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EVALUATION OF THE ZYGOMATIC IMPLANT PLACEMENT USING 3D SURGICAL GUIDE

Ahmed M. Qassem[1*] M.Sc, Mervat M. Khalil[2] PhD, Mohamed M. Shokry[2] PhD, Adham A. ElAshwah[2] PhD

ABSTRACT

BACKGROUND: Zygomatic implants provide as an alternative to extensive grafting techniques for addressing atrophic posterior maxilla. The placement of zygomatic implants is technically complex, often leading to severe problems and various prosthetic difficulties due to inaccurate positioning. Virtual surgical planning enhances the precise placing of zygomatic implants and promotes advantageous prosthetic results.

AIM OF THE STUDY: This study was conducted with the aim of evaluating the three-dimensional morphological and functional accuracy of virtual surgical planning (VSP) guided zygomatic implant placement.

MATERIALS AND METHODS: Zygomatic implants were utilized to support the posterior areas of the rehabilitation. The implant was placed by transferring the preoperatively planned position to the surgical field utilizing cone beam computed tomography (CBCT) and an implant planning software to create a 3D-printed surgical guide. A three-dimensional radiographic examination was carried out immediately to assess the precision of the virtual surgical planning.

RESULTS: A total of eight implants in this study. In all patients two zygomatic implants were inserted, one on each side. The mean linear coronal deviations between virtually planned and actually placed implants was 1.49 ± 0.53, which ranged from 1.01 – 2.90. The mean linear apical deviations between virtually planned and actually placed implants was 2.08 ± 0.55, which ranged from 2.89 – 6.89. The mean angular deviations between virtually planned and actually placed implants was 2.08 ± 0.55, which ranged from 2.89 – 6.89.

KEYWORDS: zygomatic implant, virtual planning accuracy, 3D printing, surgical guide.

RUNNING TITLE: Zygomatic implant placement using surgical guide.

1-M.Sc., 2018, Faculty of Dentistry, Alexandria University, Egypt.
2-Professor of Oral and Maxillofacial Surgery, Department of Oral and Maxillofacial Surgery Faculty of Dentistry, Alexandria University, Egypt.

Corresponding author:
ahmed.kassem.dent@alexu.edu.eg

INTRODUCTION

Rehabilitating severely atrophic maxillae is a significant hurdle. Frequently, the use of conventional implants is restricted due to insufficient bone quantity and substandard bone quality, especially in the posterior regions where the maxillary sinus is pneumatized (1). Various treatment methods exist for achieving an ideal functional and aesthetic rehabilitation, including sinus augmentation, onlay and inlay grafts, split crest approach, pterygoid implants, osteogenic distraction, and zygomatic implants (2).

Branemark and colleagues (3) proposed zygomatic implants in the late 1980s as an alternative treatment for patients with significant deformities of the maxilla caused by tumor resections, trauma, and congenital malformations. By 1998, a clinical protocol was created and published for this purpose. Subsequently, zygomatic implants were also utilized for additional purposes, such as rehabilitation of completely edentulous patients with severe maxillary atrophy, excessive maxillary sinus pneumatization, and instances where previous attempts to augment the maxillary sinus were unsuccessful (4, 5).

Zygomatic implants can be installed either manually or with the assistance of presurgical virtual planning and guidance systems. When strategizing the placement of zygomatic implants, it is crucial to consider both the vertical and horizontal planes (6).

Computer-guided implant placement offers numerous benefits in comparison to free-hand surgery, such as less invasive surgery with a decrease in both the duration and number of stages involved. Moreover, these methods enable the prosthetic-driven implant placement with more accurate results and simplified procedures, rendering them suitable even for doctors with limited training (7-9). A major issue with guided zygomatic implant insertions is the application of methodologies derived from traditional implantology, which is based on a two-dimensional perspective. However, zygomatic implants require meticulous consideration of the third angular dimension (10). Utilizing a bone-supported surgical template to guide the placement of zygomatic

implants appears to be a logical approach for enhancing safety and precision. Attaining the precise angle of zygomatic osteotomies remains challenging, and further research using randomized clinical trials is necessary to evaluate the reliability of these procedures (8).

