Real Versus Virtual Position of Single Implants Installed in Premaxilla via Guided Surgery: A Proof of Concept Analyzing Positional Deviations

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The aim of this research letter was to report the results of a pilot study designed to compare the real and virtual position of implants placed using computer-guided flapless implant surgery for single restorations in the premaxilla. A total of 8 patients (2 men and 6 women) with a mean age of 40 years old (range: 32–73 years) had a total of 11 implants inserted using a tooth-supported stereolithographic guide. After implant placement, the positions (coronal, central, and apical) and angulation of the implants installed in relation to those planned were determined via the superposition of pre- and postoperative 3-dimensional models using Dental Slice software (Bioparts, Brasília, Brazil). The mean angular deviation was 2.54° ± 0.71°. The deviations found for the coronal, central, and apical positions were 1.3 ± 0.77 mm, 1.49 ± 0.58 mm, and 2.13 ± 1.32 mm, respectively.

INTRODUCTION

Computer-guided flapless implant surgery, a surgical method prosthetically guided via computerized planning, is performed using a prototype surgical guide and represents one of the great advances in implantology.1–10 Compared with conventional surgery, the placement of flapless implants has become increasingly popular because it is faster, is less invasive, and has enabled the restoration in more challenging cases.2,11 From a biological point of view, the absence of flaps increases the postoperative peri-implant vascularization12 and promotes the reduction of gingival inflammation, the height of the junctional epithelium, and bone loss around the implant.13 Adoption of this surgical approach is thought to increase the oral rehabilitation success rates, as this noninvasive technique is directly associated with precise and predictable esthetic and functional planning.

However, flapless guided surgery also has limitations. First, the surgeon works in a closed field, and the incorrect angulation of the implant can lead to complications. Second, multiple steps are required, including preoperative computerized tomography (CT) examination (double scanning), preparation of the CT guide, surgical-prosthetic planning using software (computer-assisted implant planning), and the manufacture and use of a prosthetic surgical guide. These presurgical procedures are complex, and the possibility of errors is high and might result in deviations between the planned and placed implant.3,5,14–16

Several studies have aimed to improve the precision of computer-guided flapless implant surgeries, mainly focusing on the discrepancies during the transference of virtual planning by superimposing 3-dimensional (3D) pre- and postoperative computer-assisted design (CAD) models. In vitro studies with dry or epoxy resin mandibles5,17 revealed mean angular deviations between 1.54° and 4.5°, and controlled clinical studies reported mean angle deviations between 1.72° and 7.9°.1,3,4,7–10,14–16,18 However, few clinical studies have evaluated single restorations in esthetic areas using computer-guided flapless implant surgery. Furthermore, the clinical studies conducted using tooth-supported guides did not calculate the angular deviations in the maxilla and mandible separately to precisely evaluate the predictability of guided surgical systems for implant placement. The hypothesis tested is that the virtually planned position and the guided surgical implant installation do not present clinically relevant deviations. Therefore, this pilot study aims to compare the real and virtual positions of implants inserted via computer-guided flapless implant surgery in the premaxilla using tooth-supported stereolithographic guides in patients with implant-supported single prostheses.

MATERIALS AND METHODS

The Research Ethics Committee approved this prospective clinical study under protocol no. 0001273 (PUC-PR, Curitiba, Paraná, Brazil). The study was conducted in accordance with the Declaration of Helsinki (1964). Eight patients from the
Dental Implant Clinic of the Latin American Institute of Research and Dental Education (ILAPEO, Curitiba, Paraná, Brazil) who had lost at least 1 tooth in the premaxilla were selected. The inclusion criteria used to select patients were the availability of bone tissue with a sufficient height and thickness to install implants of at least 3.5 mm in width by 10 mm in length; the presence of edentulism in the premaxilla of the upper jaw; the presence of teeth adjacent to the prosthetic space, with or without fixed prosthesis; and the absence of systemic problems and local inflammatory, degenerative, or infectious lesions as assessed by medical history, clinical examination, and laboratory tests. The exclusion criteria were systemic involvement; local inflammatory, degenerative, or infectious lesions; and insufficient amount of bone for implant placement. All patients enrolled in the study signed a free and informed consent document.

Impressions of the maxillary and mandibular arches were acquired using condensation silicone (Speedex, Vigodent, Rio de Janeiro, Brazil) and used to prepare a CT guide in colorless self-curing acrylic resin (VIP Flash, Pirassununga, São Paulo, Brazil). In the vestibular flange of the CT guide, 5 random perforations were performed with a No. 4 round drill and filled with gutta-percha (Figures 1a and b).

