0.27 (0.08)	0.34 (0.14)	0.16 (0.11)	0.99 (0.57)
Kim, 2019	Deltanine		Not mentioned	0.603 (0.19)	Not mentioned	1.97 (0.84)
	R2gate		Not mentioned	0.609 (0.18)	Not mentioned	1.92 (0.52)

Numerical data

Table 7

El Kholy, 2019 (2)	Full arch	0.284(0.133)	0.675 (0.429)	Not mentioned	4.363 (1.682)
	4 teeth	0.289 (0.159)	0.616 (0.255)	Not mentioned	4.731 (1.601)
	3 teeth	0.562 (0.086)	1.195 (0.397)	Not mentioned	5.688 (1.521)
	2 teeth	1.015 (0.124)	1.657 (0.209)	Not mentioned	7.713 (1.236)
Cushen, 2013	Experienced surgeons	0.63 ±0.28	0.34 ±0.15	0.59 ±0.12	2.60 ±1.25
	Inexperienced surgeons	0.77 ±0.33	0.42 ±0.19	0.62 ±0.13	3.96 ±1.64
	Total	0.69 ±0.31	0.38 ±0.17	0.60 ±0.13	3.28 ±1.60

FG surgeries

Table 8 -
Drill key group

Studies included in the statistical analysis

	Guidance level	Guidance method	Control	Brand	Dental status	Guide support	Guide fixation (number of pins)	Number of patients	Number of implants	Guided implant placement
<u>*Randomized Clinical Trials*</u>										
Smithkarn, 2019	*FG*	Drill keys	P, V	Straumann	SE	T	No	26	30	✔
Farley, 2013	*FG*	Drill keys	P, V	Biomet 3i	SE	T	No	5	10	✔
Vercryussen, 2014	*FG*	Drill keys	V	Materialise Universal	PE/TE (4-6 implants)	M	Yes (3-4)	12	55	✖
	FG	Drill keys	V	Materialise Universal	PE/TE (4-6 implants)	B	Yes (3-4)	12	53	✖
	FG	Drill keys	P ,V	Facilitate (Dentsply)	PE/TE (4-6 implants)	M	Yes (3-4)	14	52	✔
	FG	Drill keys	P, V	Facilitate (Dentsply)	PE/TE (4-6 implants)	B	Yes (3-4)	12	52	✔
Younes, 2018	*FG*	Drill keys	V	N.M	PE (≥2 implants)	T	N.M	10	21	✔
Schneider, 2019	*FG*	Drill keys	P,V	Straumann or Facilitate	PE	T	No	11	11	✔
	FG	Drill keys	P,V	Straumann or Facilitate	PE	T	No	11	11	✔
Kaewsiri, 2019	*FG*	Drill keys	P,V	Straumann	SE	T	No	30	30	✔
Kiatkroekkraim, 2019	*FG*	Drill keys	P,V	Straumann	SE	T	No	22	20	✔
	FG	Drill keys	P,V	Straumann	SE	T	No	22	30	✔
<u>*Control trials*</u>										
Petterson, 2010	FG	Drill keys	P, V	Nobel Guide	TE	M	Yes (?)	25	139	✔
D'haese, 2009	FG	Drill keys	P, V	Astra Tech AB	TE	M	Yes (4)	13	78	✔
Geng, 2015	FG	Drill keys	P, V	Straumann	TE, PE	M/T	Yes	24	30	✔
Van de Wiel, 2014	FG	Drill keys	P, V	Facilitate (Dentsply)	TE	M	Yes (3)	16	75	✔
Verhamme, 2013	FG	Drill keys	P, V	Nobel Guide	TE	M	Randomized	30	104	✔
								Total: 355	Total: 891	

