# Effect of Smoking Habits on Accuracy of Implant Placement Using Mucosally Supported Stereolithographic Surgical Guides

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## ABSTRACT

*Background:* Smoking is considered as a factor for implant survival and peri-implant bone loss of dental implants. Several studies revealed the negative effect of smoking on osseointegration and its dose-related effect.

*Purpose:* To evaluate the effect of smoking habits on accuracy of implant placement using mucosally supported stereolithographic surgical guides.

*Material and Methods:* Six OsseoSpeed™ implants (Astra Tech AB, Mölndal, Sweden) were inserted into the maxilla in 13 patients. Patients were excluded if they suffered from any systemic disease or if they were actually taking any kind of medication. Software (Mimics® 9.0) was used to fuse images of the virtually planned and actually placed implants, and locations and axes were compared between the nonsmoking and smoking subgroups. As the mucosal biotype could probably influence accuracy data, 12 reference points were defined within each patient to define a mean mucosal thickness value.

*Results:* In the smoking subgroup, 36 implants were placed compared with 42 in the nonsmoking subgroup. Mean coronal deviation was 1.04 mm (range: 0.29–2.45 mm) among the smokers compared with 0.80 mm among the nonsmokers (range: 0.29–1.67 mm). At apical point, mean deviation was 1.26 mm (range: 0.39–3.01 mm) among the smokers compared with 1.02 mm among the nonsmokers (range: 0.32–2.59 mm). Mean angular deviation was 2.64° (range: 0.41–6.81°) among the smokers compared with 2.57° among the nonsmokers (range: 0.16°–8.86°). Significant differences were found when comparing global coronal and apical deviation between the smokers and the nonsmokers ($p < .05$). Evaluating mucosal thickness, mean value was 3.19 mm (range: 2.39–4.01 mm) among the smokers compared with 2.43 mm among the nonsmokers (range: 1.44–3.03 mm).

*Conclusions:* Statistically significant differences were found when comparing the accuracy of dental implant placement of the smokers with the nonsmokers. Smokers have significant thicker supporting mucosal tissues compared with nonsmokers, which may explain inaccuracy due to less stability of the surgical guide or the scanning prosthesis.

KEY WORDS: accuracy, biotype, dental implants, guided surgery, smoking, stereolithography

## INTRODUCTION

Recently, computer-aided designed (CAD) procedures were introduced on a large scale on the dental market to facilitate dental implantation protocols. There are three practical ways to apply this technique in a clinical setting: guided surgery using drill guides processed by stereolithographic rapid prototyping,[1–5] computer–milled templates,[6–8] or computer navigation systems.[9] Hereby, it becomes possible to virtually plan the ideal implant position taking both anatomical and restorative information into account.[10–14] The virtually planned implant position can afterward be transferred to the patient and steer the surgical procedure.

A stereolithographic-guided surgery system mainly consists of a stereolithographic surgical guide with guide sleeves for fixture installation, additional guide sleeves

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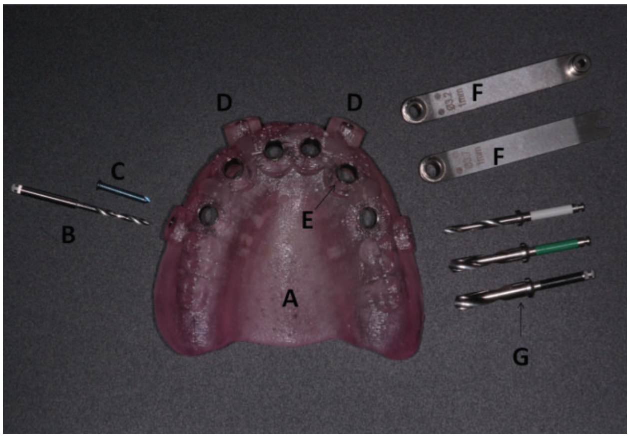


**Figure 1** Overview of surgical components and instruments used in a stereolithographic guided surgery system (Facilitate software system, Astra Tech AB, Mölndal, Sweden): (A) stereolithographic surgical guide; (B) fixation screw drill; (C) fixation screw; (D) guide sleeve for fixation screw installation; (E) guide sleeve for fixture installation; (F) drill keys inserted in the guide sleeves to guide drilling procedure; (G) depth calibrated drills.

