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Original article

2D/3D accuracies of implant position after guided surgery using different surgical protocols: A retrospective study

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Purpose: To compare the 2D and 3D positional accuracy of four guided surgical protocols using an analysis of linear and angular deviations.
Methods: DICOM and .STLs files obtained from a CBCT and a digital impression were superimposed with software to plan implant position. Fifty-six patients were subdivided into 4 groups: FGA group (template support [Ts]: teeth [T]; bed preparation [Bp]: fully guided [FG]; implant insertion [Ii]: 3D template [3Dt]; device [D]: manual adapter [MA], FGM group (Ts: T; Bp: FG; Ii: 3Dt; D: fully guided mounter [FGM]), PG group (Ts: T; Bp: FG; Ii: manual; D: none) and MS group (Ts: mucosa; Bp: FG; Ii: 3Dt; D: FGM). The position of 120 implants was assessed by superimposing the planned and final position recorded with a digital impression.
Results: In FGA group, 3D deviations were 0.92 ± 0.52 mm at the implant head and 1.14 ± 0.54 mm at the apex, and the angular deviation (ang. dev.) was 2.45 ± 1.24°. In FGM group, were 0.911 ± 0.44 mm (head) and 1.11 ± 0.54 mm (apex), and the ang. dev. was 2.73 ± 1.96°. In PG group, were 0.95 ± 0.47 mm (head) and 1.17 ± 0.488 mm (apex), and the ang. dev. was 3.71 ± 1.67°. In MS group, were 1.15 ± 0.45 mm (head) and 1.42 ± 0.45 mm (apex), and the ang. dev. was 4.19 ± 2.62°. Ang. dev. of MS group was different from the other groups ($P < 0.05$).
Conclusions: Guided surgery showed a sufficient accuracy.

1. Introduction

In recent years, there has been an increase in demand for fixed implant-supported prostheses [1]. Correct positioning of dental implants is crucial to fulfil both functional and aesthetic success [2]. In addition, a well-planned surgery minimizes risks such as sinus perforation, dehiscences, fenestrations, and mandibular nerve damage and prevents contact between a dental implant and the root of an adjacent tooth [3,4]. Moreover, it is possible to check parameters such as the distance between two or more implants, the distance between a tooth and an implant, and implant depth [5,6]. Prosthetic aspects such as the implant emergence profile can also be evaluated by using the abutment projections and some software packages [7].

Accuracy in guided implant surgery can be evaluated by matching the planned position of the implant in the software with the final position of the implant in the patient's mouth [8]. The accuracy of implant position depends on the accumulation of all errors in each phase of the process: data acquisition with computed tomography (CT) or cone-beam computed tomography (CBCT), conventional or digital impression taking, data processing to manufacture a surgical guide, placement of the guide during surgery, movement of the template during drilling, and mechanical error caused by tolerance of surgical instruments [9,10].

Three surgical approaches are currently in use: freehand, computer-guided, and computer-navigated surgery [11]. After planning the surgical procedure in three dimensions (3D), a static resin surgical template is produced using the stereolithography rapid prototyping technique [12,13]. The design of the surgical tem-

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plate is created by superimposing the CBCT data with the digital impression and the digital wax-up of the mouth, including the planned implant position [14]. The planned implant position can be transferred to the patient with the surgical template. In contrast, computer-navigated surgery, also called dynamic guided surgery, is based on motion-tracking technology, which allows for real-time monitoring of the drill and the modification of the implant position during surgery [15,16]. The final restoration can be projected to be screw retained instead of luted, avoiding the risk of cement debris accumulating in the implant sulcus [17]. According to a recent review by Tahmaseb et al. [18] on the accuracy of computer-guided surgery, the mean positioning error at the implant head was 0.9 mm for partially edentulous cases and 1.3 mm for fully edentulous cases. The mean positioning error at the implant apex was 1.2 mm for partially edentulous cases and 1.5 mm for fully edentulous cases. The angular deviation was 3.3° for partially and fully edentulous cases. This review concluded that the accuracy of computer-guided systems surgery is within the clinically acceptable range but a safety margen of at least 2 mm should be respected. A systematic review and meta-analysis concluded that the type of tissue support for the surgical template influenced the accuracy of computer-aided implant surgery. Bone-supported templates led to greater deviation in implant angle, entry point, and apex position compared with dental- and mucosa-supported templates. No differences in implant position accuracy were recorded between mucosa- and dental-supported templates [19].

