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Purpose. The goal of this clinical study was to determine the angular deviations between planned and placed zygomatic implants using stereolithographic surgical guides in human cadavers.

Materials and Methods. A total of 16 zygomatic implants were placed, four in each cadaver, using SLA surgical guides generated from CT. A new CT scan was made after implant insertion. The angle between the long axis of the planned and actual implant were calculated.

Results. The mean angular deviation of the long axis between the planned and placed implants was 8.06 ± 6.40 (Mean ± SD) for the anterior—posterior view, and 11.20 ± 9.75 (Mean ± SD) for the caudal—cranial view.

Conclusions. The use of the zygomatic implant, in the context of this protocol, should probably be re-evaluated because of the some large deviations that were noted. There is a need for an implant insertion guiding system since this last step is carried manually. It is recommended the utilization of the sinus slot technique together with the CT-based drilling guide to enhance the final results. Further research to enhance the precision of zygomatic implant placement should be made.
Accuracy evaluation of computed tomography derived stereolithographic surgical guides in zygomatic implant placement in human cadavers

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INTRODUCTION
Presurgical planning is essential to achieve excellent esthetic and functional outcomes with dental implants. Many conflicting variables such as the mandibular canal, maxillary sinus, and adjacent teeth need to be considered before implant surgery. Practitioners have generally used conventional dental radiographs (panoramic and periapical radiographs)\(^1\) and conventionally fabricated surgical guides\(^2,3\) for implant placement. The panoramic radiographs that are commonly used in implant treatment planning are limited by their characteristics of magnification and distortion as well as lack of sharpness of the image. Also, a panoramic radiograph is a 2-dimensional image providing little information about the buccal-lingual width of the jawbones\(^4\). The surgical guides conventionally fabricated on diagnostic stone casts do not provide information about the varying thicknesses of the mucosa, topography of underlying bone, or anatomical structures, and they do not remain stable during surgery because of reflected soft tissue\(^2\).

Computed tomography (CT) is a helpful tool for implant patients, especially for situations with anatomical limitations, insufficient bone dimensions, and poor bone density\(^5,6\).
The use of CT imaging enhances the correlation between implant planning and actual implant placement compared with conventional radiographic methods.7

Currently there are few software systems using CT scans to aid in planning surgery and produce surgical drilling guides. These guides are manufactured in such a way that they match the location, trajectory, and depth of the planned implant with a high degree of precision. As the dental practitioner places the implants, the guides stabilize the drilling by restricting the degrees of freedom of the drill trajectory and depth. Earlier studies concluded that the 3D planning resulted in implant positioning with improved biomechanics and esthetics.8-10 Use of such a system usually removes complications including mandibular nerve damage, sinus perforations, fenestrations, or dehiscences8,11. And computer-aided design (CAD) and computer-aided manufacturing (CAM) software may improve the association between dental implant planning and insertion, regarding 3D determination of the patient’s jaw anatomy and fabrication of both anatomical models and surgical guides.8,12-14.

Some studies have recently illustrated promising results with stereolithographic (SLA) surgical guides.12,15-18 The SLA consists of a vat containing a liquid photopolymerized resin.18 A laser mounted on top of the vat moves in sequential cross-sectional increments of 1 mm, corresponding to the slice intervals specified during the CT formatting procedure. The laser polymerizes the surface layer of the resin on contact. Once the first slice is completed, a mechanical table immediately below the surface moves down 1 mm, carrying with it the previously polymerized resin layer of the model. The laser subsequently polymerizes the next layer adjacent to the previously polymerized layer.18 In this manner, a complete SLA model of the maxilla and the surgical guides is created.

Restoration of the atrophied edentulous maxilla poses a great dilemma to the oral and maxillofacial surgeon and restorative dentist. Patients with adequate maxillary bone are ideal candidates for implants, but are the exception. Patients with moderate to severe atrophy
challenge the surgeon to discover alternative ways to use existing bone or resort to augmenting the patient with autogenous or alloplastic bone materials.