for fixation screw installation, drill keys of different heights, and depth-calibrated drills to prepare the osteotomies (Figure 1). Most CAD systems allow the fabrication of a skeletal-, dental-, or mucosal-supported surgical guide. Dental- and mucosal-supported guides could be used in a flapless surgical protocol. The used method should be precise and ensure a high level of reproducibility. In a prospective clinical study,[15] accuracy of mucosal supported stereolithographic surgical guides in fully edentulous maxillae was evaluated. Seventy-eight OsseoSpeed (Astra Tech AB) implants of 3.5 to 5 mm in width and 8 to 15 mm in length were installed consecutively in 13 patients. The implants were functionally loaded on the day of surgery and implant location was assessed with a computer tomography (CT) scan. The deviation at the entrance point ranged between 0.29 and 2.45 mm (SD: 0.44 mm), with a mean of 0.91 mm. Average angle deviation was 2.60° (range 0.16–8.86°; SD: 1.61°). At the apical point, the deviation ranged between 0.32 and 3.01 mm, with a mean of 1.13 mm (SD: 0.52 mm).

It was concluded that clinicians should be warned that three-dimensional implant 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 stereolithographic guide.[15]

Smoking is considered as a factor for implant survival[16] and peri-implant bone loss[16] of dental implants. Three hundred twenty-nine patient records containing information on 712 installed implants were scrutinized retrospectively, and periapical radiographs were analyzed for interproximal bone level.[16] The overall survival rate was 98.3%. Implants in smokers had a threefold higher failure rate compared with nonsmokers (5/104 = 4.8% vs 7/608 = 1.2%). Sixty implants from 21 smokers lost statistically significantly ($p = .001$) more bone than the 303 implants in 148 nonsmokers. Especially the maxilla is more prone to bone loss compared with the mandible (1.70 mm vs 1.26 mm, $p < .001$). Another retrospective study[17] described the effect of smoking on initial fixture failure before functional loading with fixed prosthetic restorations. Out of 208 installed Brånemark fixtures in the mandible, only one failed (0.5%), and no detrimental effect of smoking on fixture survival could be detected. In the maxilla, 10/244 fixtures failed (4%); 7/78 fixtures failed in smokers, and 3/166 in nonsmokers. It was concluded that smoking is a significant, although not the only important, factor in the failure of implants prior to functional loading. The adverse smoking effects are related to the inhaled tobacco smoke and can be divided into two phases: a volatile and a particulate phase. The volatile phase, accounting for 95% of the cigarette smoke, provides nearly 500 different components, including nitrogen, carbon monoxide, and carbon dioxide.[18] The roughly 3,500 different chemicals released in the particulate phase include nicotine, nornicotine, anatabine, and anabasine and represent the majority of the carcinogens of cigarette smoke.[18] Smoking has been determined to adversely affect bone mineral density, lumbar disc health, the relative risk of sustaining wrist and hip fractures, low back pain, and the dynamics of bone and wound healing.[19] Several studies revealed the negative effect of smoking on osseointegration and its dose-related effect.[20]

A stereolithographic guide designed for rehabilitation of fully edentulous maxillae is designed in a way that it should cover a maximum of supporting mucosal structures in order to position the guide properly. Differences in mucosal resilience between a smoking and a nonsmoking patient could lead to an alteration in the degrees of freedom when positioning a scanning prosthesis or a surgical guide. Therefore, variations in thickness of mucosal structures between smokers and nonsmokers could lead to a different resilience and a different outcome regarding accuracy of stereolithographic surgical procedures.

## AIM

The aim of the present article is to evaluate the effect of smoking habits on the deviation between virtually planned and clinically placed dental implants in patients treated with full mucosally supported stereolithographic surgical guides. The treatment protocol was scrutinized and approved by both ethical committees of Ghent University Hospital and Onze-Lieve-Vrouwe Hospital Aalst in Belgium.

## MATERIALS AND METHODS

### Patient Selection

Thirteen consecutive patients requiring a fixed rehabilitation of the total edentulous maxilla were selected for this clinical trial. A written medical anamnesis was performed and signed by each of the participants. Only patients in good general health were included. Patients were excluded if they suffered from any systemic disease or if they were actually taking any kind of medication. The study population was composed of a smoking and a nonsmoking subgroup. All patients underwent periodontal examination at intake. Periodontal treatment was performed when necessary. Hopeless teeth were extracted at least 3 months prior to implant surgery. As a result, initial post-extraction bone resorption took place before surgery.[21] After extraction of the last remaining teeth, a provisional immediate removable denture was delivered to the patients containing radiographic glass spheres. These glass spheres act as radiographic markers.

