A Clinically Relevant Accuracy Study of Computer-Planned Implant Placement in the Edentulous Maxilla Using Mucosa-Supported Surgical Templates

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ABSTRACT

Purpose: The purpose of the study is to determine the clinically relevant accuracy of implant placement in the edentulous maxilla using computer planning and a mucosa-supported surgical template.

Materials and Methods: In each of in total 30 consecutive edentulous patients suffering from retention problems of their upper denture, two or four Brånemark MkIII Groovy (Nobel Biocare®, Zürich, Switzerland) implants in the maxilla were installed. Preoperatively, first, a cone-beam computer tomography (cone beam computer tomography) scan was acquired, followed by virtual implant planning. Hereafter, a surgical template was designed to allow flapless implant placement using the template as a guide. To inventory the accuracy of implant placement, a postoperative CBCT scan was obtained and matched to the preoperative scan. The accuracy of implant placement was validated three-dimensionally. The Implant Position Orthogonal Projection validation method was applied to measure the clinically relevant implant deviations (i.e., in both the bucco-lingual and mesio-distal plane). Also, the influence of type of surgery, use of fixation pins, and position on the dental arch were investigated with regard to implant deviations.

Results: In total, 104 implants were installed. In bucco-lingual direction, a mean implant deviation of 0.67 mm was scored at the implant tip, of 0.51 mm at the shoulder, of −0.83 mm in depth, as also a mean deviation of angulation of 1.74°. In mesio-distal direction, a mean implant deviation of 0.75 mm was found at the implant tip, of 0.60 mm at the implant shoulder, of −0.75 mm in depth, and a deviation of angulation of 1.94°. Of all implants, 74% was placed not deep enough compared with the planning. Implant position on the dental arch, the use of fixation pins, and type of surgery showed no significant effect on implant deviations. However, a significant difference for implant deviations in both buccal and mesial direction was observed, explained by a nonoptimal positioning of the surgical template.

Conclusions: 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.

KEY WORDS: cone-beam CT, implant placement, implantology, oral and maxillofacial surgery, validation, validation method, virtual implant planning

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INTRODUCTION

Fully edentulous patients may complain about the retention of their mucosal borne upper denture because of lack of stability, lack of retention, poor support, and poor neuromuscular control. To overcome these problems, an implant-supported overdenture can be suggested.

To offer a stable osseous environment for an endosseous implant, at least 2 mm, peri-implant bone should be present.[1] Unfortunately, conventional panoramic radiographs do not provide such detailed information of patient's anatomy. This can only be obtained using computer tomography or cone beam computer tomography (CBCT).[2] To take the best advantage of the available amount of bone, thereby reducing the need for preimplant bone augmentation procedures, virtual implant planning systems have been introduced. These systems take bone availability, bone quality, anatomical, and prosthetic aspects into consideration. To transfer the planned implant position to the patient, often a surgical template is designed that allows flapless implant installation.

In literature, very limited number of authors reported on the accuracy of implant placement in the maxilla of fully edentulous patients.[3–7] No study was found to evaluate implant accuracy after virtual implant planning in a clinically relevant manner. Neither study was found on the accuracy of placing two or four implants in the fully edentulous maxilla.

The purpose of this study was to evaluate the 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.

MATERIAL AND METHODS

Patients

In this prospective study, 30 consecutive fully edentulous patients were enrolled, suffering from retention problems of their upper denture. Only those patients who had sufficient bone volume to allow installation of two or four dental implants in the maxilla, without the need of preoperative bone augmentation procedures were selected. All patients were treated in the Department of Oral & Maxillofacial Surgery of the Radboud University Nijmegen Medical Centre.

Virtual Implant Planning

Preparation and Implant Planning. First, the fit of the current denture was checked. When needed, the denture was relined using a soft reliner (Soft-Liner, GC Dental Industrial Corp., Tokyo, Japan) to be sure that an optimal fit was present.