Various techniques have been described to approach the atrophic maxilla, including use of tilted implants in the para-sinus region\textsuperscript{19-22}, implants in pterygoid apophysis\textsuperscript{23,24}, grafting of the maxillary sinus floor\textsuperscript{25,26}, the use of short, wide implants\textsuperscript{27,28}, different types of grafts\textsuperscript{29-31}, and zygoma implants\textsuperscript{32-40}. The incidence of implant loss in the severely resorbed posterior maxilla is approximately 15% without a sinus bone graft\textsuperscript{41}.

The zygoma implant has been designed by Brånemark\textsuperscript{33,34,42} for those situations where there is insufficient bone in the upper jaw, which would otherwise require onlay or inlay (sinus) bone grafts. Zygomatic bone is excellent for the anchorage of implants, as has been validated in several anatomical studies\textsuperscript{43-46}. These authors agree that the quality of zygomatic bone is superior to that of the posterior maxilla, and the importance of the cortical portion of the zygomatic bone for anchoring implants\textsuperscript{43} has been described. Furthermore, zygomatic implants display initial primary stability, since it has been demonstrated that the zygomatic bone area where the implant is inserted has wider and thicker trabecular bone\textsuperscript{45}.

Implant placement in the zygoma bone, however, can be difficult due to the variable anatomy and varying degrees of atrophy possible in the maxillofacial region\textsuperscript{47}. The technique is not without risk because the drill path is close to important anatomic structures. A significant error can be induced by only a slight deviation of the drill path direction\textsuperscript{48}.

The clinical effectiveness of the use of the drill guide and the important advantage on the aesthetical outcome has been described\textsuperscript{49}. For zygoma implants, the accuracy of the transfer of the preoperative plan to the surgical field is even more crucial. Given an appropriate visualization, 3D CT images provide an unparalleled depiction of the complex anatomical topography that has to be respected when deciding on the trajectory of a zygoma implant.
Personalized drilling templates may be fabricated by a computer-based transfer from the available 3D CT planning data\textsuperscript{50}, which allows incorporation of all predetermined biomechanical, aesthetic and anatomical factors during the surgical procedure.

The goal of this clinical study was to determine the angular deviations between planned and placed zygomatic implants in human cadavers using SLA-based drilling guide technology.

MATERIAL AND METHODS

The study protocol was approved by the Institutional Ethics Committee of the Federal University of Minas Gerais. Four human cadavers were considered for the study.

Standardized CT scanning procedures were followed for each cadaver, performed by the same radiologist operating a CT machine (Classic i-CAT\textsuperscript{®}, Imaging Sciences International, Hatfield, PA, USA). The CT data for each cadaver were imported to the planning software (Dental Slice\textsuperscript{®} software, BioParts Prototipagem Biomédica, Brasília, Brazil) allowing the surgical team to simulate implant placement on the 3D model. Taking into consideration the anatomic structures, the surgical team interactively simulated the position of the implant on each plane. Once the implant is planned, its angulation can still be adjusted and its dimensions adapted to obtain the optimal position of the implant (Figure 1). The implant is directed in a lateral and upward direction with an angulation of 45° from a vertical axis. The end point has to encroach into the zygomatic bone, which has a thickness of about 10 mm. The zygoma implant thus follows an intra-sinusal trajectory. After initial positioning of the implant, several minor adjustments can be made until the implant is surrounded by bone at its entry and end points and to ensure that the intermediate part does not perforate the anterior maxillary wall. A rapid prototyping machine using the principle of
stereolithography was used to fabricate the SLA models and guides. The aim is to create an individualized drill guide that is suited to the bone profile.

The SLA machine also read the diameter and angulation of the simulated implants and selectively polymerizes resin around them, forming a cylindrical guide corresponding to each implant. Surgical grade stainless steel tubes were attached into the cylindrical guide. In order to prevent lateral angulation of the drill during the drilling process, drill guides (made by Peclab Ltda, Belo Horizonte, Brazil) that perfectly adapts to the stainless steel tubes were made (Figure 2). Drilling of the zygoma implants were performed using four drills. Consequently, four sets of drill guides were provided. The inner diameter of the drill guides is 0.3 mm greater than the diameter of the corresponding drill. The angulation, mesiodistal and buccolingual positioning of each implant as planned using 3D computer simulation software was transferred to the SLA surgical guide.