### Planning Procedure

The scanning was performed using a Siemens Somatom Definition 64-slice dual source CT scan according to the dual scan procedure outlined in the scanning protocol by Materialise (Materialise NV, Leuven, Belgium). The CT scan was taken without interarch contact, = using an occlusal index. Afterward, a second CT scan (dual scan) was taken from the prosthesis only. The resulting CT images were converted into a digital imaging and communications in medicine image and transformed into a three-dimensional virtual model using the Facilitate™ software system (Astra Tech AB). The clinician (J.D.) who placed the virtual implants in the resulting three-dimensional model also performed the surgeries. Six implants and four fixation screws (Astra Tech AB) were planned for each patient. The images were returned to the manufacturer for surgical guide fabrication. The procedure is described in detail previously.[15]

### Surgical and Prosthodontical Procedure

The surgery was performed under locoregional anesthesia, with appropriate aseptic and sterile procedures. During the operation, the surgical guide was placed on the mucosa and properly fixed to the maxilla using at least four equally distributed fixation screws. An interocclusal putty index was used to confirm proper seating of the template. After fixation of the stereolithographic guide, the osteotomies were prepared at 1,500 rpm and limited to the desired depth by a vertical stop on the drills. No punching of the gingival tissues was performed prior to the preparation of the implant sites. Six OsseoSpeed implants, with a $TiO_2$-blasted fluoride-modified surface, were inserted into the maxilla with a maximum insertion torque of 50 Ncm. The implants were placed to a specific depth, limited by the vertical stop on the fixture mount. During implant installation, the fixtures were guided into the prepared osteotomies. Immediately after implantation, 20° UniAbutment or angulated abutments (Astra Tech AB) were screwed onto the implants and hand-torqued. The height and angulation was determined prior to surgery using the CAD/computer-aided manufacturing (CAM) software package. After installation of the abutments, 20° UniAbutment pick-up copings were mounted and an impression was made on abutment level using a silicone material (Permadyne Penta H, ESPE, London, Ontario, Canada) with the existing removable prosthesis used as a tray. Within 8 hours, a temporary screw-retained fiber reinforced acrylic bridge was delivered to the patient and connected to the abutments. Occlusion and articulation were corrected whenever necessary. All suprastructures were torqued at 15 Ncm.

### Accuracy Analysis

Within 4 to 8 weeks after surgery, a new CT scan was taken. Software (Mimics® 9.0, Materialise NV) was used to fuse the images of the virtually planned and actually placed implants, and the locations and axes were compared (Figure 2). In order to evaluate the deviations between the planned and the placed implants, an object registration was performed to pairwise align the

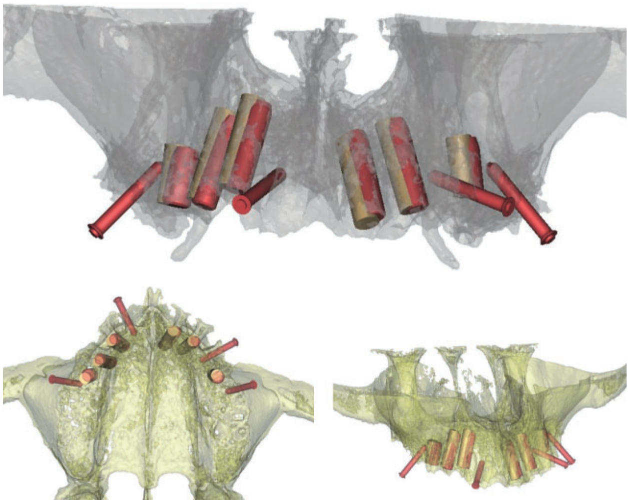

**Figure 2** Fusion of the preoperatively planned implants (*red*) with the post-op scanning data (yellow) (ref: D'haese and colleagues, Clin Implant Dent Relat Res, 2009).[15]