Table 9 -
Keyless group

	Guidance level	Guidance method	Control	Brand	Dental status	Guide support	Guide fixation (number of pins)	Number of patients	Number of implants	Guided implant placement
Randomized control trials										
Tallarico (2), 2019	FG	Keyless system	P	Osstem Guide Taper Kit, Osstem	PE (∈ SE: unclear)	T	Yes (2-4)	20	57	✔
Tallarico (3), 2019	FG	Keyless system	P	OsstemGuide Kit, Osstem	SE, PE (min. 1 implant required)	T	Yes (2-4)	30	90	✔
Clinical trials										
Tallarico, 2019	FG	Keyless system	P	OsstemGuide Kit, Osstem	PE (min. 5 teeth remaining)	T	Yes (2-4)	39	119	✔

FG/HG

Studies included in the statistical analysis

Table 10 -
Drill key and keyless

	Guidance level	Guidance method	Control	Brand	Guide support	Guide fixation (number of pins)	Number of patients	Number of implants	Guided implant placement
Vercruyssen, 2014	HG (pilot drill)	N.M	N.M	N.M	T	No	12	51	✖
Younes, 2018	HG (pilot drill)/FH	Scan protesis (no sleeve)	P	N.M	T	No	11	24	✖
Geng, 2015	HG (pilot drill)	Surgical guide	V	Straumann	M/T	Yes	N.M	29	✖
Moon, 2016	FG/HG (drilling > 2.8 mm ⌀ = HG drilling)	Keyless system	P	Dentis	M	Yes	1	8	✔
	FG/HG	Keyless system	P	Dentis	T	No	4	11	✔

Table 11 - FG dataset

RCTs - full guided surgery (drill key group)						
First author, date, reference	Groups	Coronal implant deviation in mm (SD)	Apical implant deviation in mm (SD)	Vertical implant deviation in mm (SD)	Apical angle deviation in ° (SD)	Sample size (n implants)
Smithkarn, 2019	Static CAIS group	1.0 (0.6)	1.3 (0.6)	0.7 (0.6)	3.1 (2.3)	30
Farley, 2013	CAD CAM group	1.45 (0.06)	1.82 (0.60)	−1.24 (0.68)	3.68 (2.19)	10
Vercruyssen, 2014	Mat Mucosa	1.23 (0.60)	1.57 (0.71)	Not mentioned	2.86 (1.6)	55
	Mat Bone	1.60 (0.92)	1.65 (0.82)	Not mentioned	3.79 (2.36)	53
	Fac Mucosa	1.38 (0.64)	1.60 (0.70)	Not mentioned	2.71 (1.36)	52
	Fac Bone	1.33 (0.82)	1.50 (0.72)	Not mentioned	3.20 (2.70)	52
Younes, 2018	FG surgery	0.73 (0.10)	0.97 (0.19)	Not mentioned	2.30 (0.92)	21
Schneider, 2019	T1 (FG surgery)	0.54 (0.33)	0.9 (0.43)	0.11 (0.62)	2.41 (1.4)	11
	T2 (FG surgery)	0.61 (0.27)	1.02 0.64	–0.32 (0.9)	2.69 (1.78)	11
Kaewsiri, 2019	Static CAIS group	0.97 (0.44)	1.28 (0.46)	Not mentioned	2.84 (1.71)	30
Kiatkroekkraim, 2019	Intraoral scan group	0.87 (0.49)	1.10 (0.53)	0.59 (0.48)	2.41 (1.47)	30
	Extraoral scan group	1.01 (0.56)	1.38 (0.68)	0.69 (0.54)	3.23 (2.09)	20

RCTs - full guided surgery (keyless group)						
First author, date, reference	Groups	Coronal implant deviation in mm (SD)	Apical implant deviation in mm (SD)	Vertical implant deviation in mm (SD)	Apical angle deviation in ° (SD)	Sample size (n implants)
Tallarico (2), 2019	Fully digital group	0.52 (0.30)	Not mentioned	0.58 (0.44)	2.25 (1.41)	28
	Conventional group	0.44 (0.26)	Not mentioned	0.46 (0.34)	2.10 (1.18)	29
Tallarico (3), 2019	Control group	0.52 (0.30)	Not mentioned	0.58 (0.44)	2.25 (1.41)	41
	Experimental group	0.61 (0.49)	Not mentioned	0.37 (0.28)	1.98 (2.38)	49