The aim of the present retrospective clinical study was to evaluate the 2D and 3D positional accuracies of implants among four different guided surgical protocols using an analysis of linear and angular deviations. The null hypothesis was that there was no difference in accuracy between the four surgical protocols. This trial is reported in accordance with the STROBE (STrengthening the Reporting of OBservational studies in Epidemiology) statement (https://www.strobe-statement.org/) for observational studies.

2. Materials and methods

The clinical trial protocol was submitted to the Sanitary Regional Service of the Emilia-Romagna, Bologna-Imola Ethical Committee (BI-EC) and approved with permit number 17136. The patients included in this retrospective study were consecutively treated with computer-guided implantology between March 2016 and September 2017. Surgical planning, surgeries, and prosthetic procedures were performed by two expert clinicians (C.M. and V.S.) in their private practice office. All participants provided informed consent.

2.1. Patient selection

Patients were enrolled in the study only if they met all of the following criteria:

1 Adequate bone height and thickness to place an implant with a minimum length of 6.0 mm (range: 6.0–12.0 mm) and a minimum diameter of 3.3 mm (range: 3.3–4.8 mm).
2 Natural dentition or fixed restorations for opposing occlusions.
3 Bone sites healing for at least 4 months since extractions were done.

Any potential implant position, based on patient requirements, was considered eligible for this retrospective clinical trial (Table 1).

Fifty-six patients were recruited for computer-guided surgery: 28 women and 28 men with a mean age of 54.2 ± 13.8 years (range: 20–84 years). Patients had partially (n = 51) and completely (n = 5) edentulous arches. In total, 120 implants were inserted. All implants belonged to the Straumann dental implant system (Straumann Dental Implant System, Basel, Switzerland). The type of implants, in detail, are reported in Table 2.

Table 1
Details of the retrospective study about patients, implant positions, implant lengths, operators, and type of dental gaps.

Number of implants for each sex	Male Female	28 28
Number of implants for each jaw	Maxilla	61
	Mandible	59
Number of implants for each dental gap and template support	Single missing tooth with mesial dental support	23
	Single missing tooth with mesial and distal dental support	38
	Two missing teeth with mesial dental support	35
	Complete edentulism with mucous support	24
Number of implants for each implant lengths	6 mm	12
	8 mm	36
	10 mm	60
	12 mm	12
Number of implants for each surgical technique	Flapless	24
	Open flap	96
Number of implants for each implant position	Incisive region	21
	Canine region	10
	Premolar region	43
	Molar region	46
Distribution of surgeries between the two operators	Operator 1	73
	Operator 2	47

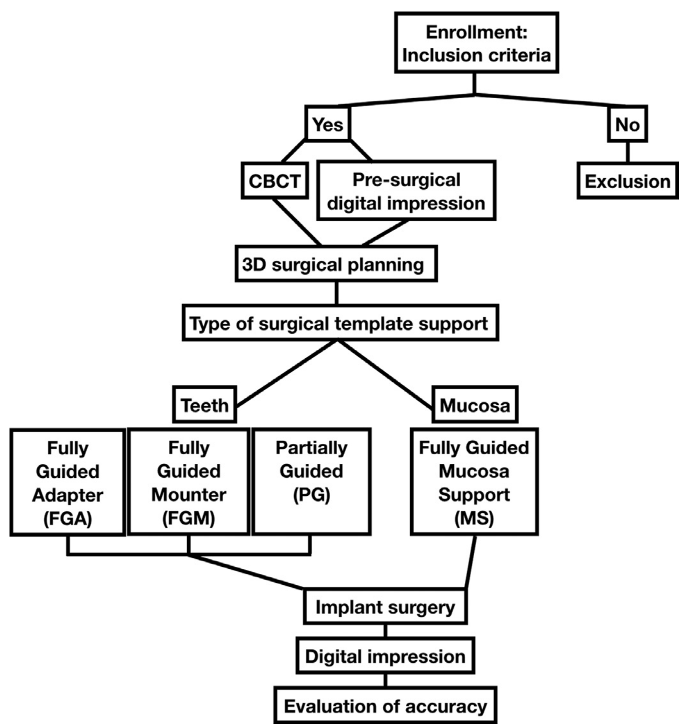

Fig. 1. Patient enrollment and subdivision into the four groups.