The aim of this study was to evaluate the three-dimensional accuracy of virtually guided zygomatic implant placement in posterior edentulous maxilla in comparison to the preoperative virtual surgical plan.

Materials and methods

Study design

The study was conducted on a sample consisting of eight edentulous posterior maxillary areas who met the inclusion criteria.

Sample size was estimated assuming 5% alpha error and 80% study power. The mean value of implant deviation at apical position was calculated to be 3.83±3.00mm.

Based on the difference between two dependent means, the minimum sample size was be calculated to be 7 implants increased 8 implants to make up for lost to follow up cases. Software sample size was based on Rosner's method. Calculated by Gpower 3.0.10.

Patients were selected from the outpatient clinic of the Oral and Maxillofacial Surgery Department at Alexandria University's Faculty of Dentistry. Each patient executed an informed consent form preceding the procedure and was given information about the clinical procedure, possible risks, and complications. Implementation of the Helsinki Declaration guidelines and ethical exemption from the local Research Ethics Committee (IRB NO: 00010556-IORG: 0008839) was granted before the commencement of the study.

Inclusion criteria

Patients had missing posterior maxillary teeth extracted requiring implant supported restoration, patients had adequate ridge diameter to accommodate implants of minimum 3.5 mm in width, non smokers, patients were selected free from any sinus pathology, no gender preface in selection of the patients, patients between 30 to 60 years old and participants who were both willing and completely capable of adhering to the study protocol.

Exclusion criteria

Medically compromised persons with conditions that adversely impact clinical procedures or outcomes, maxillary sinus pathologies, smokers, acute oral infections, history of radiotherapy or chemotherapy in head and neck region, inadequate interocclusal space and alcohol or drug abuse.

Preoperative virtual surgical planning (VSP)

Virtual surgical planning process

Planning was accomplished using CBCT, DICOM format, segmentation software using Blue Sky Bio software with a surface-based rendering for surgical planning and simulation. A dual-scan technique utilizing CBCT was employed, wherein each participant underwent two CBCT scans: the initial image included the denture with gutta percha fiducial markers alongside the radiography index, while the second scan featured simply the denture. A 2D DICOM file was generated with the patient wearing a dental prosthesis to delineate the image thresholds, excluding any soft tissue and exclusively highlighting bone with segmentation software. The midface bones and teeth were isolated, and a three-dimensional (3D) reconstruction of the segmented midface and dental hard tissue was produced. An adequate segmentation of the denture prosthesis was performed. The segmented midface parts were transferred in a Standard Tessellation Language (STL) format to a specialized software for their 3D printing using the Fused Deposition Modelling (FDM) method. In the designing software zygomatic implant positions were planned by using data from CBCT scan. The implant site in the study was guided by the anatomically and prosthetically driven protocol. The trajectory of the zygomatic implant body will differ based on the relationship between the zygomatic buttress and the intraoral initiation point, ranging from entirely intrasinus to entirely extrasinus. The planned prosthesis was used to determine the final implant position. The positioning of the zygomatic implant is neither 'internal' nor 'external' to the sinus wall; rather, it facilitates the placement of the zygomatic implant in accordance with the patient's anatomy and the anticipated location of the teeth. Fixation pins/ screws were added ensuring that they do not encroach on the placed implant position. A bone supported guide was fabricated on the maxillary bone for all implants. The bony supported guide was exported as on STL file. The STL file was imported into a 3D printing software program and using a desktop printer to print the guide in FDA approved surgical guide resin (eResin-PLA, Wuhan, Shenzhen, China). The bony supported guide was adapted on the segmented midface, ensuring seating of the guide. Figure (1)

Preoperative Sterilization

Guides and templets were sterilized following the Canter for Disease Control (CDC) recommended guidelines, by soaking the finished product in fresh 70% Isopropyl Alcohol (IPA) for 5 minutes.

II- Surgical procedure

1- Preoperative patient preparation

All registered patients perform necessary laboratory examinations, and clearance for surgery from the anesthesia specialist has been secured.