The SLA bone-supported surgical guide type was used. The surgical drill guide was fitted onto the maxilla and fixated with two or three osteosynthesis screws (10.0 x 1.5 mm). The drilling procedures were performed using appropriate drills for each corresponding implant according to the manufacturer’s instructions. A total of 16 zygomatic implants were placed (SIN Sistema de Implante®, São Paulo, Brazil), all 4.0 mm of diameter ranging from 37.5 to 57.5 mm of length. Four implants were placed in each cadaver, two in the canine region, two in the first molar region, using SLA surgical guides generated from CT. A new CT scan was made for each cadaver after implant insertion.

The Adobe Photoshop Elements® software (Adobe Systems Incorporated, Version 2.0, 2002) was used to match images of the planned and placed implants, and their positions and axes were compared. The preoperative and postoperative CT scans in an anterior-posterior (Figure 3) and in a caudal-cranial (Figure 4) view were aligned observing the superposition of anatomic markers. The angle between the long axis of the planned and actual
implant (Figure 5 and 6) were calculated using the VistaMetrix® software (SkillCrest, Version 1.36.0, 2009). Basic descriptive statistics was employed to analyze the data obtained using standard software (Excel®, Microsoft Corp.).

RESULTS

In the right posterior implant of cadaver 4 (C4) the angular deviation between the planned and the actual implant position in an anterior-posterior view was 0.35°, the smallest deviation, while the left posterior implant of cadaver 3 (C3) in a caudal-cranial view showed the largest deviation (37.60°). A more detailed presentation of the angular deviation between planned and placed implants in an anterior-posterior and in a caudal-cranial view in the four cadavers is found in Table 1.

The mean angular deviation of the long axis between the planned and placed implants was 8.06 ± 6.40 (Mean ± SD) for the anterior—posterior view, and 11.20 ± 9.75 (Mean ± SD) for the caudal-cranial view. The minimal and maximal values for the anterior—posterior view were 0.35° and 21.20°, and 0.76 and 37.60° for the caudal-cranial view.

DISCUSSION

The strength of the anchorage in the zygoma compensates the bad quality of the bone, mostly type IV in the posterior maxilla. From a biomechanical point of view, it has been demonstrated that, if the zygoma fixtures are connected to anterior implants, the masticatory forces applied to the fixed prosthesis are transferred to the zygoma44.

The CT scanning template is the principal key to the system because it permits the transfer of the predetermined prosthetic setup to the actual implant planning. The scanning
template is an exact replica of the desired prosthetic outcome, and allowed both surgeon and restorative dentist to base the implant planning on the desired prosthetic outcome. The treatment plan is thus driven by the prosthetic end result. Some other studies have assessed the magnitude of error in transferring the planned position of implants from CT scans to a surgical guide. In the in vitro study by Besimo et al. the deviation between the positions of the apex of the proposed implants in cross-sectional CT images and on the corresponding study cast was measured in 77 sites. The transfer errors for the maxilla and mandible were 0.6 ± 0.4 mm and 0.3 ± 0.4 mm. However, they concluded that the transfer errors noted in their study were not clinically relevant because other factors involved in transferring positional and angular measurements from CT images to the actual surgical area may result in greater errors. Another in vitro study by Sarment et al. included 50 implants placed into 5 epoxy resin edentulous mandible models. Each epoxy resin mandible received 5 implants in each side. On the right side, 5 implants were inserted using a conventional surgical guide, whereas on the left side, 5 implants were inserted using an SLA surgical guide. When compared with conventional guides, they noted significant improvements in all measurements with SLA surgical guides. They stated that the clinical significance of this result may be relevant when multiple parallel distant implants are placed and where the degree of accuracy is critical to obtain a single prosthetic path of insertion. Their studies, although very relevant, were made only with normal dental implants in the jaws, and not in the zygoma.

Van Assche et al. placed 12 implants in 4 formalin-fixed cadaver jaws. When compared with the planned implants, they noted average angular deviation of 2° ± 0.8°, mean linear deviation of 1.1 ± 0.7 mm at the neck, and 2 ± 0.7 mm at the apex in the placed implants. Another human cadaver study by Van Steenberghe et al. included 6 zygoma implants with surgical drilling guides using CT data. They matched preoperative CT scans
with postoperative CT scans to evaluate the deviation between the planned and placed zygoma implants. They reported that the angular deviations in axis for 4 planned and placed implants were <3°, whereas one implant showed 3.1° and the last one showed 6.9° angular deviation in axis.

