Accuracy of implant placement in the posterior maxilla as related to 2 types of surgical guides: A pilot study in the human cadaver

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Statement of problem. The position of implants may have an effect on obtaining osseointegration without complications and on the outcome of the prostheses.

Purpose. The purpose of this study was to compare the accuracy of implant placement with computer-guided surgery and freehand surgery in the atrophic area of the posterior maxilla.

Material and methods. Six human cadavers (Kennedy class I) were included in the study. The specimens were randomly classified into 2 categories by using a computer: computer-guided surgery (n=3) and freehand surgery (n=3). Thirty-nine implants were planned with the software. Two types of surgeries were performed. The preoperative computed tomography data were matched with the postoperative computed tomography data by using voxel-based registration software. The position of the planned implants was compared to the actual position of the implants. A multivariate analysis was used for each variable (bone density, length of implant, implant angulation, and surgical technique) to evaluate the effect of these variables on the implant accuracy. The level of significance used in this study is .05 (5%).

Results. The statistical tests (Kolmogorov-Smirnov bootstrap) found that guided surgery offered significantly better accuracy for the platform ($P=.002$), apex ($P=.001$), and angle ($P<.001$). However, the accuracy of the 2 methods was similar for the depth parameter ($P=.186$). The bone density did not influence the implant placement accuracy.

Conclusions. Computer-guided surgery was more accurate than a freehand approach for placing implants into bilateral edentulous zones in the posterior maxilla. (J Prosthet Dent 2014;■:■-■)

Clinical Implications

Computer-guided surgery was consistently more accurate than freehand surgery in terms of the position of the implants. Computer-guided surgery may offer improved accuracy when placing dental implants in the atrophic residual bone of the posterior maxilla.

The analysis of small residual bone volumes has been facilitated by progress in the field of 3-dimensional imaging, which allows implant planning with greater precision than 2-dimensional examinations.[1] The difficulty of 3-dimensional imaging arises when the surgeon attempts to transfer the virtual planning to the clinical osseous site. The accuracy of this transfer is important to avoid complications (nonosseointegration, migration of the implant into the sinus, and sinusitis).[2] Three different surgical methods are currently available for this transfer: freehand surgery, computer-guided surgery, and computer-navigated surgery.[3-5] The freehand approach involves the use of software for implant planning; the plan must then be transposed on the surgical site (following perforations in radiopaque teeth, the radiographic guide can serve as a tool to help surgeons during implant placement). Computer-guided surgery involves the use of a static surgical template that reproduces the virtual implant position directly from computed tomographic data but does not allow intraoperative modification of the implant position.[4] With computer-guided implant surgery, 3 types of support are available for the guide: mucosa, bone, and teeth. The different types of support can be combined, for example, teeth and mucosa. Computer-navigated surgery involves the use of a surgical

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navigation system that reproduces the virtual implant position directly from computed tomographic data and allows intraoperative changes in implant position.[4] This last technique is used less commonly. The available literature is limited regarding comparisons of implant accuracy for these different types of surgery. Some studies have reported the results of computer-guided surgery on partially edentulous patients.[6-9]

The treatment of the posterior maxilla creates a specific challenge for clinicians because of poor quality and quantity of residual bone and poor access. Numerous reconstruction techniques have been suggested; in particular, sinus lift techniques have shown promising results, although sinus graft techniques are not without risks and complications, including sinus floor perforation and sinusitis.[10,11] Another technique is the graftless procedure, which uses short implants[12,13] (devices with designed intrabony lengths of 8 mm or less) or angulated implants.[14,15] The use of 1 single type of short implant may be preferable to bone augmentation because the treatment is expeditious, less expensive, and associated with reduced morbidity.[16] Short implant-supported prostheses appear to be a valid option for treating the atrophic jaw.[12] The use of tilted implants can also avoid the need for sinus grafting procedures.[14,15,17,18] Tuberosity implants are generally angulated and conform to the graftless treatment concept.[19-21] The low density of the bone is also a problem when implants are inserted in the posterior maxilla. The low density complicates the control of the instruments during the drilling and implant placement.