To register the position of the denture (and later surgical template) in relation to the bone, two CBCT scans were taken using the i-CAT® 3D Imaging System (Imaging Sciences International Inc., Hatfield, PA, USA) according to the double scan procedure.[8] One scan was made of solely the denture on which 14 to 20 glass spheres with a diameter of 2 mm (KGM Kugelfabrik Gebauer GmbH, Fulda, Germany) were glued, functioning as radiopaque markers. The other scan contained the patient wearing this marked denture, while instructions were given to bite in habitual occlusion. No radiographic index to obtain occlusion was used. To obtain such index, the patient needs to occlude with a pressure which is similar during both the scanning procedure as during implant placement. When treating patients in general anaesthesia because of the used muscle relaxants, this is not possible. The scan was checked for movement artifacts and absence of space/air between denture and underlying soft tissues to be certain of a proper fit of the denture, and as such, also of the surgical template. Both CBCT scans were taken using a setting of 120 kVp, pulses of 3 to 8 mA, 8 cm scan height, and exposure time of 20 seconds and were reconstructed with an 0.3 mm isotropic voxel size.

From both acquired scans, three-dimensional reconstructions of the alveolar bone and the marked denture were created using the Procera Clinical Design® software (Nobel Biocare®, Zürich, Switzerland). No Nobel Biocare calibration object[9] was used, as this was not available at that time. By registering the same markers on both scans, the position of the denture related to the bone was obtained. With respect to both the available bone volume and antagonistic teeth, two or four Brånemark MkIII Groovy (Nobel Biocare) implants were virtually planned at their optimal position by an oral maxillofacial surgeon. Fixation pins (Guided Anchor Pin Ø 1.5 mm, Nobel Biocare) were planned for the first series of cases and left away in more recent plannings as the surgeons were hindered in their surgical performance by the fixation pins. Based on the virtual implant planning, a surgical template was ordered from Nobel Biocare

(Gothenburg, Sweden) which was produced using stereolithography.[10,11]

Surgical Implant Placement Procedure. Patients received implants using only local anesthesia or, in general, nasotracheal anesthesia without local anesthesia. Implant installation was performed according to the NobelGuide procedure. The surgical template was randomly fixated with or without the use of fixation pins. When no fixation pins were used, the position of the surgical template purely relied on digital pressure. By giving pressure to the central palatal part of the surgical template using the forefinger, the fit of the template can be controlled continuously. Changes in fit can be registered not only by eye, but also by feeling. It was hypothesized that this method would at least be as good as applying fixation pins.

Brånemark MkIII Groovy implants with regular platform (Ø 3.75 mm) and/or narrow platform (Ø 3.3 mm) were selected and inserted according to the planning. A two-stage procedure was chosen; cover screws were placed as to allow osseointegration of the implants without loading. As all implants were installed flapless, the patients were allowed to wear their dentures immediate postoperatively.

After a 5-month period of integration, the implants were exposed. When necessary, a mucosa-plasty was performed to ensure that all implants were surrounded by attached mucosa. Finally, the prosthetic rehabilitation was completed by the fabrication of a removable implant-supported denture using individual attachments or a bar-clip system.

Implant Validation

Within 2 weeks after implant installation, a postoperative CBCT scan was acquired using the same settings as for the preoperative scans. Both the pre and postoperative three-dimensional reconstructions, as well the virtual implant planning, were loaded into the NobelGuide® Validation software (Version 2.0.0.4, Medicim NV, Mechelen, Belgium) and processed. As such, the planned and postoperative data sets of implant positions could be compared, and three-dimensional deviations of implant tip and shoulder, as also implant angulation and depth, could be calculated.

Together with a three-dimensional computer model of the denture, for each patient, these results were imported into Matlab® (version 7.5.0.342 [R2007b], The MathWorks Inc., Natick, MA, USA) for postprocessing. The Implant Position Orthogonal Projection validation method[12] was used to evaluate these results in a clinically relevant manner. Using this validated method, extensively described by Verhamme and colleagues,[12] the three-dimensional measured implant deviations were transferred to deviations in planes perpendicular and tangential to the dental arch representing the bucco-lingual (BL) and mesio-distal (MD) planes (Figure 1).

The effect of fixation pins was evaluated by comparing the accuracy of all implants placed "with" and all implants placed "without" pins. The three-dimensional BL and MD deviations were measured for the variables "implant tip," "shoulder," "angulation," and "depth."