2- Operative procedure

All patients underwent general anaesthesia with nasotracheal intubation while in a supine position. A throat pack was applied to prevent the aspiration

of foreign bodies. The head and neck surgical region was cleansed with povidone-iodine surgical scrub solution, thereafter draped with sterile towels to expose just the surgical sites. Local anesthetic combined with hemostatic medications employed to achieve optimal hemostasis during the surgery. An incision was made from one tuberosity to the other, accompanied by two vertical releasing incisions in the zygomatic pillar region. A complete thickness mucoperiosteal flap was raised, facilitating the observation of the alveolar crest, the lateral wall of the maxillary sinus, and the inferior margin of the zygomatic arch. Figure (2a, b)

The placement of the zygomatic implant is neither 'internal' nor 'external' to the sinus. If the path of the implant body being intrasinus then the sinus slot position traced in the guide and lateral widow using piezoelectric tips (ACTEON® Group, France) and sinus elevation hand Instruments were used for precise osteotomy for sinus access. The initial bone marking was done using a piezoelectric tip BS5. This was followed by the deepening of the mark using SL1 tip. Figure (2c) A piezoelectric tip (SL3), known as an elephant-foot-like tip, was used to dissect the bony window from the sinus membrane bluntly, and then a surgical tissue forceps was used to remove the lateral bony window. After exposing the sinus membrane, special sinus elevation hand instruments were carefully used to separate the membrane from the sinus walls and floor until the desired height was reached. Figure (2d) The 3D-printed surgical guide was placed intraorally and firmly fixed the surgical guide to the maxilla using fixation pins/screws. Figure (2e) The crestal mark was made for the implant entrance with the round bur. The round bur was penetrated and pass through to the sinus while checking the direction of the bur through the sinus window. The procedure continued with the Twist Drill 2.8 mm until the outer cortical layer of the zygomatic bone at the incisura. Osteotomy widened with Twist Drill 3.2 mm. Finalizing the osteotomy with twist drill 3.6 mm. Figure (2f) Verifying the depth of the prepared bone site with the angled depth indicator performed to ensure that the selected implant length was fully seat without apical bone interference. Zygomatic implant (JDentalCare, Modena, Italy) placed according to the manufacturer's instructions. Figure (2g, h)

The multi-unit abutments (MUA) were installed with a shoulder preparation drill, thereby preventing bone irregularities that could jeopardize proper screwing. Subsequently, the flap was closed utilizing 3/0 silk sutures. A provisional prosthesis was placed for modification. The occlusal holes were adjusted to align with the predetermined location of the titanium cylinders, facilitating the smooth fitting of the prosthesis. The temporary prosthesis was attached to the titanium cylinders using cold-cure acrylic resin. The cold-cure acrylic resin was combined and applied to the occlusal holes, thereafter finished and polished.

Prosthetic phase

Typically, six months after surgery a high-density acrylic resin prosthesis with temporary coping were removed and the arch was scanned by intra-oral scanner according to the manufacturer's recommendation to be imported into additional software to allow creation of an open STL file and designing the final prosthesis. The fit and occlusion was checked using polymethyl methacrylate (PMMA) trial. All-ceramic implant supported fixed prosthesis with titanium framework used to replace the immediate provisional prosthesis. Figure (3)

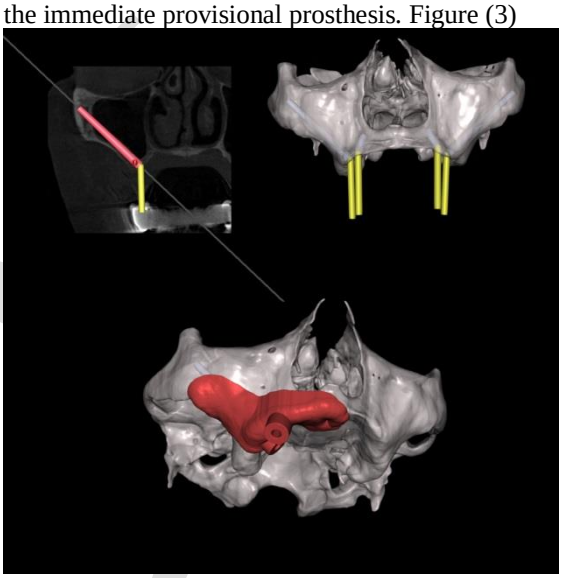

Figure (1): Pre-operative digital plan.