preoperative three-dimensional representations of the jaws with their counterparts in the postoperative images. In this case, an iterative closest point algorithm was used to match the jaws. The thereby established coordinate transformation operations were also applied to the three-dimensional representations of the planned implants, allowing for relative comparisons with respect to the postoperative implant positions. All evaluations were performed in the Mimics 9.0 software. Four deviation parameters (i.e., global, angular, depth, and lateral deviation) were defined and calculated between the planned and the placed implants using the coordinates of their respective apical and coronal points[22] (Figure 5). All parameters except the angular deviation were determined for both the coronal and the apical centers. The global deviation was defined as the three-dimensional distance between the coronal (or apical) centers of the corresponding planned and placed implants. Next, the angular deviation was calculated as the three-dimensional angle between the longitudinal axis of the planned and placed implant. To establish the lateral deviation, a plane perpendicular to the longitudinal axis of the planned implant and through its coronal (or apical) center is defined and is referred to as a reference plane. The lateral deviation was calculated as the distance between the coronal (or apical) center of the planned implant and the intersection point of the longitudinal axis of the placed implant with the reference plane. The depth deviation was calculated as the distance between the coronal (or apical) center of the planned implant and the intersection point of the longitudinal axis of the planned implant with a plane parallel to the reference plane and through the coronal (or apical) center of the placed implant. Deviations were measured for both study groups in order to make a comparison between the different groups. All the analyses were performed by an independent investigator who was blinded for both the subgroups.

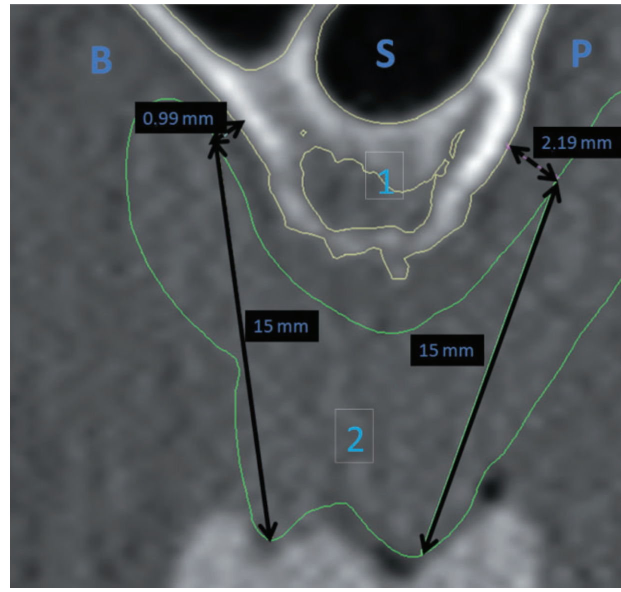


**Figure 3** Evaluation of mucosal thickness at first molar level by drawing a tangential line at an arbitrarily chosen distance of 15 mm from the buccal/palatal cusp: B = buccal; P = palatal; S = sinus maxillaries; 1 = alveolar crest; 2 = scanning template.

## Evaluation of Mucosal Thickness

In order to evaluate the thickness of the mucosal supporting tissues, 12 reference points were defined within each patient. The reference points were located at the first left molar, the left canine, the left central incisor, the right canine, the right first molar, the midpalatal suture at canine level, and the midpalatal suture at first molar level. The mucosal thickness was defined as the distance between the surface of the alveolar crest and the base of the scanning template. The mucosal thickness was measured by drawing a tangential line at an arbitrarily chosen distance of 15 mm for the buccal/platal cusp for the molars and at 15 mm distance from the incisal line for canines and incisors for each reference point (Figures 3 and 4).

## STATISTICAL ANALYSIS

Statistical analysis was performed with SPSS® for Windows (16.0) computer software (SPSS Inc., Chicago,