**Preoperative CT scan (double scanning) and virtual planning**

All patients underwent the double scanning technique. First, a CT was performed using a CT guide in occlusion (Figures 2a and b); next, a scan of only the CT guide was performed. This technique enables the segmentation and combination of the patient images with those of the CT guide and the visualization of the positioned CT guide in relation to the bone structure of the patient. The CT scans were performed using a standardized protocol: The patient’s head was positioned along the occlusal plane, parallel to the ground, and in the median sagittal plane, perpendicular to the ground, using cone-beam CT (CBCT; I-Cat, Imaging Sciences, Hatfield, Pa). The acquisition factors for the CT scans were constant: 5 mA, 120 kV, a voxel size of 250 μm, and an exposure time of 26 seconds. The CBCT images contained in the Digital Imaging and Communications in Medicine (DICOM) files were converted and input into Dental Slice (Bioparts, Brasilia, Brazil), where the virtual surgical and prosthetic planning was performed (Figure 3). Based on the information concerning bone height and thickness, the implant positions and the prosthetic abutment dimensions (ie, diameter, length, number, and height of the transmucosal portion of the abutments) were selected (Table 1). Subsequently, the stereolithographic guide was generated based on the planning information.
Flapless implant surgery and prosthesis installation

A tooth-supported stereolithographic guide was tested in position on the patient before surgery to assess the stability of the guide and the need for adjustment to prevent an undesired position (Figure 4). The patients underwent local terminal infiltrative anesthesia with 2% mepivacaine hydrochloride and epinephrine at a dilution of 1:100 000. The stereolithographic guide was fixed using 10 fastening pins, and the implants were inserted using a guide surgery method (Neoguide, Neodent, Curitiba, Paraná, Brazil), which involves the use of surgical instruments with a progressive sequence of drill diameters. Implants with a Morse taper platform (Neodent) were used for all of the patients, and the diameter and length varied according to bone quality and availability. During the irrigation of the implants, the rotor rotation remained at 30 rpm, and the irrigation was complemented with syringes. After implant installation, the prosthetic components were installed, and the provisional crowns were placed.

Postoperative CBCT and image overlap analysis

After completion of the postoperative CBCT, approximately 7 days after surgery, the DICOM files were used to overlap the images of the planned and installed implants using DentalSlice (Bioparts Prototipagem Biomedica) based on the anatomical anomalies and markings of the CT guide following the methodology proposed by Soares et al.20 (Figure 5). The postoperative CBCT examinations were performed using the same parameters used to acquire the preoperative CBCT to compare the positions between the installed and planned implants. The outcomes variables were analyzed using the 3D CAD model used to plan the position of the implants superimposed and aligned with the postoperative model, and the following references were subsequently captured on the long axis of each planned and placed implant: 1 point at the apical end of the implant (D1), 1 point at the central region of the implant (D2), 1 point at the coronal limit of the implant (D3), and 1 direction vector along the long axis of the implant. The D1, D2, and D3 points were determined by calculating the linear distances between the apical, central, and coronal reference points of the implants in relation to the positions of the installed and planned implants, respectively. The angular deviation was also calculated (A) (Figure 6). A summary of the sequence applied in the methodology is described in Figure 7.

RESULTS

The study sample included 8 patients (6 women and 2 men) with a mean age of 40 years (range: 32–73 years). Four implants were installed in the central incisor region, 2 implants...
were placed in the lateral incisor region, and 5 implants were placed in the premolar region. A summary of the data related to surgical and prosthetic phases is shown in Table 1. The linear and angular values for the 11 implants, as well as the means and SDs, are presented in Table 2. Deviations were observed for all measured distances. The highest linear distance recorded was 4.72 mm in the apical region, and the lowest value recorded was 0.13 mm in the central region. The maximum angular deviation measurement was $3.18^\circ$, and the minimum deviation was $0.58^\circ$. The evaluation of the anterior and posterior segments (Figure 8) indicated that the mean linear values tended to be higher in the anterior region, whereas the mean angular values were similar between the segments.
The mean apical distance was 2.13 mm (Table 2 and Figure 8). Distances between 0.50 mm and 3.10 mm were also similar. Arisan et al. compared mean angular deviation of 2.54°, which varied between 0.50° and 3.10°. The mean coronal distance was 1.37 ± 0.71 mm, whereas the mean apical distance was 2.13 ± 1.32 mm (Table 2 and Figure 8).