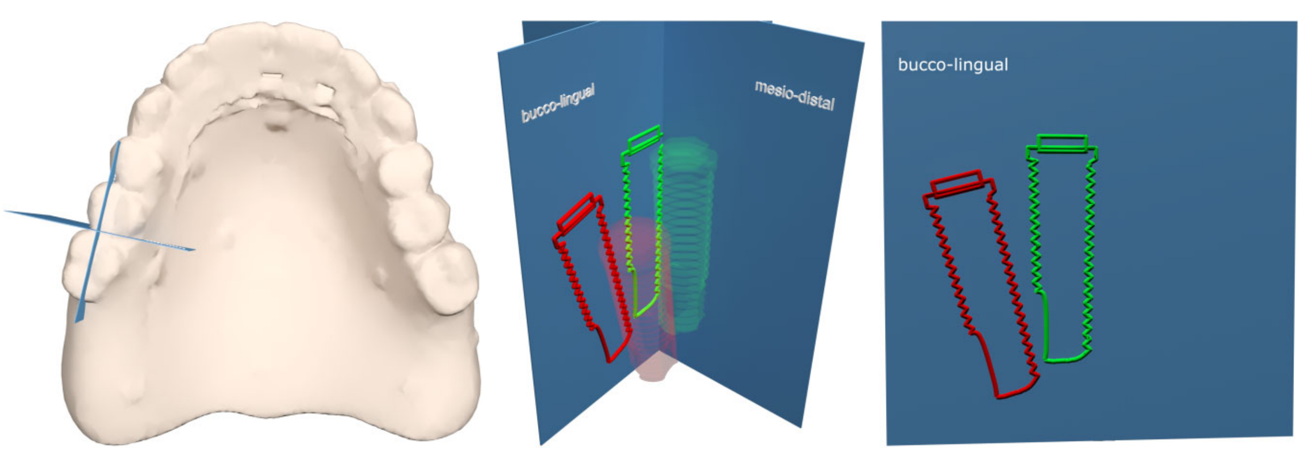

Figure 1 Orthogonal projection of the three-dimensional implant positions on the dental arch to the bucco-lingual and mesio-distal planes.

With respect to "implant tip" and "implant shoulder," it was investigated whether these moved in a buccal or lingual fashion in the BL plane as also in a mesial or distal direction in the MD plane. When, in comparison to the planning, both implant tip and shoulder were positioned more buccally with a deviation larger than 0.5 mm, this was interpreted as a complete buccal movement. Diagonal movement meant that the implant tip moved more than 0.5 mm to buccal and the implant shoulder more than 0.5 mm to lingual or vice versa. This was also investigated in the mesial and distal direction.

Also, the impact of implant length and implant position on the dental curve was validated. Additionally, differences in accuracy between procedures performed in local versus general anesthesia were inventoried.

Statistical Analysis

To analyze the influence of the implant parameters on the deviations between the planned outcome and the clinically achieved implant position, linear mixed models were used. The influence of implant characteristics was used as fixed factor in the model with random patient intercept. In case of a statistically significant effect of a factor, Bonferroni corrected pairwise comparisons[13] were made to investigate which levels of the factor were statistically different from each other.

The following deviation parameters were analyzed: implant tip deviations in the BL and MD plane and three-dimensional deviations, implant shoulder deviations in the BL and MD plane and three-dimensional deviations, implant angular deviations in the BL and MD plane and three-dimensional deviations, implant depth deviations in the BL and MD plane and three-dimensional.

Each of the following factors were analyzed separately to investigate their influence on the deviation: BL position, MD position, position on dental arch, use of fixation pins, type of surgery, and implant length. All statistical analysis was performed using SAS (SAS Institute Inc., Cary, NC, USA).

Statistical comparisons were considered statistically significant when the p value is <0.05.

RESULTS

In total, 104 implants were installed in 30 patients; 12 were female, 18 were male. In eight patients, two implants were placed, and in 22 patients, four implants were placed. Fixation pins were used in 19 patients, while in 11 cases, no fixation pins were applied. In 19 patients implant installation was performed under local anesthesia, and in 11 cases, in general anaesthesia (Table 1).

The implant position on the dental arch, the use of fixation pins, and the type of surgery showed no statistical significant difference for any variable (Table 2).