Patients were divided into four groups based on the type of surgical protocol used to place implants and on the support of the surgical template (Fig. 1 and Table 3). Implant beds were prepared using a fully guided approach in all groups. In edentulous patients, a mucosa-supported template was used, whereas in partially edentulous patients, the template had a full (mesially and distally) or

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Table 2
Types of dental implants for each group.

Implant type	Number of implants
Straumann Bone Level Tapered (BLT)	21
Straumann Standard Plus (SP) Regular Neck (RN)	72
Straumann Standard Plus (SP) Narrow Neck Crossfit (NNC)	1
Straumann Bone Level (BL) Narrow Crossfit (NC)	14
Straumann Standard Plus (SP) Wide Neck (WN)	12
Total	120

Table 3
Details of the study groups.

Group	Fully Guided Adapter (FGA)	Fully Guided Mounter (FGM)	Partially Guided (PG)	Fully Guided Mucosa Support (MS)
Number of implants	24	30	42	24
Template support	Teeth	Teeth	Teeth	Mucosa
Bed preparation	Fully Guided	Fully Guided	Fully Guided	Fully Guided
Implant insertion	3D template	3D template	Manual without 3D template	3D template
Device	Manual Adapter	Fully Guided Mounter	None	Fully Guided Mounter

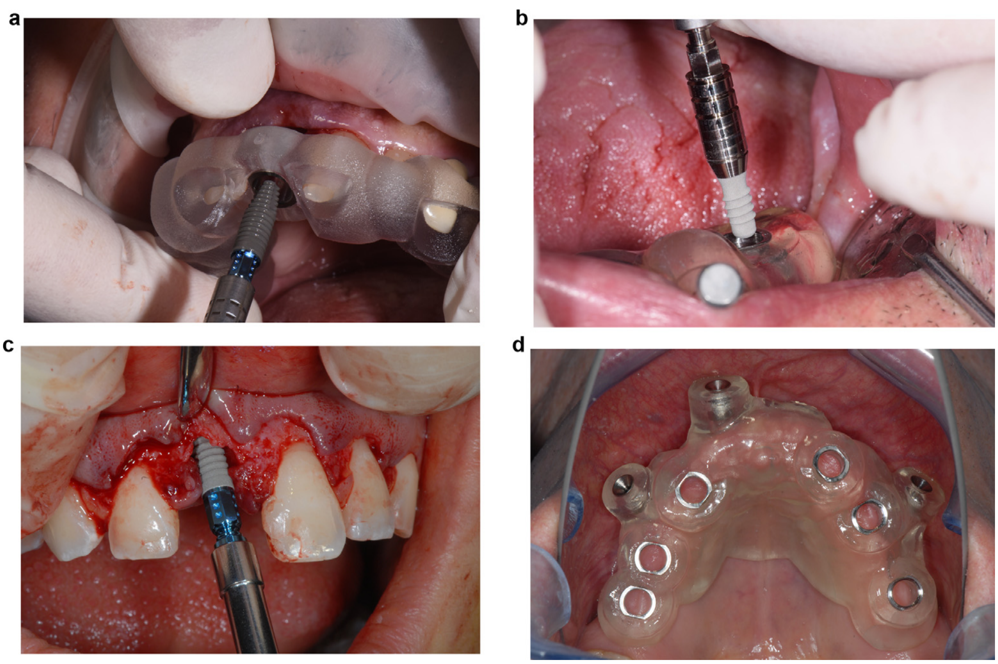

Fig. 2. (2a) Fully guided adapter (FGA) group: implant placement using a manual adapter. (2b) Fully guided mounter (FGM) group: implant placement using a guided mounter connected to the implant. (2c) Partially guided (PG) group: the implant was manually positioned. (2d) Fully guided mucosa support (MS) group: surgical templates had a mucosa support, and the placement was completely guided.

partial dental support (dental supported mesially and mucosa supported distally).