Ersoy et al. evaluated patients who used a tooth-supported guide (7 patients and 9 implants) and found a mean angular deviation of 3.71° ± 0.93°, which was significantly higher than the results presented in this pilot study (2.54° ± 0.71°). Ozan et al. found a mean angular deviation of 2.91° ± 1.3° in a sample of 30 implants for single restorations in the mandible and maxilla; their mean was similar to that of the present study. The deviations in the coronal (0.87 ± 0.4 mm) and apical (0.95 ± 0.6 mm) distances were also similar. Arisan et al. compared 2 guided surgery systems using 10 tooth-supported guides and found mean angular deviations of 3.5° ± 1.38° and 3.39° ± 0.84° for systems I and II, respectively. The angular deviations found in these cited studies were larger than those found in the present study. This difference might have occurred, in part, because the techniques used in previous studies were partially guided, and the implants were manually inserted, thereby resulting in greater inaccuracy. In contrast, the current surgery was guided from beginning to end. Similarly, the mean angular deviations found by Di Giacomo et al. and Valente et al. of 7.25° ± 2.67° and 7.9° ± 4.7°, respectively, were considered high compared with those obtained in the present study (2.54° ± 0.71°). This difference might have occurred because the surgical technique was partially guided and the surgical guides were changed during the surgery, depending on the drill diameter used in the instrumentation. The present study used a single surgical guide from beginning to end, and the surgery was fully guided. Only the drill guide coupled to the surgical guide was changed, keeping the surgical guide fixed in place; this procedure generated greater precision in implant positioning. In contrast, Van Assche et al. conducted a clinical study and observed that the mean angular deviations of the planned and placed implants were lower (2.2° ± 1.1°) than those obtained in the present study (2.54° ± 0.71°). Unlike the present study, those authors scanned all tomographic guides.

TABLE 1
Planning the bone beds of 8 implants, including diameter, length, amount, and transmucosal height of the prosthetic abutments

<table>
<thead>
<tr>
<th>Case</th>
<th>Region No.</th>
<th>Bone Type</th>
<th>Bone Height</th>
<th>Bone Thickness</th>
<th>Cortical Thickness</th>
<th>Implant Type</th>
<th>Diameter/Length</th>
<th>Prosthetic Abutments (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>III</td>
<td>15.46</td>
<td>5.85</td>
<td>0.98</td>
<td>Titamax CM EX</td>
<td>3.75/13</td>
<td>Universal angled abutment (30°)</td>
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<td>2</td>
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<td>III</td>
<td>19.48</td>
<td>4.15</td>
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<td>Titamax CM EX</td>
<td>3.5/15</td>
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<td>3</td>
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<td>4.47</td>
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<td>3.75/11</td>
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<td>III</td>
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<td>4.06</td>
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<td>3.5/9</td>
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<td>III</td>
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<td>0.66</td>
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<td>4.3/13</td>
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<td>4.62</td>
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DISCUSSION
This study evaluated the transference of virtual planning using overlapping pre- and postoperative 3D CAD models as described by previous studies applying similar methodologies. The hypothesis that the virtually planned position and the guided surgical implant installation do not present clinically relevant deviations was accepted. The use of computer-guided flapless implant surgery with tooth-supported stereolithographic guides among 8 patients over a total of 11 implants placed in the anterior and posterior regions of the maxilla showed similar results to those of previous studies. The mean angular deviation was 2.54° ± 0.71°, which varied between 0.50° and 3.10°. The mean coronal distance was 1.37 ± 0.77 mm, whereas the mean apical distance was 2.13 ± 1.32 mm (Table 2 and Figure 8).

FIGURE 7. Summary of the sequence applied in the methodology.
using spiral CT and used an additional fixation procedure with intraosseous screws in the tooth-supported surgical guide during surgery.

Other in vitro studies\(^5,7\) and clinical studies\(^1,3,4,7,8,11,14,18\) used this methodology to evaluate the transference of virtual planning by superimposing pre- and postoperative 3D CAD models. Sarment et al\(^17\) compared the virtual position with the actual position of 5 implants placed in dry jaws using a prototyped guide and found mean deviations of 1.5 mm and 2.1 mm in the cervical and apical regions, respectively. Viegas et al\(^5\) conducted an in vitro study to evaluate the variations in the transference of the virtual planning of 22 implants in 11 identical replicas of the human jaw and found a mean angular deviation of 1.45\(^8\). In contrast, Soares et al\(^20\) observed a mean angular deviation of 2.16\(^8\) when studying 18 implants inserted into polyurethane jaws. However, any comparison between a clinical study and an in vitro study should be made with caution because various parameters (in addition to the technique itself) must be controlled in studies involving patients, such as mouth opening, saliva, blood, guide adjustment, procedure speed, and so on. Controlling the surgical procedure is simpler when using dry or epoxy resin mandibles and stable surgical guides.