For the effect of BL position, statistically significant differences ($p < .05$) were seen at the implant tip, shoulder, and angular deviations between the virtually planned implant positions and actually placed implant positions. For the implant tip deviations, statistically significant differences were seen between a >0.5 mm buccal implant position compared with a >0.5 mm lingual implant position ($p = .0067$), between a >0.5 mm buccal implant position compared with a <0.5 mm error in implant position ($p < .0001$), and between a >0.5 mm lingual implant position compared with a <0.5 mm error in implant position ($p < .0001$). For the implant shoulder deviations, statistically significant differences were seen between a >0.5 mm buccal implant position compared with a <0.5 mm error in implant position ($p = .0006$) and between a >0.5 mm lingual implant position compared with a <0.5 mm error in implant position ($p < .0001$). For the angular deviations, statistically significant differences were found between a >0.5 mm buccal implant position compared with a >0.5 mm lingual implant position ($p = .0354$), between a >0.5 mm buccal implant position compared with a <0.5 mm error in implant position ($p = .0126$), between a >0.5 mm lingual implant position compared with a >0.5 mm diagonal implant position ($p = .0058$), and between a <0.5 mm error in implant position compared with a >0.5 mm diagonal implant position ($p = .0059$).

For the effect of MD position, statistically significant differences were seen at the implant tip, shoulder, and angular deviations. Both for the implant tip and shoulder deviations, significant differences were seen between a >0.5 mm distal and >0.5 mm mesial implant position compared with a <0.5 mm error in implant position ($p < .0001$ for all effects).

For the angular deviations, statistically significant differences were seen between a >0.5 mm mesial implant position compared with a <0.5 mm error

TABLE 1 Subdivision of the Total Number of Implants Per Effect

Effect		*n* Implants	Percentage
Bucco-Lingual Deviation	Error <0.5 mm	39	37.5
	>0.5 mm Buccal	43	41.3
	>0.5 mm Lingual	19	18.3
	Diagonal	3	2.9
Mesio-Distal Deviation	Error <0.5 mm	35	33.7
	>0.5 mm Mesial	44	42.3
	>0.5 mm Distal	20	19.2
	Diagonal	5	4.8
Position on Dental Arch	12–13	30	28.8
	14–15	22	21.2
	22–23	30	28.8
	24–25	22	21.2
Use of Fixation Pins	Pins	64	61.5
	No Pins	40	38.5
Type of Surgery	General	42	40.4
	Local	62	59.6
Implant Length	8.5 mm	2	1.9
	10.0 mm	20	19.2
	11.5 mm	14	13.5
	13.0 mm	51	49.0
	15.0 mm	17	16.3

in implant position ($p = .0214$) and between a <0.5 mm error in implant position compared with a >0.5 mm diagonal implant position ($p = .0164$) (Table 3).

For the outcome of depth deviation, 5% of all implants were placed >0.5 mm too deep, 74% was placed >0.5 mm too superficial, and 21% was placed within a margin of 0.5 mm.

For implant length, no statistically significant difference was found with an exception of implants of 8.5 mm length. However, only two implants of this length were used, so there will be a lack of statistical power.

TABLE 2 Overview of *p* Value Range for Each Effect

Effect	*p* Value Range
Bucco-Lingual Position	.000–.933
Mesio-Distal Position	.000–.729
Position on Dental Arch	.067–.783
Use of Fixation Pins	.162–.991
Type of Surgery	.573–.961
Implant Length	.002–1.000

An overview of mean implant deviations including 95% confidence intervals and maximum deviation is provided in Table 4 and Figure 2.

DISCUSSION

Computer-aided implant planning showed to be a valuable tool over the last years, allowing more accurate and safer implant surgery with increased implant survival rates.[14–16] Data acquisition took place using a CBCT scanner providing a relative low radiation dose, radiographic images of proper quality to create a preoperative surgical implant planning.[17–20]

In this study, deviations between planned and postoperative implant position, implant deviations were determined in a clinically relevant manner, that is, decomposed in a BL and MD vector, and not solely in a three-dimensional distance as performed in most other studies.[3–7,10,21–30]

Moreover, depth was separated from the tip and shoulder point deviations, resulting in true deviations in a specific direction. In this way, clinical limitations and inaccuracies of computer-aided implant planning