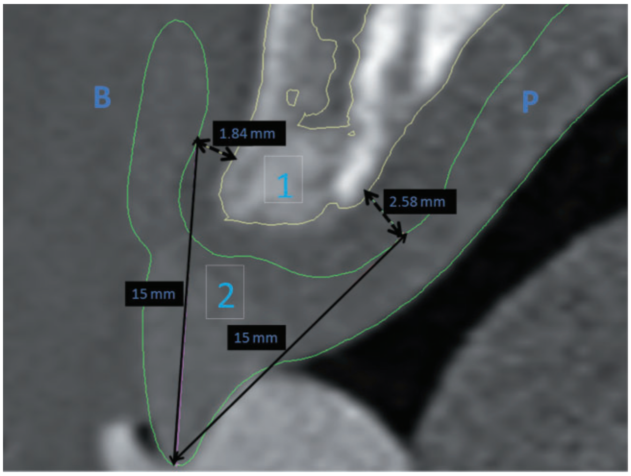


**Figure 4** Evaluation of mucosal thickness at central incisor level by drawing a tangential line at an arbitrarily chosen distance of 15 mm from the incisal edge: B = buccal; P = palatal; 1 = alveolar crest; 2 = scanning template.

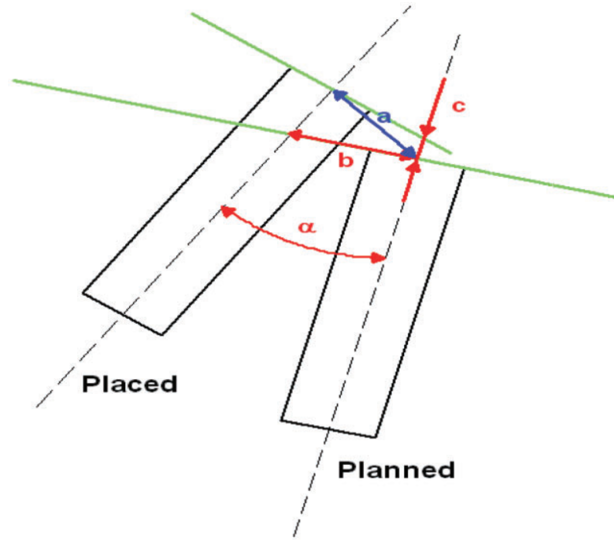


**Figure 5** Three-dimensional evaluation of the virtual planned and the in vivo-placed implants: a = global; b = lateral; c = depth; α = angle. (ref: Van De Velde and colleagues, Clin Oral Implants Res, 2008).[22]

IL, USA). Descriptive statistics were based on all implants for each different implant length group and for incisor, premolar, and molar sites separately. As not all data were equally distributed, a nonparametric analysis was performed (Kruskal–Wallis test followed by Mann-Whitney *U* test). Differences were considered statistically significant if $p < .05$. The deviation parameters were analyzed on implant level. Evaluation of the mucosal thickness was performed on patient level.

## RESULTS

### Surgical and Prosthetical Procedure

Thirteen edentulous adults were included in this clinical trial. The population was composed of 11 males and two females. Mean age was 53.3 years (range 36–72). Out of the 13 patients, six were current smokers (more than 10 cigarettes/day). In total, 78 implants were inserted of 3.5 to 5 mm in width and 8 to 15 mm in length. In the smoking subgroup, 36 implants were placed compared with 42 in the nonsmoking subgroup. One implant in the smoking group was lost shortly after insertion because of abscess formation caused by remnants of impression material.

### Accuracy Analysis

Seventy-seven out of the 78 implants were analyzed postoperatively by matching the preoperative planning with the in vivo position of the implants (Figure 5), and the results are summarized in Table 1. Mean coronal deviation was 1.04 mm (range: 0.29–2.45 mm) among the smokers compared with 0.80 mm among the nonsmokers (range: 0.29–1.67 mm). At apical point, mean deviation was 1.26 mm (range: 0.39–3.01 mm) among the smokers compared with 1.02 mm among the nonsmokers (range: 0.32–2.59 mm). Mean angular deviation was 2.64° (range: 0.41–6.81°) among the smokers compared with 2.57° among the nonsmokers (range: 0.16–8.86°). Significant differences were found when comparing the global coronal and apical deviation between the smokers and the nonsmokers ($p < .05$) (Figure 6).

No significant differences were found when comparing the global angular deviation. Evaluating the cumulative percentage of implants and their corresponding global apical deviation, it was observed that 65% of all implants showed an apical deviation higher than 1 mm in the smoking group compared with 45% in the nonsmoking group. Looking at the 2 mm cutoff point, 15% of the implants from the smokers subgroup showed a higher apical deviation (Figure 7) compared with almost 0% from the nonsmokers subgroup.