The purpose of this study was to compare the accuracy of implant placement with computer-guided surgery and freehand surgery in the atrophic area of the posterior maxilla. The first null hypothesis was that the type of surgery has no effect on the precision of the implant placement, and the second null hypothesis was that the factors of length of the implant and tilting or absence of tilting of the implant do not influence the precision of the implant placement.

MATERIAL AND METHODS

Six anatomic partially edentulous human cadaver specimens were included in the present study at the Laboratory of Functional Anatomy Department, University Paris Descartes, France. French legislation and the rules of the board of the anatomy department regarding the use of anatomic specimens were respected throughout the study.

The 6 cadaver specimens selected arrived in the laboratory between September and December 2011; they had no major infectious diseases, an edentulous bilateral posterior maxilla (2 to 4 teeth missing, terminal edentulous jaw, and Kennedy-Applegate class I), no residual roots or implants, well-conserved teeth in the anterior region with no visible mobility, residual crest bone greater than 6 mm wide, bone volume compatible with implant placement without grafting (short or tilted implants), and a sinus without grafts. The specimens were frozen and thawed between each step as necessary (4 steps).

The 6 specimens were randomly divided into 2 categories by using a computer. Group FH (freehand surgery) consisted of specimens A, B, and F, and group GS (guided surgery) consisted of specimens C, D, and E. Impressions were made (step 1). A diagnostic waxing (step 2) was converted into a radiographic guide made of autopolymerizing acrylic resin (ProBase cold; Ivoclar Vivadent AG); 6 to 9 gutta percha markers with a diameter of 1.5 mm were inserted into the radiographic guide. Computed tomography (CT) scans with a double-scanning protocol were conducted on each specimen (step 3).[22] The first scan (guide + cadaver) was completed and followed by a second scan with the radiographic guide only. During the CT scan, the radiographic guides were placed, and the scans were performed with a medical CT (Somatom Sensation 10 scanner; Siemens). The CT scan settings included a 0-degree gantry tilt, 120 kV, 80 mA, a slice thickness of 0.75 mm, and a reconstruction increment of 0.5 mm. The same settings were used for both scans. All specimens were treated with the same protocol, as previously described.[22-24] Q1

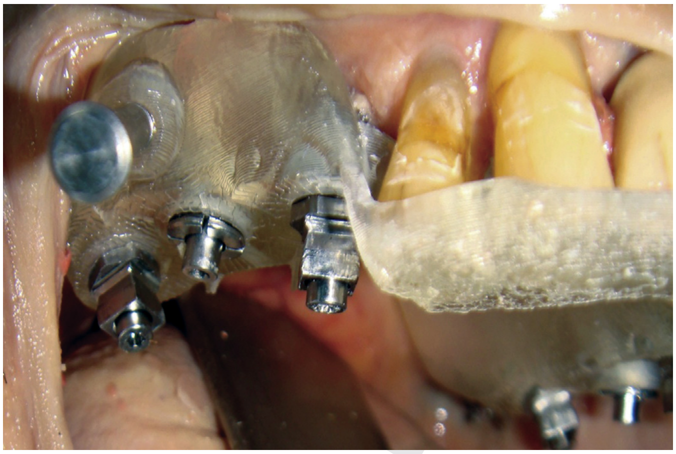
Software (NobelClinician; Nobel Biocare) was used in the preparation and treatment plan for all specimens (Table I). All of the implants included in the study were tapered (NobelSpeedy Groovy [external hexagon connection]; Nobel Biocare) and had a diameter of 4 mm.

The frozen specimens were allowed to return to room temperature for several hours before surgery (step 4). For the specimens of group FH, the radiographic guides were transformed into simple surgical templates (a window was created in the radiographic guide by eliminating the occlusal and cingulum faces of the teeth). For group FH, a surgical technique using the

TABLE I. Number of implants per specimen and per side

	No. of Implants				
Specimen	Right Side	Left Side	Premolar Site	Molar Site	Total
A	3	3	2	4	6
B	4	3	3	4	7
C	3	3	2	4	6
D	3	5	3	5	8
E	3	2	2	3	5
F	3	4	3	4	7
					39