TABLE 3 Summary of Statistically Significant Variables

Variable	Compared Effects (Implant Deviation)		*p* Value
Bucco-Lingual Tip Deviation	>0.5 mm buccal	>0.5 mm lingual	.0067
	>0.5 mm buccal	<0.5 mm error	<.0001
	>0.5 mm lingual	<0.5 mm error	<.0001
Bucco-Lingual Shoulder Deviation	>0.5 buccal	<0.5 mm error	.0006
	>0.5 mm lingual	<0.5 mm error	<.0001
Bucco-Lingual Angular Deviation	>0.5 mm buccal	>0.5 mm lingual	.0354
	>0.5 mm buccal	<0.5 mm error	.0126
	>0.5 mm lingual	>0.5 mm diagonal	.0058
	<0.5 mm error	>0.5 mm diagonal	.0059
Mesio-Distal Tip Deviation	>0.5 mm distal	>0.5 mm mesial	<.0001
	>0.5 mm mesial	<0.5 mm error	<.0001
Mesio-Distal Shoulder Deviation	>0.5 mm distal	>0.5 mm mesial	<.0001
	>0.5 mm mesial	<0.5 mm error	<.0001
Mesio-Distal Angular Deviation	>0.5 mm mesial	<0.5 mm error	.0214
	<0.5 mm error	>0.5 mm diagonal	.0164

could be evaluated to improve the possibility of safe and accurate implant placement.

Bucco Lingual and Mesio-Distal Deviations

Results of this study showed that 41.3% of all implants were placed completely buccally and 42.3% completely mesially compared with the planned implant position.

A possible explanation for the buccal positioning of implants could be the following. Logically, all implants were planned between the cortical plates of the alveolar process, meaning that, especially in the canine tooth region, implants were angulated with their tip towards the palate. This implicates that during drilling, the angled drill head had to be placed towards the cheeks, with the drill tip angulated towards the palate. As inadequate mouth opening, high tension in the lips or cheek can make treatment more difficult,[31] and the drill head could be pushed more towards the palate, meaning

TABLE 4 Mean Deviations, Mesio-Distal, Bucco-Lingual, Three-Dimensional

		MD	BL	Three-Dimensional
Tip (mm)	Mean	0.751	0.674	1.587
	95% CI	0.169	0.119	0.178
	Max	2.315	2.973	4.332
Shoulder (mm)	Mean	0.600	0.509	1.368
	95% CI	0.109	0.115	0.170
	Max	2.206	2.304	4.205
Angle (°)	Mean	1.938	1.743	2.819
	95% CI	0.401	0.253	0.362
	Max	6.683	13.216	13.471
Depth (mm)	Mean	−0.746	−0.831	−0.843
	95% CI	0.230	0.223	0.227
	Max	−1.495	−1.406	−1.525

MD = mesio-distal; BL = bucco-lingual.

TABLE 5 Comparison of the Three-Dimensional Accuracy Results of Implant Placements in the Maxilla from Previously Performed Studies with the Present Study

Number of Implants		D'Haese[4] 78	Pettersson[6] 89	This Study 104
Tip (mm)	Mean	1.31	1.05	1.59
	95% CI	0.52	0.36	0.18
	Max	3.01	2.63	4.21
Shoulder (mm)	Mean	0.91	0.80	1.37
	95% CI	0.44	0.28	0.17
	Max	2.45	2.68	4.33
Angle (°)	Mean	2.60	2.31	2.82
	95% CI	1.61	1.25	0.36
	Max	8.86	6.96	13.47
Depth (mm)	Mean	N/A	−0.06	−0.84
	95% CI	N/A	0.39	0.23
	Max	N/A	2.05	1.53

CI = confidence interval; N/A = not applicable.