### Evaluation of Mucosal Thickness

Twelve recordings per patient were used to define a mean patient value for mucosal thickness. Table 2 represents the results on patients' level. In the smokers group, mean mucosal thickness was 3.19 mm (range:

**TABLE 1 Mean Values and Range (in mm or degrees) of Global Coronal Deviation, Global Apical Deviation, and Angular Deviation for the Different Study Groups**

| | Smoking Habit | *n* | Mean | Range |
|---|---|---|---|---|
| Global coronal deviation (mm) | Nonsmoker | 42 | 0.8 | 0.29–1.67 |
| | Smoker | 35 | 1.04 | 0.29–2.45 |
| Global apical deviation (mm) | Nonsmoker | 42 | 1.02 | 0.32–2.59 |
| | Smoker | 35 | 1.26 | 0.39–3.01 |
| Angular deviation (degrees) | Nonsmoker | 42 | 2.57 | 0.18–8.86 |
| | Smoker | 35 | 2.64 | 0.41–6.81 |

2.39–4.01 mm) compared with 2.43 mm in the nonsmokers (range: 1.44–3.03 mm) subgroup. A statistically significant difference was found between the smokers and the nonsmokers on a patient level ($p < .05$).

## DISCUSSION

Stereolithographic surgery for guided implant implantation is a hot topic in dental implantology. Up to now, few data are available dealing with accuracy of those systems, and the influence of smoking habits is not yet investigated.

This article points out that a statistically significant difference was found for global coronal and apical accuracy of implant placement when comparing smokers with nonsmokers. This could have important clinical consequences when applying this technique in a smoking population. A remarkable effect was also noticed when looking at the cumulative percentage of implants in relation to the global apical deviation (Figure 7). At the arbitrarily chosen 1 mm cutoff point, it was observed that 65% of the implants show an apical deviation higher than 1 mm in the smokers group compared with 45% in the nonsmokers group. Looking at the 2 mm cutoff point, still, 10% of the implants in the smokers group have a higher apical deviation compared with almost 0% in the

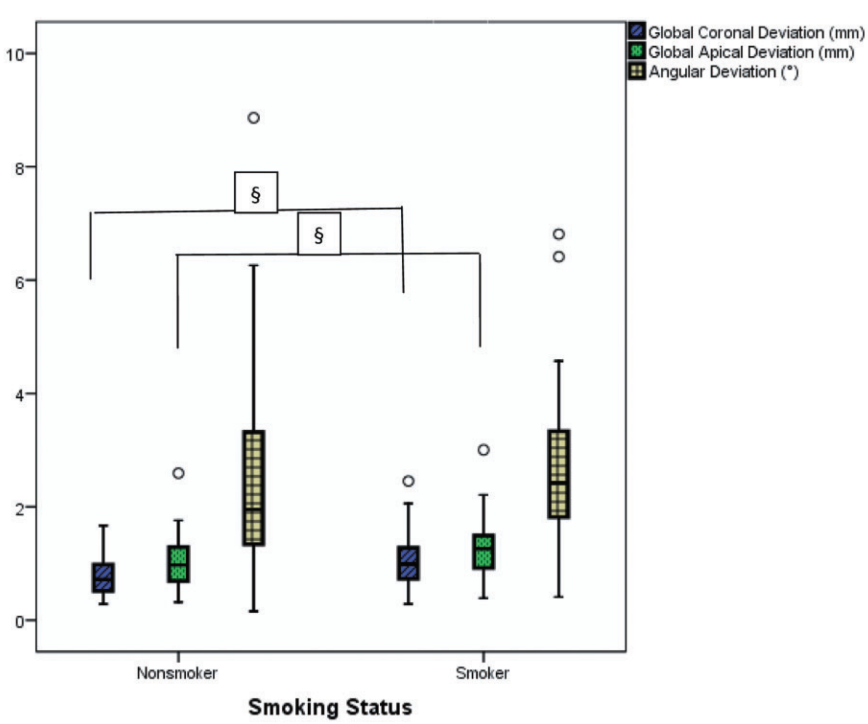


**Figure 6** Box plot showing median, quartile, range, and outliers of global coronal deviations (in mm), global apical deviations (in mm), and global angular deviations of 77 implants. The extreme outliers (o) represent initially unstable implants. Bars represent statistically significant differences (Mann-Whitney $U$ test; § = $p < .05$).