The final result of accurate implant positioning using the flapless surgical technique depends on various factors.\(^10,15,16,21\) The first factor concerns patient indications. Patients should be selected primarily based on bone availability and mouth opening. In guided surgery, the height of the surgical guide requires the use of long drills. Valente et al\(^14\) observed that the final drill had to be used without the guide, resulting in significant deviations in the final positioning of the implants for patients whose mouth opening did not allow for the use of long drills. Hahn\(^22\) indicated the appropriate clinical conditions for patient selection regarding single restorations using flapless implant surgery: a sufficient bone height and thickness to allow the placement of an implant 3.8 mm in diameter by 12–16 mm in length; keratinized mucosa with a thickness of least 3 mm; the presence of 1 adjacent tooth that can withstand masticatory loads in occlusion; and the ability to stabilize the implant during installation. In addition, monitoring the bone density during drilling is essential to avoid apical deviations between the position of the planned and placed implants.\(^4,14\) Low bone density of the maxilla can influence the trajectory of the implant and cause higher apical deviations in the maxilla than the mandible.\(^16\)

The proper preparation of the CT guide is of fundamental importance to the success of flapless implant surgery. After the scanning process, the image segmentation, and the software integration, the CT images guide the planning of the positions of the implant and prosthesis. In addition, the surgical guide is generated based on 3D images of the CT guide. Depending on the region to be implanted (full edentulous arch, partial edentulous arch, partial tooth loss, or single restorations), the CT guide should meet certain criteria. Given that the present study involved single restorations, a tooth-supported CT guide constructed of colorless acrylic resin was used to evaluate its adjustment to the occlusal/incisal surface of the teeth.

When working with tooth-supported stereolithographic guides, a few adjustments are often necessary for occlusal adaptation. These adjustments are necessary because of the difficulty in reproducing the occlusal anatomical details via the CT apparatus in the presence of artifacts (eg, hard beam). In an attempt to overcome this deficiency, some researchers have performed 3D laser scanning directly on the teeth or a plaster model to merge this image with the CT image. This method results in a detailed image of the occlusal surface of the teeth and a more suitable tooth-supported guide.\(^8\) Another factor that should be considered is the deviation during preparation.

### Table 2

<table>
<thead>
<tr>
<th>Patient</th>
<th>Implant Region No.</th>
<th>Implant Length (mm)</th>
<th>Coronal Distance (mm)</th>
<th>Central Distance (mm)</th>
<th>Apical Distance (mm)</th>
<th>Angle (°)</th>
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<tr>
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<td></td>
<td>0.77</td>
<td>0.58</td>
<td>1.32</td>
<td>0.71</td>
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</table>

**FIGURE 8.** Linear and angular measurements of the implants in the anterior and posterior segments of the maxilla.
of the stereolithographic surgical guide (approximately 0.1 to 0.2 mm), which is related to the accuracy of the stereolithography system, the physical properties of the material used, and the placement method of the washers in the guide.\textsuperscript{15}

The CT quality can also influence image segmentation and the consequent adaptation of the surgical guide. Deviations in image acquisition and data processing can reach 0.5 mm/\textsuperscript{23} Previous clinical trials of guided surgery involving a prototyped surgical guide used spiral CT scans to achieve dual scanning (a CT of the patient using the CT guide and 1 of the CT guide alone).\textsuperscript{3,4,14} With the advent of CBCT, however, many researchers have used CBCT images for guided surgery.\textsuperscript{10,15,16} The CBCT was adopted in this study because of its advantages, including the reduced radiation dose, speed and ease of performance, lower cost, capacity to accurately reproduce maxillofacial anatomical structures\textsuperscript{24-26} and adequate image quality to enable image segmentation and stereolithography.\textsuperscript{7,25} In addition, this pilot study performed dual scanning (ie, CBCT of the patient with the tooth-supported guide and CBCT of the guide alone), whereas Van Assche et al\textsuperscript{7} exclusively used CBCT to acquire patient images using the guide. Because the surgical guide is generated based on the segmented image of a 3D volume and because of the difficulty in segmenting the guide images generated by the CBCT device, these authors chose to scan all CT guides using spiral CT to achieve greater accuracy. Based on the results of studies concerning the transference of virtual planning, these authors concluded that the deviations in the implants relative to their expected positions were acceptable (mean angular deviation = 2.2°; horizontal deviation = 0.6 mm; apical deviation = 0.9 mm). These authors obtained similar results using CBCT and spiral CT scans; therefore, they argued that CBCT could be efficiently used to prepare a stereolithographic surgical guide.