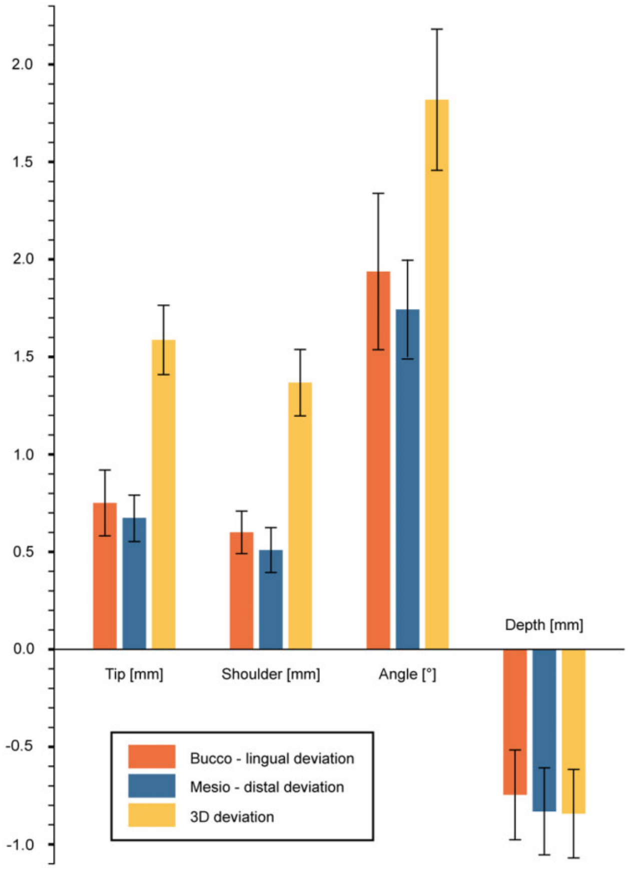

Figure 2 Graphical overview of the mean implant deviations for the bucco-lingual, mesio-distal, and three-dimensional direction for implant tip, shoulder, angulation, and depth.

the tip rotated to the buccal side assuming the surgical template was correctly positioned. Inaccuracies are then mainly explained because of play between the drill, drill guide, and sleeve in the surgical template.[12]

The combination of a completely buccal and mesial displacement could be explained by an anterior movement of the surgical template. An anterior movement of the surgical template, obviously, results in an anterior placement of the implants. However, as the implants are placed into a horseshoe-like dental arch, an anterior movement automatically is accompanied by a lateral, thus buccal movement, of the implant positions (Figure 3).

In general, to reduce these deviations, as described by Koop and colleagues,[32] it is of major importance to use the drill in a centric position, parallel to the cylinder in the surgical template. Furthermore, it is important to pay extra attention to the surgical template while it is positioned on the resilient mucosa and to verify its position permanently, preventing it in shifting anteriorly.

Implant Position on the Dental Arch

In this study, no tendency or significant differences were found for implant position on the dental arch. D'Haese and colleagues[4] described 13 patients, each receiving six implants in the maxilla. They concluded that implants in the posterior (premolar and molar) region of the maxilla showed a tendency to have a larger deviation compared with the anterior (incisor and canine) region, although not to a statistically significant level. In the present study, all implants were placed into the alveolar process extending from lateral incisor to only the second premolar. This small range of dental arch in which the implants were placed could explain why no differences in accuracy were found.

Implant Depth

In this study, most implants were placed not deep enough. This could be caused by debris collected in the bone cavities as a result from the drilling procedure, as such preventing the implant from reaching its planned depth; however, all implants reached their final placement depth when comparing the implant driver position with regard to the surgical template. Another explanation could be that the threshold value used to generate the three-dimensional model of the radiographic guide was incorrect, resulting in a surgical template that is placed too high on the alveolar process.[12,33]

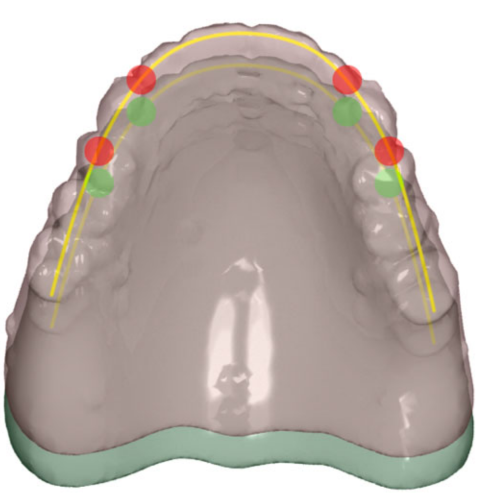

Figure 3 Graphical overlay to indicate buccal and lateral movement of the postoperative implant positions (*red*) because of an anterior movement of the planned implant positions (*green*).

Unfortunately, at the time of this study, no calibration object[9] was available to obtain an optimal threshold value for the generation of the three-dimensional model.

Fixation Pins

The additional value of fixation pins to provide stability to the surgical template and thereby resulting in a more accurate transfer from planning to patient was not corroborated in this study. Others claimed that the position of the fixation pins is very critical, as described by Van Assche and colleagues[27] and d'Haese and colleagues.[4] Obviously, it is important to place fixation pins both in the anterior and posterior region to avoid rotation of the surgical template. However, because of the resilience of the mucosa, the surgical template can easily be fixated in a rotated position, resulting in a rotated position of all implants. In addition, a bite index to fixate the surgical template will not work because of the muscle relaxants used during general anesthesia cases and inaccuracies in the occlusal surface of the surgical template.[33] Moreover, in this study, all patients were fully edentulous so there was no possibility of using a stable lower dentition combined with a bite index to obtain an optimal position of the surgical template. In partial edentulous cases, fixation pins might have additional value. By not using fixation pins, exclusively the shape of the alveolar process is used to function as a support for each implant position. Only in cases of a flat palatal profile still slight movements could be discerned. As an advantage, by leaving out the pins, the surgeon is not hindered in positioning the drill in the surgical template.