Table 11 - FG dataset

CTs - full guided surgery (drill key group)						
First author, date, reference	Groups	Coronal implant deviation in mm (SD)	Apical implant deviation in mm (SD)	Vertical implant deviation in mm (SD)	Apical angle deviation in ° (SD)	Sample size (n implants)
D'haese, 2009	Mean deviation values	0.91 (0.44)	1.13 (0.52)	Not mentioned	2.60 (1.61)	78
Pettersson, 2010	Without any movement	0.85 (0.47)	1.07 (0.54)	0.09 (0.46)	2 (1.41)	139
Geng, 2015	FG surgery	0.89 (0.78)	1.10 (0.85)	0.24 (0.54)	2.9 (3.0)	59
Van de Wiele, 2014	Inexperienced	0.871 (0.495)	1.102 (0.531)	0.483 (0.495)	2.788 (1.475)	75
Verhamme, 2013	Mean deviations	1.368 (0.170)	1.587 (0.178)	-0.843 (0.227)	2.819 (0.362)	104

<table>
<tr><th colspan="7">CTs - full guided surgery (keyless group)</th></tr>
<tr><th>First author, date, reference</th><th>Groups</th><th>Coronal implant deviation in mm (SD)</th><th>Apical implant deviation in mm (SD)</th><th>Vertical implant deviation in mm (SD)</th><th>Apical angle deviation in ° (SD)</th><th>Sample size (n implants)</th></tr>
<tr><td rowspan="4">Tallarico, 2019</td><td>Center 1</td><td>0.61 (0.49)</td><td>Not mentioned</td><td>0.37 (0.28)</td><td>1.98 (2.38)</td><td rowspan="2">48</td></tr>
<tr><td>Center 1 (only closed holes)</td><td>0.50 (0.37)</td><td>Not mentioned</td><td>0.33 (0.25)</td><td>1.30 (1.56)</td></tr>
<tr><td>Center 2</td><td>0.48 (0.44)</td><td>Not mentioned</td><td>0.42 (0.37)</td><td>1.06 (1.56)</td><td>71</td></tr>
<tr><td>Total</td><td>0.53 (0.46)</td><td>Not mentioned</td><td>0.42 (0.37)</td><td>1.43 (1.98)</td><td>119</td></tr>
</table>

Table 11 - FG dataset

In vitro - full guided surgery (drill key group)						
First author, date, reference	Groups	Coronal implant deviation in mm (SD)	Apical implant deviation in mm (SD)	Vertical implant deviation in mm (SD)	Apical angle deviation in ° (SD)	Sample size
Kauffman, 2018	SFT group (screw-fixed template)	*0.53 (0.34)*	*0.89 (0.39)*	*0.54 (0.40)*	*3.33 (1.42)*	20
	HFT group (hand-fixed template)	*0.52 (0.27)*	*0.84 (0.45)*	*0.62 (0.44)*	*3.10 (1.93)*	20
Van Kroningen, 2015	CBCT 2 (AccuiTomo)	0.66 (0.35)	0.60 (0.35)	0.46 (0.39)	1.04 (0.48)	36
Petterson, 2014	Surgeon 1	0.53 (0.33 – 0.73)	0.69 (0.32 – 1.14)	- 0.49 (-0.71/-0.28)	1.57 (0.32-3.73)	30
	Surgeon 2	0.64 (0.27 – 1.19)	0.72 (0.27 – 1.46)	- 0.63 (-1.17 - 0.22)	0.86 (0.06-3.73)	30
	Surgeon 3	0.58 (0.33 – 0.82)	0.69 (0.39 – 1.10)	- 0.48 (-0.78 – 0.12)	0.95 (0.15-2.63)	30
	Surgeon 4	0.62 (0.30 – 0.94)	0.69 (0.28 – 1.19)	- 0.53 (- 0.84/-0.27)	0.89 (0.08-3.56)	30
	Surgeon 5	0.57 (0.32 – 0.84)	0.89 (0.51- 1.33)	- 0.42 (-0.65/0.00)	1.67 (0.84-4.39)	30
	Deviation for all implants	*0.63 (0.24)*	*0.77 (0.32)*	*- 0.55 (0.28)*	*1.09 (1.16)*	150
Turbush, 2012	Group 1 (tooth-supported guide)	1.00 (0.33)	1.15 (0.42)	Not mentioned	2.26 (1.30)	50
	Group 2 (mucosa-supported guide)	1.47 (0.43)	1.65 (0.48)	Not mentioned	2.29 (1.28)	50
	Group 3 (bone-supported guide)	1.08 (0.33)	1.53 (0.90)	Not mentioned	2.17 (1.02)	50
Gjelvold, 2019	SLA group	0.39 (0.01)	0.49 (0.17)	0.34 (0.18)	1.25 (0.49)	10
	DLP group	0.27 (0.08)	0.34 (0.14)	0.16 (0.11)	0.99 (0.57)	10
El Kholy, 2019 (2)	Full arch	0.284(0.133)	0.675 (0.429)	Not mentioned	4.363 (1.682)	240
	4 teeth	0.289 (0.159)	0.616 (0.255)	Not mentioned	4.731 (1.601)	45
	3 teeth	0.562 (0.086)	1.195 (0.397)	Not mentioned	5.688 (1.521)	45
	2 teeth	1.015 (0.124)	1.657 (0.209)	Not mentioned	7.713 (1.236)	45
Cushen, 2013	Experienced surgeons	0.63 (0.28)	0.34 (0.15)	0.59 (0.12)	2.60 (1.25)	50
	Inexperienced surgeons	0.77 (0.33)	0.42 (0.19)	0.62 (0.13)	3.96 (1.64)	50
	Total	0.69 (0.31)	0.38 (0.17)	0.60 (0.13)	3.28 (1.60)	100