In the fully guided adapter (FGA) group, implants were placed using a manual adapter with three serigraph lines to indicate the depth of the implant insertion (Fig. 2a). In the fully guided mounter (FGM) group, the insertion was made using a guided mounter that was directly connected to the implant (Fig. 2b). The head of the mounter had three notched lines for positioning a fork to stop the insertion. In the partially guided (PG) group, implants were manually positioned. In these three groups, the teeth were used as a template support (Fig. 2c). In the fully guided mucosa support (MS) group, surgical templates had a mucosa support (Fig. 2d), and the placement was completely guided, as in the FGM group. In all patients requiring a mucosa-supported template, a flap-free surgical approach was used, and the mucosa-supported templates were fixated by anchor pins (Anchor pin, Straumann, Waldenberg, Switzerland). In partially edentulous patients, an open-flap surgical approach was used.

2.2. Surgical planning

For each patient, a CBCT (NewTom VGi, Quantitative Radiology, Verona, Italy) with noncontact arches was performed using a silicon index to obtain DICOM (Digital Imaging and Communications in Medicine) files. The thickness of each axial section was 0.150 mm. A digital impression was made using one of two different intraoral scanners (True Definition, Software version 5.1.1, 3M Espe, St. Paul, MN, USA, and intraoral scanner DWIOS, software version 1.7, DentalWings, Montreal, Canada) to obtain a .STL (STereo Lithography interface format) file of the dental arches to make a digital wax-up of the extracted teeth and to superimpose the DICOM files with the .STL files of the impression and the digital wax-up.

Three-dimensional surgical planning was performed using coDiagnostiX 9.7 (Dental Wings Inc, Montreal, Canada). The DICOM file was segmented to eliminate the low-density tissues and to visualize the bone surface and teeth. Multiple segments of the same

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Table 4
Details of the sleeve position and drill handle used for each implant.

Sleeve position	H6	H6	H4	H4	H2
Drill handle 1 mm	30	–	30	–	–
Drill handle 3 mm	–	40	–	18	2

file were obtained from the segmentation procedure, allowing for different structures to be viewed. DICOM files and .STL files obtained from the digital impression and wax-up were superimposed to plan the final position of the implants.

2.3. Surgical template

Surgical templates were designed using coDiagnostiX 9.7, with a diameter of 5 mm for the metallic sleeve and appropriate heights selected for the surgical templates. In the design, it was possible to specify the distance between the osseointegration level of the implant and the position of the sleeve, in relation to the final positions of the implants along the z-axis. There were three possible distances: 2 mm (H2), 4 mm (H4), and 6 mm (H6) from the implant head (Table 4). Once this distance was selected, the software automatically calculated the length of the drills and the height of the drill handle. The final design of the surgical template was exported as a .STL file for printing (Objet Eden 500v, Stratasys Ltd, Minneapolis, MN, USA) with a biocompatible photopolymer (Objet MED610, Stratasys Ltd). The system-specific metal sleeves with a 5-mm diameter (T-sleeves, Straumann AG) for guided surgery were manually pushed into the respective nots.

2.4. Surgical protocol

The implant bed of all implants was prepared using implant drills according to the surgical protocol. The surgical system used in this study included four drill handles that fit into corresponding sleeves. Each drill handle was equipped with a cylinder with an additional height of 1 mm at one end and 3 mm at the other end. Each drill diameter (2.2 mm, 2.8 mm, 3.5 mm, 4.2 mm) was available in three different lengths: 16 mm (short), 20 mm (long), and 24 mm (extra long), with a drill stop. Once the implant distance was determined, the surgical protocol generated by the software specified the drill length and drill handle to use at each operating step. A single-stage surgery was performed, and a healing abutment was screwed onto the implants at the end of the surgery.

Hopeless teeth, if any, were subsequently extracted to improve the stability of the surgical template and to provide additional reference points in the postoperative .STL files for the evaluation of implant accuracy.

2.5. Postoperative implant position

After a waiting period of at least 4 months to achieve osseointegration, implant positions were detected using one of the two intraoral scanners previously used to obtain a .STL file. No postoperative CBCT was performed. All digital impressions were performed using original scan bodies (Scan-body, Straumann Cares Digital Solutions). A special tool (treatment evaluation) of coDiagnostiX 9.7 software was used by a third calibrated operator to superimpose the postoperative implant position with virtual dental models used for preoperative planning (Fig. 3). Differences between the planned and postoperative implant positions at the implant head and implant apex, and the angular deviation of the implant's axis, were calculated by the software. The total spatial deviation was obtained by calculating the differences between the planned and final position on the x-, y-, and z-axes. Using the formula $3\text{Ddev} = \sqrt{x^2 + y^2 + z^2}$, a single value was obtained for each clinical case that reflected the difference between the planned and postoperative implant positions.