Anesthesia

Type of anesthesia showed no influence on the accuracy of implant placement. Main advantage of general anesthesia is that the patient will not move during surgery, and a large mouth opening can be achieved because of muscle relaxants. Advantages of local anesthesia are shorter hospitalization, less comorbidities, and low costs, making this the preferred type of surgery for both surgeon and insurance companies.[34] Disadvantage of local anesthesia could be the extra volume that is added to palate and alveolar process which might influence the position of the surgical template during surgery. This effect could be reduced by applying a gentle massage to the site which encourages dispersal of the agent.

System Accuracy

In the total trajectory of implant placement using a computer planning, inaccuracies are introduced at different stages: during image acquisition and planning,[17–20,33,35,36] in the production of the surgical templates,[33,35–37] in the instruments during implant placement,[12,32,38] and post-operative again during image acquisition and the validation process.[12,39] As three-dimensional imaging and printing techniques are evolving quickly, related system inaccuracies will probably reduce in the near future.

Discussion of Results

Several studies showed in vivo results on the accuracy of implant placement using surgical templates. However, most of these studies presented accuracy results consisting of a combination of fully edentulous and partially edentulous, different types of support of the surgical template and implant placement in both mandible and maxilla.[3,21,22,24,26,28,40,41]

Only a very limited number of studies addressed solely the topic of accuracy of implant placement in the maxilla of fully edentulous patients using a mucosa-supported surgical template.

Pettersson and colleagues[6] investigated 25 fully edentulous patients. In 15 patients receiving implant in their upper jaw, five or six implants were placed, showing a mean three-dimensional deviation for "implant tip" of 1.05 mm (range 0.25–2.63), a mean deviation for "shoulder"; of 0.80 mm (range 0.10–2.68), a mean "angular deviation" of 2.31° (range 0.24 to 6.96), and a mean "depth deviation" of −0.06 mm (range −1.65 to 2.05).

Also d'Haese and colleagues[4] investigated the accuracy of implant placement in the maxilla of 13 fully edentulous patients. A total of 78 implants were placed using mucosa-supported surgical templates. Accuracy evaluation showed a mean tip deviation of 1.13 mm (range 0.32–3.01), a mean shoulder deviation of 0.91 mm (range 0.29–2.45), and a mean angular deviation of 2.60° (range 0.16–8.86).

An overview of the results of the study by Pettersson and colleagues[6] and d'Haese and colleagues[4] compared with this study can be found in Table 5. However, because the focus of this study was mainly on clinically relevant BL and MD deviations instead of three-dimensional deviations, it remains difficult to compare the results of this study with other studies found in literature.

Vasak and colleagues[7] evaluated postoperative implant accuracy by taking the coronal direction as BL, sagittal direction as MD, and vertical axis as depth deviation. This method may be relatively accurate in the posterior regions; the MD and BL direction will nevertheless be reversed when looking at the anterior regions. In BL direction, a mean tip deviation of 0.7 mm and mean shoulder deviation of 0.47 mm were found, and in MD direction, 0.59 mm and 0.45 mm, respectively. These tip and shoulder deviation correspond to the result of this study. Angular deviations found by Vasak and colleagues were described as three-dimensional deviations with a mean of 3.53° and are slightly higher than in this study. Depth deviation was described as an absolute value and do, therefore, not assign whether implants are placed too deep or too superficial and therefore cannot be compared with this study.

None of the found studies describe the accuracy of placement of two or four implants in the maxilla of fully edentulous patients using mucosa-supported surgical templates.

CONCLUSION

Computer-aided implant planning using surgical templates showed to be a clinically relevant tool for the placement of two or four implants in the maxilla of fully edentulous patients. In specific cases, this technique will therefore eliminate the need of a bone grafting procedure. Results of this study showed that, compared with three-dimensional implant deviations, clinically relevant implant deviations in the BL and MD direction provide new insights in the sources of implant deviations. Paying extra attention to the placement of the surgical template in anterior/posterior direction seems crucial in being able to reduce implant deviations in the buccal and mesial direction.

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