The deviations observed in the guided surgery systems can also be related to the surgical ability of the clinician and can include errors in the positioning and fixation of the surgical guide, the movement of the guide during drilling, and the definition of the drill stop in the wrong position.\textsuperscript{14} Professionals with extensive experience in conventional implant placement techniques should perform guided surgeries. Extensive knowledge about the anatomy of the maxillomandibular complex as well as a strong ability and great sensitivity during instrumentation are required to guarantee high predictability for this surgical technique. When a guided surgery is performed using drills that pass through the interior of the metal washers, manual sensitivity can become impaired, often producing the sensation that the bone is denser than in reality. In addition, the surgeon should account for the degree of tolerance between the drill and the washer, which varies between 0.15 and 0.20 mm.\textsuperscript{14} Finally, comparative studies on the accuracy of implant placement using different types of surgical guides have found that tooth-supported guides show less deviation than mucosa-supported and bone-supported guides. Mucosa-supported guides allow micromovements because of their mucosal flexibility, whereas tooth-supported guides are more stable.\textsuperscript{4,10,15,21,27}

The present study did not find complications, such as trepanation of the nasal cavity, fenestration of the bone wall, or fracture of the surgical guide, during surgery. Van Assche et al\textsuperscript{7} performed a clinical study of 8 patients who underwent flapless guided surgery using tooth-supported stereolithographic guides for the insertion of 21 implants and observed that fracture occurred in 1 surgical guide that had to be modified. In that case, the analysis of the planned and placed implants indicated a considerable angular deviation between 6.2° and 8.3°. Those researchers argued that the production of a CT guide with a minimum thickness ranging from 2.5 mm to 3.0 mm is essential to prevent fractures. Tooth-supported guides used for single restorations tend to have increased stability compared with traditional surgical guides prepared in case of multiple teeth absence. Therefore, the former might present lower probabilities of fracture and micromovements.\textsuperscript{16}

Different technologies have been used to improve accuracy and to facilitate the guided surgery treatment planning.\textsuperscript{28,29} A common way to prepare a case for a guided surgery technique is by scanning either the impression cast of patient jaws or performing intraoral scanning. In the first case, an impression of the edentulous area and its antagonist is obtained, a cast is produced, and the desired tooth is waxed; with a digital surface scanner (laboratory), both casts (work area and antagonist arch) are scanned, with the waxed tooth in and out of position. This scanned images (STL file), together with the patient’s CBCT, will be used to do the virtual planning using software. An alternative would be using the intraoral scanner directly in the patient’s mouth, avoiding the necessity of taking an impression.\textsuperscript{30} The present pilot study was conducted in a different way, using the double scanning technique, which is well supported in the literature as a viable and predictable technique.\textsuperscript{20,31} The most notable difference, it that the double scanning technique does not need any type of scanner, which may facilitate and enhance its use for any situation, once the CBCT is a prerequisite for both double scanning or using the scanner techniques. For most dentists, CBCT is a more accessible technology as the scanners, either laboratory or intraoral, are expensive and not always available; therefore, this may reduce the use of the guided surgery technique for some dentists worldwide.

Despite the limitations of this pilot study associated with the small sample size, which reduces the external validity of the results, based on this proof-of-concept study, single crown computer-guided flapless implant surgery presented angular and positional inclinations comparable to those reported in the literature; thus, it, may be indicated as a safe and predictable treatment plan. However, despite the advantages offered by guided surgery for single restorations (particularly in esthetic regions), the computerized planning and prototyped surgical guide method can result in additional treatment costs, but these can be justified as a benefit of more accurate planning, especially with regard to complex rehabilitation cases with multiple implants in different bone regions.\textsuperscript{17}

\textbf{ABBREVIATIONS}

3D: three dimensional  
CAD: computer aided design  
CBCT: cone-beam computerized tomography  
CT: computerized tomography
Real vs Virtual Position of Implants: Guided Surgery

DICOM: Digital Imaging and Communications in Medicine

ACKNOWLEDGMENTS

Special thanks to the employees of ILAPEO (Latin American Institute of Dental Research and Education) who were involved in this study and definitely played an important role on the final results. Some of the material used in the study protocol, was supplied by Neodent, Curitiba/PR, Brazil, which kindly donated the implants, prosthetic components, and surgical guide.

NOTE

Dr G. Thomé has a conflict of interest in that he is the president of Neodent’s Scientific and Administrative Council (Neodent, Curitiba/PR, Brazil). All other authors have no financial interest in any company or any of the products mentioned in this article.

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