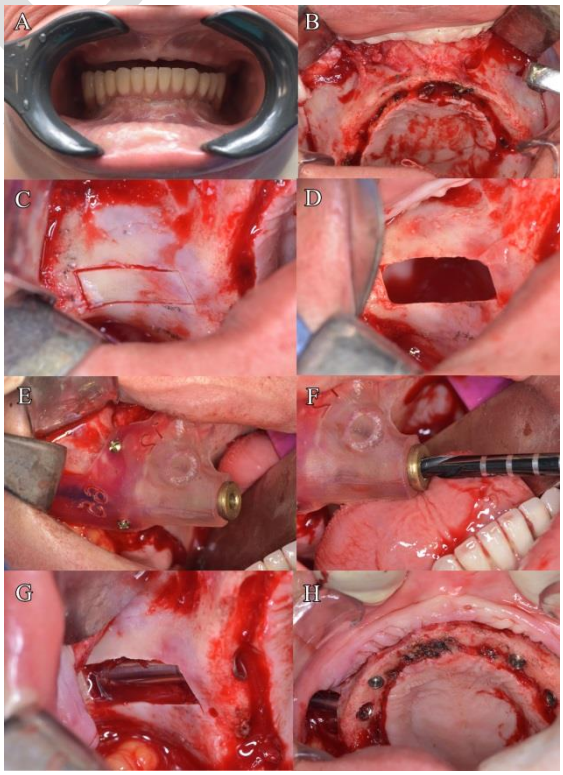

Figure (2): (A) preoperative picture **(B)** Full thickness flap **(C)** Lateral window marking **(D)**

Sinus membrane elevation **(E)** Fixation of surgical guide **(F)** Implant site preparation with dedicated drill for the zygomatic fixture **(G), (H)** zygomatic implant in place.

Figure (3):(A) Fixed provisional prosthesis **(B)** Digital intraoral impression **(C)** Digital designing of prosthesis **(D)** Polymethyl methacrylate (PMMA) trial **(E), (F)** final prosthesis

RESULTS

Demographic Data

A total of four patients participated in this study. In all patients two zygomatic implants were inserted, one on each side. Two additional conventional implants were placed for each patient in the anterior maxilla. The mean reported age of the enrolled patients was 51.50 ± 5.32 years, with age that range from 45.0 – 58.0 years old. A total of two male participants (50%) were enlisted in this study, opposite to two female subjects (50%). The male-to-female ratio of the study was 1:1.

The patients underwent zygomatic implant prosthetic rehabilitation for edentulism, due to severe maxillae atrophy. The selection occurred at the Outpatient Clinic of the Oral and Maxillofacial Surgery Department, Faculty of Dentistry, Alexandria University.

The implants were positioned in the spaces of the maxillary second premolars and the maxillary first molars.

Eight implants were placed; two implants with 4.3 mm diameter × 42.5 mm length were placed, three implants with 4.3 mm diameter × 45 mm length were placed, one implant with 4.3 mm diameter × 47.5 mm length was placed, one implant with 4.3 mm diameter × 50 mm length was placed and one implant with 4.3 mm diameter × 52.5 mm length was placed which were selected according to the ridge width and zygomatic bone width detected by CBCT preoperatively and the length of the zygomatic fixations were selected according to the CBCT images from the insertion point up to the clog point. All patients were followed up both clinically and radiographically for 6 months.

Operative Data

Based on the anaesthesiologist demand, all of the operated patients in this study were kept under observation in the hospital. All the patients were dismissed from the hospital after a single night stay.