The x-axis represented the buccolingual direction, with buccal values considered as positive and lingual values as negative. The y-axis represented the mesial-distal direction, with distal values scored as positive while mesial values were negative. Similarly, apical placement was scored as positive and coronal placements was scored as negative along the z-axis. However, the value of 3Ddev was always positive, as x, y, and z values are squared in the equation.

Two-dimensional deviations in implant position were also calculated to determine whether changes along the z-axis had a negative influence on clinical and calculated results. These differences were calculated using the formula $2\text{Ddev} = \sqrt{x^2 + y^2}$.

2.6. Statistical analysis

Statistical analysis was performed using JMP 13 (SAS Institute, Cary, NC, USA). A Shapiro–Wilks test was conducted preliminarily to confirm the normal distribution of the data in the four groups ($p > 0.05$). Differences between the planned and final position at the implant head and apex were tested using one-way analysis of variance (ANOVA), followed by Tukey HSD post hoc analysis for multiple comparisons. The significance level was set at $\alpha = 0.05$. The same statistical procedures were used to evaluate the angular deviations along the long axis of the implant.

3. Results

Table 5 lists the results, including mean and standard deviation (SD) values. All 120 implants were placed without any complications. The mean (±SD) differences between the planned and the final 3D positions for all implants were 0.978 ± 0.476 mm at the implant head and 1.20 ± 0.51 mm at the implant apex. The mean angular deviation was 3.31° ± 1.99°. Considering the 2D positions (excluding the apical-coronal axis), the mean position differences were 0.618 ± 0.421 mm at the implant head and 0.93 ± 0.54 mm at the implant apex. In the FGA group, the mean 3D positional difference was 0.92 ± 0.52 mm and 1.14 ± 0.54 mm at the implant head and apex, respectively. The mean angular deviation was 2.45° ± 1.24°. In the FGM group, the mean 3D positional difference was 0.911 ± 0.44 mm and 1.11 ± 0.54 mm at the implant head and apex, respectively, with a mean angular deviation of 2.73° ± 1.96°. In the PG group, the mean 3D positional difference was 0.95 ± 0.47 mm and 1.17 ± 0.488 mm at the implant head and apex, respectively, with a mean angular deviation of 3.71° ± 1.67°. The mean 3D positional differences at the implant head and apex in the MS group were 1.15 ± 0.45 mm and 1.42 ± 0.45 mm, respectively, with a mean angular deviation of 4.19° ± 2.62°. The 3D positional differences at the implant head and apex were not significantly different among the four groups ($P > 0.05$, one-way ANOVA). The angular deviation of implant positions in the MS group differed significantly from those in the FGA and FGM groups ($P < 0.05$, Tukey HSD). The 2D analysis revealed that the mean positional differences at the implant head and apex were 0.48 ± 0.30 mm and 0.79 ± 0.43 mm, respectively, in the FGA group; 0.62 ± 0.38 mm and 0.88 ± 0.53 mm in the FGM group; 0.50 ± 0.30 mm and 0.82 ± 0.42 mm in the PG group; and 0.77 ± 0.40 mm and 1.14 ± 0.41 mm in the MS group. Implant positions differed significantly between the MS and PG groups and between the MS and FGA groups ($P < 0.05$, Tukey HSD). These results indicate that surgery performed using a mucosa-supported surgical template was less precise than surgery using a dental-