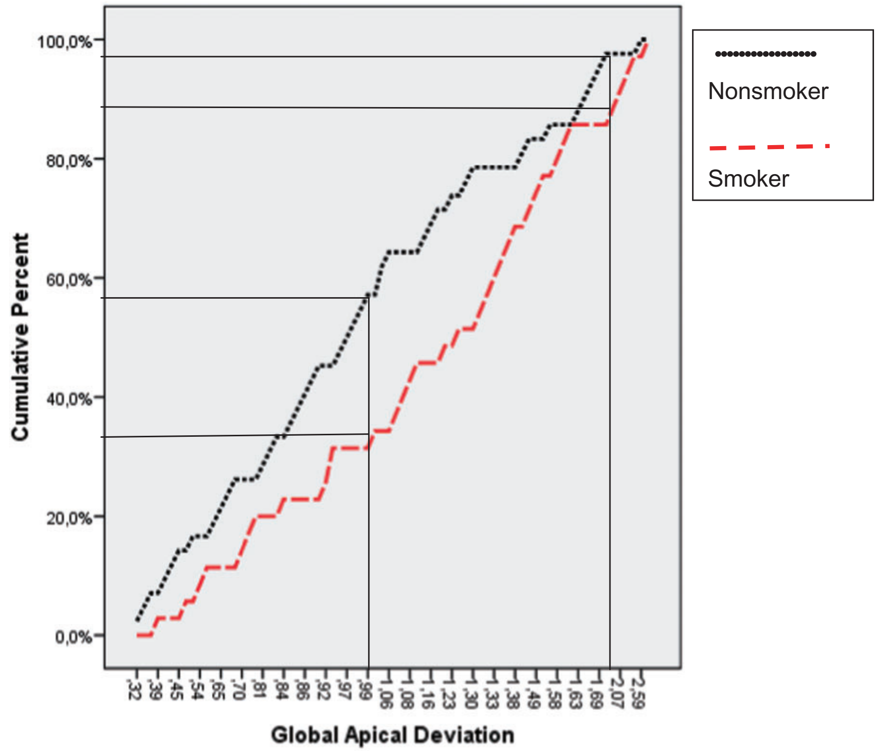


**Figure 7** Graphic showing the cumulative percentage of global apical deviation. At the arbitrarily chosen 1 mm cutoff point, 65% of the implants show an apical deviation higher than 1 mm in the smokers group compared with 45% in the nonsmokers group. Looking at the 2 mm cutoff point, 10% of the implants in smokers have a higher apical deviation compared with 0% in nonsmokers.

nonsmokers. Together, these findings lead to the conclusion that flapless implant placement using mucosally supported surgical guides should be carefully implemented in a smoking population. As only 13 drill guides were evaluated, further research is needed to confirm this statement.

**TABLE 2 Mean Patient Value for Mucosal Thickness (mm) in Relation to the Smoking Status**

| Patient | Smoking Status | Mean Mucosal Thickness (mm) |
|---|---|---|
| 1 | Nonsmoker | 2.23 |
| 2 | Nonsmoker | 1.44 |
| 3 | Smoker | 2.39 |
| 4 | Smoker | 2.80 |
| 5 | Nonsmoker | 2.69 |
| 6 | Nonsmoker | 2.62 |
| 7 | Smoker | 4.01 |
| 8 | Nonsmoker | 3.03 |
| 9 | Smoker | 2.95 |
| 10 | Nonsmoker | 2.79 |
| 11 | Smoker | 3.45 |
| 12 | Smoker | 3.55 |
| 13 | Nonsmoker | 2.23 |

An important technical aspect affecting the outcome when using this technique is the support and stability of the scanning prosthesis and the surgical guide on the mucosa. Mucosally supported devices should cover a maximal surface. This offers the surgeon a more reproducible way to position scanning template and surgical guide on the soft mucosa, leading to less positioning errors. Proper control of the fit is of major importance during the scanning procedure as well as during implant surgery. The degree of freedom in an edentulous patient is higher in patients with thick mucosal biotypes compared with patients with thinner supporting mucosal structures. Therefore, we evaluated the mucosal thickness of each patient and compared these data between smokers and nonsmokers. As a matter of fact, we kept in mind that other factors may influence the mucosal biotype. Therefore, we only selected patients not suffering from any kind of systemic disease and not taking any kind of medication. It was observed that on patient level, smokers had a significantly thicker mucosal biotype compared with