1 Lateral view of specimen treated with freehand approach (with radiographic guide).

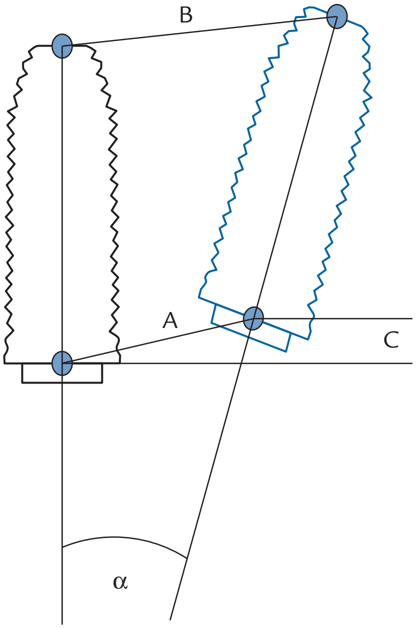


2 Lateral view of specimen treated with computer-guided surgery (with surgical guide).

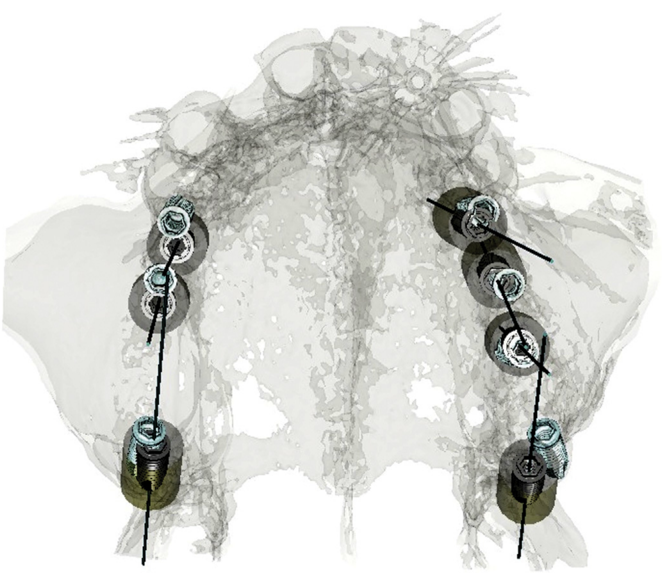
freehand approach was performed (Fig. 1). The buccal and palatal flaps were reflected to expose the underlying bone, as in routine implant surgery. A 2-mm twist drill was used to ensure the corresponding depth and angle. Then, twist drills with increasing diameters were used. For the specimens in group GS, a stereolithographic surgical guide was made by using the software (NobelClinician; Nobel Biocare) (Fig. 2). The second group (GS) was treated by using computer-guided surgery.[4] The drilling protocol was identical for all implants. The same surgeon (6 years of experience) performed all 6 surgeries. No complications occurred during the surgeries.

Once the implants were placed, a second CT scan was performed on the specimens with settings identical to those in the first scan. The 2 datasets were aligned into the same coordinate system with the software (NobelGuide Validation 2.0.0.4; Nobel Biocare). The matching and measurement method have been previously described.[24-28] The preoperative CT scan was matched with the postoperative CT scan by using the 3-dimensional voxel-based registration, previously described. The postoperative data were registered to the preoperative data by calculating the mutual information of the corresponding voxels in the 2 datasets into 1 coordinate system. The voxel-based matching software searched for corresponding gray values in the 2 data sets and aligned them. The implants from the postoperative scan were segmented from the data set, and the position and orientation of the clinically placed implants were compared with the virtually planned implant position in the coordinate system obtained from the voxel-based matching. The measurements were performed in 3 dimensions to determine both the linear and angular deviations. The software calculated the deviation between the planned positions and the actual implant positions for the outcome parameters platform, apex, depth, and angle (Figs. 3, 4). The depth deviation was calculated as the vertical distance between the middle of the occlusal plane of the placed implant and its intersection with the horizontal plane, which was drawn at the middle of the occlusal plane of the planned implant. A positive value indicates a deeper placement of the implant compared with the planned position. An experienced operator performed the matching and calculations. All of the data are presented by using descriptive statistics, including the number of observations; mean; median; and minimum, maximum, and standard deviations (SD).