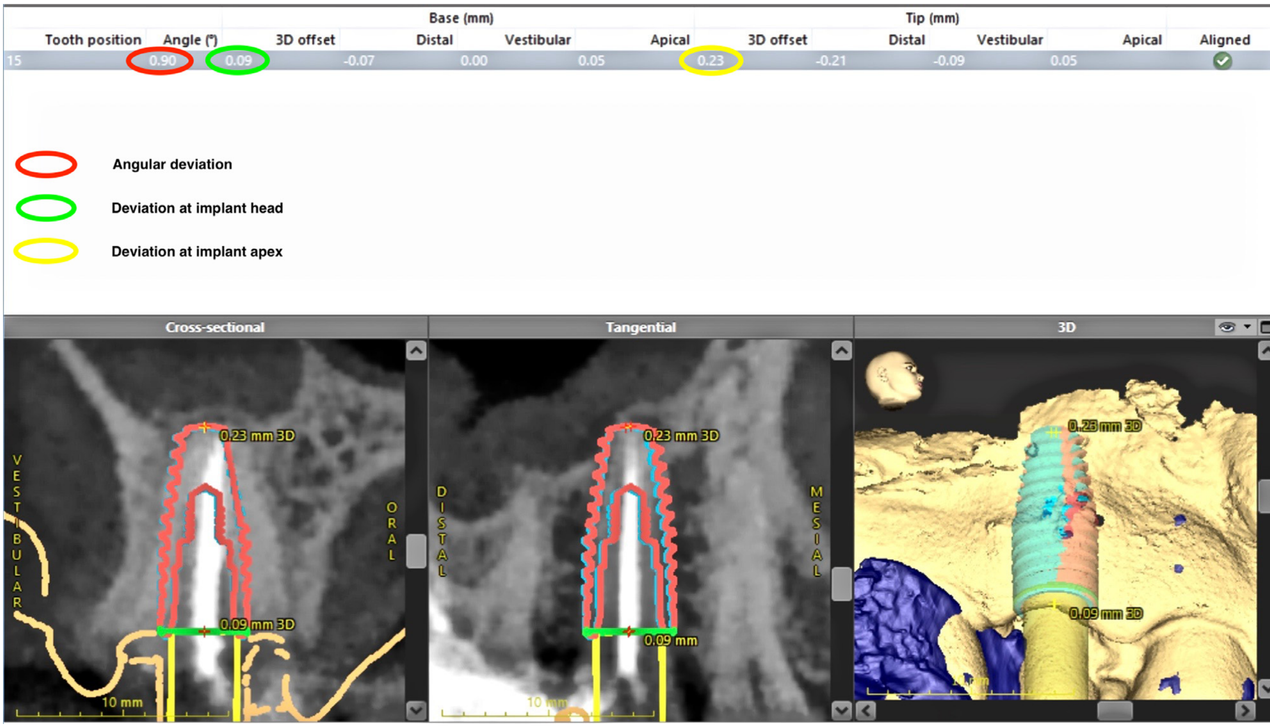

Fig. 3. Deviations of implant position were assessed by superimposing the planned and final position with the tool "treatment evaluation" of coDiagnostiX software.

Table 5
Mean spatial deviation along the x, y, z axes for the position of the implant head and apex for each patient group. 3Ddev and 2Ddev values are expressed as mean ± standard deviation.

	Buccal (x)	Lingual (-x)	Distal (y)	Mesial (-y)	Apical (z)	Coronal (-z)	3Ddev	2Ddev
Fully Guided Adapter (FGA)								
Head (mm)	0.286	−0.808	0.308	−0.18	0.412	−0.792	0.92 ± 0.52	0.48 ± 0.30
Apex (mm)	0.511	−0.632	0.481	−0.530	0.392	−0.857	1.14 ± 0.54	0.79 ± 0.43
Angular deviation (degree)							2.45 ± 1.24	
Fully Guided Mounter (FGM)								
Head (mm)	0.474	−0.583	0.272	−0.257	0.345	−0.598	0.911 ± 0.44	0.62 ± 0.38
Apex (mm)	0.826	−0.521	0.447	−0.564	0.365	−0.58	1.11 ± 0.54	0.88 ± 0.53
Angular deviation (degree)							2.73 ± 1.96	
Partially Guided (PG)								
Head (mm)	0.340	−0.312	0.323	−0.299	0.628	−0.731 (32)	0.95 ± 0.47	0.50 ± 0.30
Apex (mm)	0.510	−0.468	0.690	−0.485	0.586	−0.730	1.17 ± 0.48	0.82 ± 0.42
Angular deviation (degree)							3.71 ± 1.67	
Fully Guided Mucosa Support (MS)								
Head (mm)	0.58	−0.203	0.367	−0.52	0.441	−0.868	1.15 ± 0.45	0.77 ± 0.40
Apex (mm)	0.804	−0.465	0.781	−0.761	0.466	−0.84	1.42 ± 0.45	1.14 ± 0.41
Angular deviation (degree)							4.19 ± 2.62	