**TABLE 3 Ranking of Patients' Mean Mucosal Thickness (mm) in Relation to the Smoking Status**

| Patient Ranking | Mean Mucosal Thickness (mm) | Smoking Status |
|---|---|---|
| 1 | 1.44 | Nonsmoker |
| 2 | 2.23 | Nonsmoker |
| 3 | 2.23 | Nonsmoker |
| 4 | 2.39 | Smoker |
| 5 | 2.62 | Nonsmoker |
| 6 | 2.69 | Nonsmoker |
| 7 | 2.79 | Nonsmoker |
| 8 | 2.80 | Smoker |
| 9 | 2.95 | Smoker |
| 10 | 3.03 | Nonsmoker |
| 11 | 3.45 | Smoker |
| 12 | 3.55 | Smoker |
| 13 | 4.01 | Smoker |

nonsmokers. This could be an explanation for the fact that implant placement was significant more accurate in nonsmokers compared with smokers when using stereolithographic-guided surgery. As a thicker mucosal biotype leads to more degrees of freedom while positioning a scanning template or a surgical guide onto the supporting tissues, more deviations could be expected when using this surgical technique in a smoking population. Moreover, the fact that already a significant difference was found at entrance point between smokers and nonsmokers also supports this statement. In a previous published article,[15] we already mentioned that the production error of a stereolithographic-surgical guide is neglectable.

Besides this production error, also, the CT scan for acquisition of the anatomical data and the image segmentation itself could also be responsible for geometric errors and distortions. However, errors occurring during one of these steps may also compensate each other. Moreover, these errors should occur in both our study groups in a way that this source of error should ideally be the same for both study groups.

For the overall manufacturing process, it was described that deviations up to 0.7 mm could occur.[23] Regarding the CT scan, the scan protocol is a more important issue than the type of scanner used.[23] From the accuracy viewpoint, a high spatial resolution protocol is mandatory to obtain the best results. The factor found to have the biggest impact was, however, data segmentation. It was described that segmentations of the same data set by different persons showed high-accuracy variations.[23] Since the dual scan protocol was used, the manual segmentation did not influence the accuracy of the surgical guide. Most of the rapid prototype technology systems were found to produce deviations less than 0.25 mm.[23]

If one wants to rely on CAD surgical guides, it is critical that the devise is stable during the whole process from impression taking to placement of the surgical guide in situ. The current study did not prospectively aim to state differences between smokers and nonsmokers regarding accuracy of the CAD surgery, but it was an coincidental discovery that was observed from a previous clinical trial.[15] A further and more detailed analysis of the data indicated that a large proportion of the smoking subgroup showed the largest deviations when comparing the virtual planning with the postoperative implant position

In search of the possible explanations, a literature search was performed. No references were found to confirm the finding that stereolithographic-guided surgery was less accurate in smokers. An explanation could be a technical error. However, based on the inter-implant distance deviation measurements,[15] no large deviations were seen in the smoking subgroup. Therefore, this hypothesis was rejected, and it was concluded that the deviation could probably be explained by the fact that the degree of tilting and/or shifting of the scanning template and the surgical guide on top of the supporting mucosal structures was higher in the smoking population compared with the nonsmoking population. It is striking that the thickness of the supporting mucosal structures is significantly thicker in the smoking subgroup compared with the nonsmoking (Table 3). The suggestion made in this article is that smoking habits may influence the mucosal resilience as the supporting mucosal structures are thicker in smokers. This may lead to more degrees of freedom when positioning a scanning device or a surgical template.

## CONCLUSION

The present study is the first to investigate the effect of smoking habits on accuracy of implant placement using mucosally supported stereolithographic surgical guides. Statistically significant differences were found when comparing the accuracy of dental implant placement in smokers to nonsmokers and are probably related to differences in thickness of supporting mucosal tissues. Smokers have significant thicker supporting mucosal tissues compared with nonsmokers, which may explain inaccuracy due to less stability of the scanning prosthesis or the surgical guide. Care should be taken when implementing these protocols in a smoking population. Whether the accuracy differences also have an impact on implant survival, prosthesis survival and peri-implant complications remain to be investigated in a long-term follow-up.

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