The accuracy was evaluated for 4 outcome parameters: platform, apex, angle, and depth. The results were obtained for 39 implants, 19 of which were placed with guided surgery and 20 of which were placed with freehand surgery. Of the 39 implants, 12 had a length of 7 mm, and 27 had a length of 10 mm (see Table I). The average (standard deviation) buccolingual angle was 5.76 degrees (±4.95), and the mesiodistal angle was 12.30 degrees (±14.26). When the available bone was less than 7 mm in height, the implants were tilted to enhance the available bone (tuberosity bone). This decision to tilt the implants was made during the initial software-guided treatment planning. Then, the most posterior implants were tilted. Groups FH and GS were comparable in terms of the number of



3 Different measurements between planned position of implant and real position. A, Variation of platform of implant. B, Variation of apex of implant. C, Variation of depth (α, variation of angulation).



4 Image from cadaver F that illustrates deviations (gray, virtual implant position; blue, actual implant position) on occlusal view.

implants included and the selected length of the implants.

All of the calculations were performed by 1 statistician (Cyklad group). The 2 specimens were compared according to the controlled variables, length, density, and tilt, each of which could possibly influence the accuracy of the technique. To compare the quantitative variables with regard to sample size, a bootstrap version of the nonparametric Kolmogorov-Smirnov test was used, and the χ^2 values of the qualitative variables were calculated. The Kolmogorov-Smirnov test was used because of the small size of each sample (n<30).

A multivariate analysis was performed for each variable (platform, apex, angle, and depth) to evaluate the accuracy by considering certain explanatory variables, including the surgical technique and controlled variables (bone density, length of implant, and whether the implants were tilted). The purpose of this statistical test is to eliminate the cofactors of influence for implant placement. The multivariate analysis is able to separate the variables and indicate whether the variable 'type of surgery' exerted an influence on the outcome. The odds ratio had been established by means of numeric analyses. The variables measuring the accuracy (platform, tip, depth, and angle) were dichotomized. The cutpoints are listed in Table II and are explained as follows: 1 mm for the platform; 1 mm for the tip (this is the threshold of precision in the review of the literature by Jung); 0 mm for the depth, because the wrong insertion of the implant (either too much or too little) may have clinical consequences; and 6 degrees for the angulation.[29] The explicative variables length and density were dichotomized based on a base level: length, <10 mm or ≥10 mm (to create 2 categories of implants, 7 and 10); density, >214 or ≤214 Hounsfield units (median). Odds ratios of less than 1 indicate a higher accuracy.

TABLE II. Measurements of deviation

Deviation Type	Superior Accuracy	Inferior Accuracy
Deviation of platform (mm)	<1 mm (code 1)	≥1 mm (code 0)
Deviation of tip (mm)	<1 mm (code 1)	≥1 mm (code 0)
Angular deviation (degrees)	<6 degrees (code 1)	≥6 degrees (code 0)
Deviation of depth (mm)	>0 mm (code 1)	≤0 mm (code 0)

RESULTS

The results obtained from the calculations for groups FH and GS served as a basis for the samples: Kolmogorov-Smirnov tests for the length (P=1) and density (P=.767) and a χ^2 test (P=1) for the tilt. The results are provided in Table III.

The statistical test (Kolmogorov-Smirnov bootstrap) found significant differences in accuracy in favor of guided surgery for the deviations of the platform (P=.002), apex (P=.001), and angle ($P\leq$.001). However, no significant difference was found for the depth (vertical deviation) (P=.186).

The results of the multivariate models are given in Table IV. The results indicate that implants placed with guided surgery were more accurate. The odds ratios reveal that these differences were significant. Regarding the type of surgery (first row of Table IV), odds ratio values greater than 1 indicate that guided surgery provided more accurate implant placement. Odds ratio values less than 1 indicate a better accuracy for implant placement with freehand surgery. The platform, apex, and angle variables exhibit significant differences.

For the length of the implants (second row of Table IV), odds ratio values greater than 1 indicate that a higher level of accuracy was achieved for the implants that were less than 10 mm in length. Odds ratio values less than 1 indicate that a higher level of accuracy was achieved for the implants that were more than 10 mm in length. Only the platform variable showed a significant difference.

For the implant tilt (third row of Table IV), odds ratio values greater than 1 indicate a higher level of accuracy for the implants that were not tilted. Odds ratio values less than 1 indicate a higher level of accuracy for the implants that were tilted. Only the variable depth showed a significant difference. Bone density was the only variable that was not significant in any of the conditions.