Accuracy of virtual surgical planning

Postoperative evaluation of the accuracy of the virtual procedure was performed. The two-dimensional and three-dimensional deviation was obtained by subtracting the Actual postoperative model values from the virtual preoperative model ones. All of the linear measurements were in millimetres (mm), while angular measurements were in degree unit (°). Figure (4)

The mean linear deviations between virtually planned and actually placed implants at the coronal point was 1.49 ± 0.53, which ranged from 1.01 – 2.90. The mean linear deviations between virtually planned and actually placed implants at the apical point was 2.08 ± 0.55, which ranged from 2.89 – 6.89, as shown in (Table 1).

The angular deviations between virtually planned and actually placed implants are summarized in the. Mean angular deviation was 2.08 ± 0.55, which ranged from 2.89 – 6.89 (Table 2).

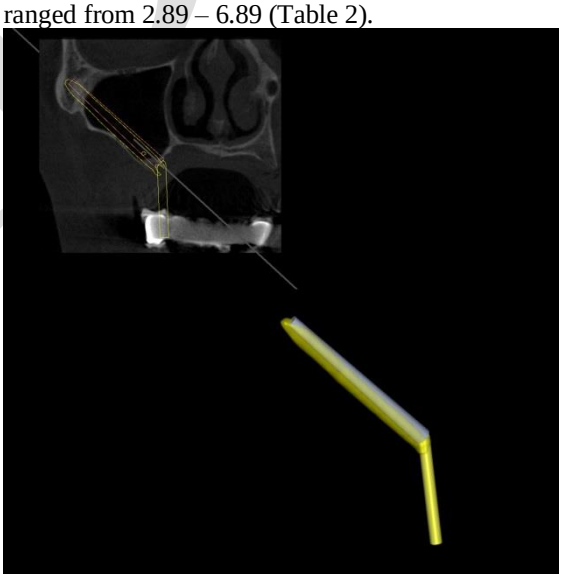

Figure (4): Measurement of deviation between planned and placed implants (yellow = placed implant, white = planned implant).

Table (1): Descriptive analysis of the studied cases according to coronal and apical deviations (n = 8).

Linear deviation	Min. – Max.	Mean ± SD.	Median (IQR)
Coronal	0.57 – 2.13	1.49 ± 0.53	1.53(1.2 – 1.9)
Apical	1.01 – 2.90	2.08 ± 0.55	2.16(1.8 – 2.4)

IQR: **Inter quartile range** SD: **Standard deviation**

Table (2): Descriptive analysis of the studied cases according to angular deviation (n = 8).

	Min. – Max.	**Mean ± SD.**	**Median (IQR)**
Angular deviation	2.89 – 6.89	4.59 ± 1.52	4.67(3.1 – 5.7)

IQR: **Inter quartile range** SD: **Standard deviation**

DISCUSSION

The discipline of guided implant insertion remains rather nascent. The scholarly discourse on this subject emerged in the early 2000s and has shown a significant surge in growth after 2020. The introduction of digital technologies into clinical practice in recent years may have contributed to this development. In the future, we can expect to see more literature on computer-assisted zygomatic implant surgery due to advancements in computer technologies specifically designed for surgical purposes, such as computer-aided design and computer-aided manufacturing (CAD-CAM), augmented reality (AR) and virtual reality (VR), deep learning networks, and surgical robots (11).

This study examines the three-dimensional precision of virtually guided zygomatic implant placement. It analyzes data obtained by comparing the pre-operative digital planning with the post-operative CBCT scan of the patients who underwent the treatment. The mean ±standard deviation were 1.49 ± 0.53 mm (coronal), 2.08 ± 0.55 mm (apical), and 4.59 ± 1.52 degrees (angular).

Chrcanovic et al., (12) conducted a study on cadavers to evaluate the accuracy of zygomatic implant guides. They found a significant difference in the angle deviation between the planned virtual surgery and the actual surgical results, ranging from 8° to 11°. According to Chrcanovi et al., (12) the average ± standard deviation angular deviation was 8.06 ± 6.40 degrees for the anterior-posterior view and 11.20 ± 9.75 degrees for the caudal-cranial view. According to Wang et al., (11) the average ± standard deviation of 3D deviations in clinical investigations on static computer-assisted zygomatic implant surgery were 1.29 ± 1.65 mm (coronal), 3.47 ± 2.17 mm (apical), and 4.39 ± 3.92 degrees (angular). Van Steenberghe et al., (10) reported a mean discrepancy of 2.0 – 2.5 mm for linear discrepancies and 3 degrees for angular displacements.