supported surgical template. Two surgeons were involved in this study. The mean positional deviations at the implant head and apex were 0.911 ± 0.50 mm and 1.21 ± 0.07 mm, respectively, for the first surgeon and 1.01 ± 0.45 mm and 1.198 ± 0.49 mm for the second surgeon. These differences were not significant ($P = 0.2395$ for implant head and $P = 0.8716$ for implant apex, one-way ANOVA). The implant length (6, 8, 10, or 12 mm) did not determine a statistically significant difference in the deviation of the implant at the apex ($P = 0.10580$) or at the head ($P = 0.40570$). When drill sleeves at position H6 were used, mean positional deviations were 0.99 ± 0.55 mm (implant head) and 1.21 ± 0.56 mm (implant apex) with a drill handle of 1 mm, and 1.07 ± 0.42 mm (implant head) and 1.3 ± 0.51 mm (implant apex) with a drill handle of 3 mm. No significant differences ($P > 0.05$, one-way ANOVA) in results were found between drill handles of 1 or 3 mm. The use of sleeves in the H4 and H6 positions also did not yield significantly different results ($P = 0.5632$). The results from the H4 and H6 positions were not compared with those from the H2 position, because only two implants were placed with the lowest position of the sleeve.

4. Discussion

This study compared the accuracy of guided implant surgery using different surgical protocols. The 2D analysis revealed statistically significant differences for positional deviations at the implant apex and head between the MS group and the FGA and FGM groups. In the present study, the surgeries performed using dental support were more accurate than those using mucosa support; thus, the null hypothesis was rejected. The angular deviation of the MS group was statistically different from the other groups, but 3D analysis revealed no significant differences in positional deviations at the implant head and apex. Nevertheless, the use of dental-supported templates led to greater positional accuracy than the use of mucosa-support templates, a finding also corroborated by Mora et al. [7] and Gallardo Raico et al. [19].

The results of the present study indicate that, if possible, the use of a dental-support template is preferable, as it allows for the possibility of opening a flap in cases of surgical modifications or complications, to have a better view of the operating field, or to improve irrigation below the template [5,20]. To ensure a more accurate surgery, it could be advisable to retain nonmobile dental elements, even those with a poor prognosis, to support the template during surgery. These teeth can be subsequently extracted or maintained until the next stage of prosthetic treatment. Bone-supported surgical templates can be used as well, but their use requires an extended flap divarication [21]. In the present study, bone-supported templates were not evaluated, and this can be considered a further limitation.

The tilting of the drill handle (and thus of the drill) through the sleeve can cause flag-waving, which affects the position of the implant apex. The use of a single insert rather than a drill and drill handle could minimize the flagging effect and consequently reduce the spatial deviation at the implant apex [22]. However, the implant length and the distance between the sleeve and the implant did not affect the apical position of the implant in the present study.

The stability of the template during the surgery can be enhanced by using anchor pins according to the surgical protocol. However, mucosa-supported templates showed micro movement even when multiple fixation pins were used, and this could have reduced accuracy [14]. In totally edentulous patients, temporary implants could standardize the position of the template for CBCT examination and during surgery. This approach led to the most accurate outcomes for completely edentulous patients but increased patient discomfort and extended treatment duration [23].

The mean spatial deviations recorded in the present study were more accurate than those reported in the meta-analysis by Tahmaseb et al. [18]: the total mean error was 1.2 mm (1.04 mm to 1.44 mm) at the entry point and 1.4 mm (1.28 mm to 1.58 mm) at the apical point, and the angular deviation was 3.5° (3.0° to 3.96°). Tahmaseb found that the surgeries performed on partially edentulous patients were more accurate than those performed on fully edentulous patients. The increased accuracy could be due to the fewer implants inserted in the present study (120 implants) compared with those included in the review. Furthermore, in the present study, far fewer patients were treated using mucosa-supported templates than in the review.