Di Giacomo et al.\textsuperscript{15} evaluated the match between the positions and axes of the planned and inserted implants when an SLA surgical guide was used. They inserted 21 implants in 4 patients using 6 SLA surgical guides using CT data, measuring the deviation between planned and inserted implants. They noted an average angular deviation of 7.25° ± 2.67° between the planned and the inserted implant axes. This average angular deviation was higher in the study of Vrielinck et al.\textsuperscript{48}, 10.46° (range: 0 to 21.0°), also an in vivo study. Other study in vivo tried to determine deviations in the position and inclination of the planned and placed implants using SLA surgical guides and to compare 3 different types (tooth-supported, bone-supported, and mucosa-supported) of SLA surgical guides\textsuperscript{18}. Under the guidelines of this study, CT-derived SLA surgical guides supported by either tooth, bone, or mucosa provided a precise tool for both flapless and conventional flap implant insertion. Naitoh et al.\textsuperscript{54} found angular deviations between planning and placement ranging from 0.5° to 14.5° with an average of 5.0°, using teeth-supported conventional guides. The CT data were used to transfer only the position and/or inclination of the implants to a laboratory-made template placed on working plaster models.

The main goal of the study was to evaluate the possibilities of skeletally supported drill guides for zygomatic implant placement in patients with severely atrophic maxillas, while still providing a predictable, permanent and successful treatment result. The mean angular deviation of the long axis between the planned and placed implants was 8.06 ± 6.40 (Mean ± SD) for the anterior—posterior view, and 11.20 ± 9.75 (Mean ± SD) for the caudal-cranial view. This aim was not completely met by this treatment concept, in terms of angular
deviations between the planned and placed implants. Despite the fact that deviations between planned and placed implants could be quite substantial, in some cases, this may not affect the ability of the restorative dentist to design and fabricate a prosthetic suprastructure onto these deviated implants. There were also deviations with good clinical results, as observed with the left side on the cadaver 1 (Figures 7 and 8).

It is not easy to make direct comparisons between in vitro studies and the present human subject, as in vitro studies provide improved control of all contributing parameters. However, it was observed large angular deviations, probably because of poor fit of the surgical guide, between other causes. The precision of the whole procedure depends largely on the ability to position accurately the drill guide on top of the bone, and to maintain that stable position during the whole procedure. The difference of osteosynthesis screws to fix the surgical guide onto the maxilla bone can also have an important role. In this study, it was used 10 mm length screws, a half length when compared to the study of Vrielinck et al.\textsuperscript{48}. The number of screws was also lesser: two or three against four or five in the study of Vrielinck et al.\textsuperscript{48}. Asymmetric distribution of the screws or uneven tightening of the screws could bring the drilling template out of balance. Furthermore, a certain error is induced as the diameter of the steel tubes is slightly larger than the drill diameter. Finally, the largest error is probably due to the fact that the final step in the procedure is carried out manually. Implant placement can not been done through the surgical drill guide due to present mechanical limitations. The drill guide, therefore, has to be removed before the implant is actually inserted, leaving the possibility of additional deviation.

The original Brånemark protocol creates a sinus window technique for placement of these zygoma dental implants. Stella and Warner’s\textsuperscript{55} published “sinus slot technique” significantly simplified the original Brånemark protocol. The “sinus slot” is a guide window made directly through the buttress wall of the maxilla, whereby the zygoma implant is guided
through the maxilla to the apex insertion at the junction of the lateral orbital rim and the zygomatic arch. This lateral sinus slot allows greater potential for bone-to-implant interface because of this lateral position, and eliminated the sinus window and sinus lining elevation for placement of the implant. This lateral window allows direct vision to the base of the zygoma bone and helps control the implant position by direct vision. The fact that we have done these surgeries in a cadaver without direct vision through the maxillary sinus may also have influenced in the results.