Given that the average length of the zygomatic implant is 45 mm, the surgical procedure's implant apex value can result in a linear discrepancy more than 1 mm when compared to the virtual design. One further disadvantage of guided surgical procedures is the challenge of keeping precise control over the bur and drill when milling the zygomatic bone. This is because the surgical mask can only provide feedback on the initial position of the alveolar bone ridge. In order to address this issue, Chow et al., (13) introduced a dual surgical guide consisting of a mucosa-supported component with two cylindrical bushes, and another component that, when securely attached to the first one, can effectively control the position of the bur apex during antrostomy. However, the limited size of the mouth cavity prevents the use of two surgical guides, which could potentially have a detrimental impact on the accuracy of the results.

Currently, there are two categories of computer-assisted zygomatic implant surgery: dynamic and static. Every approach possesses unique advantages and constraints (14). Dynamic surgical guide allows for real-time adjustment of drilling trajectories based on intraoperative conditions, such as limited mouth opening. Simultaneously, the entrance point, angulation, and drilling depth may be reliably verified and validated in real-time (15). Furthermore, the nearby anatomical features are visually presented on the screen throughout the operation, eliminating the necessity for preoperative model tests. Nevertheless, dynamic surgical guide does have some limits, such as the challenge of maintaining a stable handpiece and the need to often move between the navigation display and the operational site. This issue is further magnified when using lengthy drills for zygomatic implant surgery (16,17). In dynamic surgical guide, preoperative preparations, such as the installation of fiducial screws, are necessary. These preparations are more complex and time-consuming compared to static surgical guide (18). Another significant reason is the challenging learning curve associated with dynamic surgical guide, whereas static guided implant surgery has been found to have no impact on the learning curve, making it more accessible for beginners (19, 20).

As regards dynamic surgical guide. Wang et al., (11) reported that the mean ±standard deviation 3D deviations of clinical studies on dynamic surgical guide were: 1.61 ±0.89 mm (coronal), 2.37 ±1.11 mm (apical), and 2.89 ±1.69

degrees (angular). Overall, the coronal deviation of static surgical guide was less than that of dynamic surgical guide, whereas the apical and angular deviations of static surgical guide were greater. The utilization of static guides facilitated accurate placement of the entrance site on the alveolar ridge. Nevertheless, inadequate positioning or distortion during guide attachment can result in significant apical and angular deviations, which are also constraints of static surgical guide.

In comparison to freehand zygomatic implant placements. Gao et al., (21) found that the freehand placement accuracy of 14 zygomatic implants resulted in a coronal deviation of 6.11 ±4.28 mm, apical deviation of 4.98 ±2.66 mm, and angular deviation of 8.35 ±5.30 degrees. They observed a significant disparity between the intended and actual implant position when using freehand traditional surgery, particularly in the angular position. Grecchi et al., (22) conducted a study using cadavers to evaluate the precision of 20 freehand ZI placements. The measurements for the coronal, apical, and angular deviations were as follows: 2.04 ±0.56 mm, 3.23 ±1.43 mm, and 4.92 ±1.71 degrees, respectively. The accuracy of freehand placement was decreased in comparison to guided techniques. Utilizing digital technology has the potential to enhance the precision of zygomatic implant surgical placement and minimize the hazards associated with implant placement.

CONCLUSION

This study suggests that employing a bone-supported guide during surgery can achieve a significant level of precision, even in edentulous patients. Despite the inherent difficulties associated with osteotomy in achieving optimal driving angles owing to the length of the zygomatic implant, the guided zygomatic implant procedure exhibited minimal differences between the planned and actual implant placements. Additional research and randomized clinical trials comparing guided surgery to free-hand surgery are essential to assess the reliability of this method.

CONFLICT OF INTEREST

The authors claim to have no conflicts of interest.

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