TABLE III. Results of 4 parameters of functions of surgery (mean, SD, SEM, CI)

	Guided Surgery				Freehand Surgery				*P*
Deviation Type	Mean	SD	SEM	CI	Mean	SD	SEM	CI	(Kolmogorov-Smirnov Test)
Deviation of platform (mm)	0.932	0.6549	0.2	[0.656, 1.25]	2.060	1.1362	0.3	[1.584, 2.584]	.002
Deviation of tip (mm)	1.137	0.8902	0.2	[0.800, 1.582]	2.270	1.2359	0.3	[1.755, 2.841]	.001
Deviation of angle (degrees)	3.989	3.4756	0.8	[2.592, 5.656]	9.180	4.2831	1	[7.456, 11.137]	.000
Deviation of depth (mm)	0.184	0.4634	0.1	[−0.012, 0.395]	−0.290	1.0125	0.8	[−0.726, 0.164]	.186

SD, standard deviation; SEM, standard error of the mean.

TABLE IV. Results of multivariate models

	Deviation Platform		Deviation Tip		Angle Deviation		Depth Deviation	
Variable	*P*	Odds Ratio	*P*	Odds Ratio	*P*	Odds Ratio	*P*	Odds Ratio
Type of surgery	.004	33.603	.004	16.6	.001	22.692	*	-
Length	.043	11.707	*	-	*	-	*	-
Tilted implant	*	-	*	-	*	-	.047	4.907
Density	*	-	*	-	*	-	*	-

*Not significant.

TABLE V. Comparative results between freehand surgery and guided surgery

	Tip			Platform			Angle			Depth		
Type	Mean	SD	SEM	Mean	SD	SEM	Mean	SD	SEM	Mean	SD	SEM
Freehand surgery (FH)	2.3	1.2	0.3	2.1	1.1	0.3	9.2	4.3	1	−0.3	1	0.8
Guided surgery (GS)	1.1	0.9	0.2	0.9	0.7	0.2	4.0	3.5	0.8	0.2	0.5	0.1
Difference (=FH−GS)	1.2	0.3	0.1	1.2	0.4	0.1	5.2	0.8	0.2	−0.5	0.5	0.7

SD, standard deviation; SEM, standard error of the mean.

DISCUSSION

The results should be interpreted with caution because of the limited sample size. There were other limitations to this study. The study did not reflect real-life clinical elements, because no bleeding, no patient movement, and no problems with patient compliance were involved in a cadaver study. These aspects are important in routine surgery.

The data supported rejection of the first null hypothesis. Guided surgery was more accurate than freehand surgery in this study for the apex, platform, and angle variables. The average difference in accuracy, which favored the computer-guided surgery, was 1.1 mm (mean value) for the platform deviation, 1.1 mm (mean value) for the apical deviation, and 5.2 degrees (mean value) for the angular deviation (Table V). A more homogeneous accuracy in the position of the implants was noted (smaller standard deviations and CIs; see Table III).

The second null hypothesis was confirmed, because the multivariable models found that only the variable of type of surgery had a positive effect on precision; the variables of length, density, and tilt did not have an effect on the precision of the implant position.

The accuracy results of computer-guided surgery in this study are similar to the results of other published accuracy studies (Table VI).[6-9,28] Similar results (compared with the present study) were observed in studies that used a similar methodology, with partial edentulous zones in the maxilla, on either patients or human cadavers, with only 1 tooth-supported stereolithographic guide. Other accuracy studies have examined formalin-based human cadavers. In these studies, bone softening due to demineralization from the formalin can occur, which may affect the implant placement. The present study is closer to clinical conditions because of the absence of formalin. One deviation from the normal clinical situation was that the cadavers were frozen, which might change the properties of the mucosa. However, in this study, the radiographic and surgical

TABLE VI. Summary of reported accuracies for studies treating partially edentulous specimens with stereolithographic template