Moreover, some deviation may occur when the actual implant entry point compared to the initial treatment planning is considered. This may due to the brittle and soft consistency of bone in maxillas with severe bone atrophy.

On the left side of the cadaver number 3, one implant emerged in the infratemporal fossa (Figure 9) and the other one inside the orbit (Figure 10). This great deviation of course occurred because of the long length of the zygomatic implants (37.5-57.5 mm), 3 to 4 times that of oral implants, which means that even minute angular deviations lead to important discrepancies at the extremity. According to Vrielinck et al., it should be noted that the common practice today is to position zygoma implants without any form of physical control of the drilling trajectory. However, care has to be taken to ensure a proper mesio-cranial direction for the implant. If the implant is planned too much laterally, it would emerge in the infratemporal fossa. If, on the contrary, it is planned too much mesially it would end up in the nasopharynx or the sphenoid sinus. If the inclination of the implant is too much in the cranial direction, it would enter the fossa pterygopalatina. For an implant directed too much horizontally, no bony structures will be encountered. Based on the dimensional variability of the zygoma bone, such errors might, even with accurate 3D CT-based planning and transfer, create some potential dangers.
It must be emphasized that in the preliminary feasibility study, the implant planning may be done solely on the basis of available bone volume, i.e., implant planning may not take into account information conveyed through a preoperative prosthetic set-up, because the quantity of present bone may be minimal, due to the atrophy. Considering that, the “wrong” implants position should not affect the ability to design and fabricate a prosthetic suprastructure onto these deviated implants, despite the angular deviation.

CONCLUSIONS

The results of this study demonstrated that the use of the zygomatic implant, in the context of this protocol, should probably be re-evaluated because of the some large deviations that were noted. There is a need for an implant insertion guiding system since this last step is carried manually. It is recommended the utilization of the sinus slot technique together with the CT-based drilling guide to enhance the final results. The tridimensional CT is a helpful tool for patient candidates to zygomatic implants, because the drill path is close to important anatomic structures. The reported results may be surprising and should stimulate further research to enhance the precision of zygomatic implant placement, even considering better results obtained by former studies.

REFERENCES


44. Van Steenberghe D, Malevez C, Van Cleynenbreugel J, Bou Serhal C, Dhoore E, Schutyser F, Suetens P, Jacobs R. Accuracy of drilling guides for transfer from three-
dimensional CT-based planning to placement of zygoma implants in human cadavers.


Table 1. Angular deviations between the planned and the actual zygomatic implant positions in the four human cadavers.

<table>
<thead>
<tr>
<th>Region</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
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<td>12.30</td>
<td>4.20</td>
<td>1.46</td>
<td>14.80</td>
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<tr>
<td>Right canine</td>
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<td>4.22</td>
<td>18.30</td>
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<tr>
<td>First left superior molar</td>
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<tr>
<td>Left canine</td>
<td>8.79</td>
<td>5.74</td>
<td>4.99</td>
<td>14.10</td>
</tr>
</tbody>
</table>

A-P: anterior-posterior view; C-C: caudal-cranial view
FIGURE CAPTIONS

Figure 1. The 3D CT planning system. Axial, transversal, panoramic, and tridimensional CT slices are possible. Clinically relevant co-visualization can be obtained.

Figure 2. Drill guides to every corresponding drill were made, to perfectly adapt into the cylindrical guide.

Figure 3. Preoperative and postoperative CT scans in an anterior-posterior view were aligned observing the superposition of anatomic markers.

Figure 4. Preoperative and postoperative CT scans superposition in a caudal-cranial view.

Figure 5. Superposition of the planned and placed implants in a caudal-cranial view (cadaver 4).

Figure 6. Superposition of the planned and placed implants in an anterior-posterior view (cadaver 1).

Figure 7. Good clinical results. Left side of the cadaver 1.

Figure 8. Good clinical results. Left side of the cadaver 1.

Figure 9. Poor clinical results. One implant emerged in the infratemporal fossa of the cadaver 3.

Figure 10. Poor clinical results. One implant emerged inside the orbital cavity of the cadaver 3.
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Accuracy Evaluation of Computed Tomography Derived Stereolithographic Surgical Guides in Zygomatic Implant Placement in Human Cadavers

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