In vitro - full guided surgery (keyless group)						
Kim, 2019	Deltanine	Not mentioned	0.603 (0.19)	Not mentioned	1.97 (0.84)	10
	R2gate	Not mentioned	0.609 (0.18)	Not mentioned	1.92 (0.52)	10

Bold font signals that the values were estimated (from median/range to mean/SD)

Table 12 - HG dataset

RCTs - half guided surgery (drill key group)						
First author, date, reference	Groups	Coronal implant deviation in mm (SD)	Apical implant deviation in mm (SD)	Vertical implant deviation in mm (SD)	Apical angle deviation in ° (SD)	Sample size
Smithkarn, 2019	HG group	1.5 (0.7)	2.1 (1.0)	1.0 (0.8)	6.9 (4.4)	30
Farley, 2013	Conventional group	1.99 (1.00)	2.54 (1.23)	–1.59 (1.09)	6.13 (4.04)	10
Vercruyssen, 2014	Pilot-drill	2.97 (1.41)	2.91 (1.52)	Not mentioned	9.92 (6.01)	51
Younes, 2018	PG surgery	1.12 (0.10)	1.43 (0.18)	Not mentioned	5.95 (0.87)	24

RCTs - half guided surgery (keyless group) - NO EVIDENCE						
First author, date, reference	Groups	Coronal implant deviation in mm (SD)	Apical implant deviation in mm (SD)	Vertical implant deviation in mm (SD)	Apical angle deviation in ° (SD)	Sample size

CTs - half guided surgery (drill key group)						
First author, date, reference	Groups	Coronal implant deviation in mm (SD)	Apical implant deviation in mm (SD)	Vertical implant deviation in mm (SD)	Apical angle deviation in ° (SD)	Sample size
Geng, 2015	PG surgery (pilot guided)	0.54 (0.50)	0.81 (0.64)	0.31 (0.72)	2.56 (2.23)	29

CTs - half guided surgery (keyless group)						
First author, date, reference	Groups	Coronal implant deviation in mm (SD)	Apical implant deviation in mm (SD)	Vertical implant deviation in mm (SD)	Apical angle deviation in ° (SD)	Sample size
Moon, 2016	Mean deviation (both types of guides)	0.57 (0.61)	0.63 (0.64)	0.64 (0.57)	3.84 (1.49)	19

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