Authors	Type of Study	Imaging	Implant	UJ	LJ	Platform Average	Platform Minimum	Platform Maximum	Platform SD
Q4 Di Giacomo et al[9]	In vivo	CT	4	1	-	0.4	0.1	1.1	-
Van Assche et al[8]	Cadaver study	CT	12	1	3	1.1	0.3	2.3	0.7
Q5 Ersoy et al[7]	In vivo	CT	26	-	-	1.1	-	-	0.6
Q6 Ozan et al[6]	In vivo	CT	30	-	-	0.9	-	-	0.4
Van Assche et al[28]	In vivo	CBCT, CT	19	6	2	0.6	0.1	1.4	0.3
Noharet et al (present study)	Cadaver study	CT	19	3	-	0.9	0.1	2.8	0.7
Global average						0.8			

Authors	Tip Average	Tip Minimum	Tip Maximum	Tip SD	Angle Average	Angle Minimum	Angle Maximum	Angle SD
Di Giacomo et al[9]	2	0.8	3	-	6.9	1.9	12.2	-
Van Assche et al[8]	2	0.7	2.4	0.7	2	0.7	4	0.8
Ersoy et al[7]	1.3	-	-	0.7	4.4	-	-	1.6
Ozan et al[6]	0.9	-	-	0.6	2.9	-	-	1.3
Van Assche et al[28]	0.9	0.2	1.8	0.4	2.2	0.6	3.9	1.1
Noharet et al (present study)	1.1	0.1	4.2	0.9	4	1	13.6	3.5
Global average	1.4				3.7			

UJ, xxxx; LJ, xxxx; SD, standard deviation; CT, computed tomography; CBCT, cone beam computed tomography. Q7

guides were placed on the nonmobile teeth, representing hard tissue. If the guides had been placed on the mucosa, an increased deviation might have occurred.

The depth parameter has been evaluated in 2 studies.[8,26] The first study included edentulous cadavers with mucosal support of the surgical template. Therefore, the obtained results are not comparable with the present study. More favorable results were presented in a study by Van Assche et al[8] (−0.1 mm; SD, ±0.5), which could be explained by the fact that specimens with terminal edentulous zones were evaluated. In another report, Van Assche et al[28] included 2 patients with terminal edentulous zones and 5 patients with unilateral or bilateral edentulous zones. For the terminal edentulous zones, the pressure applied to the guide during implant insertion may have distorted the guide. Apart from these specific factors, a series of errors during the entire diagnostic and operative procedure may have contributed to an accumulation of minor errors, leading to larger deviations of the implant position. The reproducibility of the template position during the acquisition of the radiographic data and during the placement of the implants is a delicate issue.[4]

The support of the guide is an important factor. In this study, the type of support was mucosa, which may affect the process of freezing for the preservation of the specimens and thus the precision of the implant placement. Two studies have been completed that used similar conditions to this study (with a similar protocol with human cadavers and identical techniques). Pettersson et al[26] used completely edentulous maxillas, and the present study used partial edentulous maxillas (with a difference in guide support, mucosa only or with teeth). A similar study could be completed with completely edentulous jaws. The choice of the type of support for the guide is subject to discussion: in the case of the present study, hard support was used. In the case of completely edentulous jaws, when the mucosa is used as support for the guide, this support is not completely stable because the mucosa is depressible. This fact may result in problems concerning the positioning and the stability of the guide no matter which technique is used. The end results may be affected.

A second study by Pettersson et al[27] used the same guided system and matching technique. This second study was performed on patients in actual clinical situations. The results were similar; for each variable, the maximal difference was 0.15 mm for the platform, apex, and depth, and the variation in the angle was 2 degrees. The means of support (mucosa or teeth) for the guides did not appear to influence the accuracy of the implant placement when identical radiographic, surgical, and matching protocols were used.

The results of implant placement with a freehand surgical technique are difficult to evaluate and compare with other published data, as only a limited number of studies have been reported. The existing publications primarily developed the description of the various techniques used during a freehand approach.[9,14] The accuracy of the transfer of the virtual planning to the clinical site is important. The studies available concerning freehand surgery are limited. Therefore, additional studies are needed to confirm the results of the present study. These additional studies should include not only all types of support but also a group of surgeons to obtain more general data.

CONCLUSIONS

Within the limitation of the study design, it was concluded that guided surgery showed significantly better results for 3 criteria of precision (platform, apex, angle). No conclusion could be drawn concerning the depth. Only the variable of type of surgery had a positive effect on precision; the variables of length, density, and tilt did not have an effect on the precision of the implant position.

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