Few studies [24,25] have evaluated the accuracy of the mesio-distal position of the implant. A recent review by Zhou et al. [10] reported mean errors of 1.05 mm and 0.91 mm at the entry point and apex, respectively. In the present study, the largest horizontal deviation was recorded in the MS group: 0.52 mm at the implant head and 0.761 mm at the implant apex. This was probably due to the use of mucosa-support templates in this group. In the other three groups, the use of dental-support templates helped to reduce the mesio-distal deviation. An in vitro study by Schneider et al. [26] evaluated the mechanical tolerance of the system metal sleeve/drill handle/drills and that of the 3D-printed sleeves/drill handle/drills from the Straumann guided surgery system. Both the height and diameter of the metal sleeve were 5 mm, whereas drill handles were 1 and 3 mm in height, as in the present study. The mean lateral movement of the drill tip caused by the tolerance between the drill handle and sleeve was 0.42 mm, while the mean movement of the drill within the drill handle was 0.49 mm. Therefore, the mean total lateral movement was 0.91 mm. Checking alignment was crucial to verify that files (.STL and DICOM) were superimposed correctly. The mean accuracy of superimposition techniques for 3D data varies between 0.13 and 1.5 mm [27,28]. An error of 0.3 mm is considered acceptable [29]. In many clinical studies, a second postoperative CBCT was carried out to determine the final implant position, whereas in the present study, a digital impression with a scan body was used. This allowed to avoid the issue of scattering due to the presence of the implants and also to avoid administering a second radiogenic dose to the patient for research purposes [30,31]. The method used in the present study would seem to be equally precise [32]. The accuracy of dental digital impressions depends on the digital impression systems. The accuracies reported by Ali et al. [33] for five digital impression systems were 23 μm for Cadent iTero, 36 μm for 3 M Lava C.O.S., 44 μm for 3Shape D900, 68 μm for Cerec Bluecam, and 84 μm for E4D Dentist. Vandeweghe et al. [34] found a mean trueness of 0.112 mm for Lava COS, 0.035 mm for 3 M TrueDef, 0.028 mm for Trios, and 0.061 mm for Cerec Omnicam. Alikhasi et al. [35] reported that the accuracy of digital impressions of implants was not affected by the type of connection and angulation and that the accuracy was better than that of conventional impression. With regard to the technical accuracy of printed surgical templates designed using the coDiagnostiX software, the 3D deviations of the sleeves from the virtually planned position were 0.22 mm at the centre of the sleeve top, 0.24 mm at the centre of the sleeve bases, and an angular deviation of 1.5° [36]. Implant accuracy is also affected by the CBCT device, with axial deviations of up to 0.6° and linear deviations of approximately 0.5 mm [37,38].

The present study has some limitations: fixation pins and a flapless approach were used only in the MS group, and these factors can affect accuracy [39]. In addition, the differences in accuracy between surgeries performed on maxillae and mandibles were not evaluated. A recent review by Zhou et al. [10] revealed that guided surgery performed on the mandible had greater angular accuracy compared with surgery on the maxilla. A further limitation of the present study is the lack of a control group treated with free-hand surgery. A recent review performed by Chen et al. [40] showed that guided surgery has an accuracy higher than that of free-hand surgery. Younes et al. [41] found that fully guided implant surgery was the most accurate followed by pilot-drill guided and free-handed implant surgery. The apical deviation of free-handed implant surgery ranged from 2.11 mm to 4.84 mm.

In the present study, no nerve injury, excessive bleeding, or other complications arising from incorrect implant positioning were observed.

The results of the present study indicate that implants did not deviate significantly from their planned apico-coronal positions, which could otherwise cause lesions to the inferior alveolar nerve, even if outliers were evaluated. However, every guided surgery should be planned and performed with extreme caution, especially when the distance from sensitive anatomical structures is close to the limit of accuracy of guided implant surgery.

5. Conclusions

Within the limitations of this clinical study, the results demonstrate the good accuracy and predictability of the implant position with guided surgery.

The use of dental-supported surgical templates may be more accurate than the use of mucosa-supported guides, while both partially and fully guided templates can simplify surgery and aid in optimal implant placement. A careful observance of surgical protocols can reduce the differences in accuracy between the partially guided and fully guided approaches. The use of a digital impression to evaluate the final position of the implant can avoid a second CBCT. Further randomized controlled clinical trials on accuracy are still needed to provide guidelines.

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Informed consent

For this study all participants provided informed consent.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The clinical trial protocol was submitted to the Sanitary Regional Service of the Emilia Romagna, Bologna-Imola Ethical Committee (BI-EC) and approved with decision number 17136/2017.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jpor.2019.11.007.

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