



Assessment of the accuracy of computer generated surgical guide stent for implant placement using the All On Four concept

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Abstract

Objective: The aim of the current study is to evaluate accuracy of computer and image guided implant placement using 3D printed Stereolithographic Surgical Guiding Template for the all on four treatment option configuration concept.

Patients and methods: *six patients with completely edentulous maxilla were scanned with Cone-beam computed tomography (CBCT). Data was used for virtual placement, and production of surgical guiding template (SGT) with rapid prototyping for transfer of virtual plan to surgical field. Each patient received four implants each, making a total of 24 implants. Immediate post-operative CBCT was taken for all patients and the acquired image data set of each patient was merged with the pre-operative set to evaluate amount of error/ deviation between virtual and post-operative implants.*

Results:

The angular deviation showed a mean of 5.36° regardless of implant site (anterior or posterior) and with a mean of 3.65° and 7.07° for the anterior axial implants and posterior tilted implants respectively.

Linear deviation showed height discrepancy (in coronal plane) a mean of 1.65mm (SD1.14) and 1.8mm (SD1.38) for coronal and apical ends of anterior implants and a mean of 1.08mm (SD0.64) and 1.25mm (SD0.57) for the coronal and apical ends respectively of posterior implants.

Conclusion: *Computer guided implant placement using this treatment protocol proved to be accurate, with significant improvement in accuracy values of linear and angular measurements and revealing significant accuracy in the posterior implants more than the anterior ones, even though the results are promising they are error values nonetheless a safety margin should be considered when attempting computer guided implant treatment planning. Relevantly the cause of these errors is identifiable and prone for quantification, improvements and further investigation.*

Keywords: *3D changes, Maxilla, edentulism, computer guided implant, linear deviation, angular deviation.*

Introduction

Complete edentulism is a common condition of the elderly patients which can be the result of many factors such as poor oral hygiene, dental caries, and periodontal disease. There are also those patients who face edentulism due to a terminal non-restorable dentition. The edentulous condition has been shown to have a negative impact on oral health-related quality of life¹. The chief request of the edentulous patient is the possibility of a fixed alternative to the removable prosthesis. Prosthodontists are often faced with cases where the bony and soft tissue supporting structures of the completely edentulous patient are unsuitable to receive and support a prosthesis, in the late 1970s Brånemark and colleagues demonstrated the safety and efficacy of the implant-borne prosthesis². The number of implants used to support a denture and rehabilitate the edentulous maxilla has always eluded researchers.

Continuous experimental work has been done to investigate the ideal endosseous infrastructure configuration, number, type and positioning to provide efficient support for the full arch prosthesis. Considering stress distribution factors, four to six implants were considered suitable for supporting a full arch prosthesis while the placement of three implants is poor stress distribution³, also studies has

shown that individuals carrying a higher number of implants have a significantly higher progressive bone loss according to Fransson et al. 2005⁴ therefore 4 implants is regarded as a suitable number.

The All-on-4 standard rehabilitation concept uses four implants to support fixed total rehabilitation; with the anterior implants placed in an axial position inserted in lateral or central incisor positions and the posterior ones tilted up to 45degrees inserted to be emerging in the second premolar/first molar region. The use of implant tilting in the maxilla has been demonstrated to be an alternative to bone grafting⁵⁻⁸. By tilting the distal implants, a more posterior implant position (emerging at the second premolar/first molar region) can be reached reducing the cantilever, and improved implant anchorage can be achieved by benefiting from the cortical bone of the wall of the sinus and the nasal fossae.

Computer guided surgery offers the chance to accurately formulate a treatment plan and its execution with heed and precision⁹.

Therefore, the aim of this study was to evaluate accuracy of computer and image guided implant placement using 3D printed Stereolithographic Surgical Guiding Template in the all on four treatment option configuration concepts.

Patients and Methods:

Ethical Aspects:

This study's protocol was approved by the ethical committee of the College of Oral Surgery and Dental medicine, Cairo University. All patients signed an informed consent in order to participate in this study.

Patient Selection:

Six patients were selected from the outpatient clinic of the department of Oral and Maxillofacial Surgery, College of Oral Surgery and Dental Medicine, Cairo University. Patients' age ranged from 54 to 75 years. Patients were considered for this study if they fulfilled these inclusion criteria (1) Patients who had completely edentulous Maxilla and sought out fixed alternatives to the removable prosthesis, (2) Patients free of systemic conditions or were controlled, (3) Patients with sound and continuous maxilla contour and homogenous healthy bone trabeculae, and no evidence of bone deficiencies, diseases, infections nor signs of inflammation or swelling, (4) Patients with healthy mucosal covering of the residual alveolar ridge. Exclusion criteria were (1) Patients with uncontrolled or compromised systemic conditions (renal failure, liver failure, Viral hepatitis (B & C), uncontrolled diabetes, Radiotherapy, hyperparathyroidism, or on anti-coagulant therapy with INR higher than 1.4, (2) Patients with Bone diseases or conditions that may compromise future bone healing, osseointegration and implant placement outcome (Osteoporosis, Bisphosphonates therapy, Chemotherapy, Radiotherapy), (3) Patients with mouth opening less than 40 mm were excluded from the study (to accommodate surgical instruments), (4) Patients with any muscle dysfunctions, TMJ disorders, pathologies or bony asymmetry in the oral and maxillofacial region, (5) Patients with any signs of inflammation, swelling or ulceration of the mucosal

covering of the residual alveolar ridge, (6) Patients with maxillary bone height less than 10 mm and alveolar crest width less than 4 mm, in the canine to canine region.

Preoperative Workup and CBCT Imaging:

First step was the production of the RO template, which is a duplicate of the patients' pre-existing dentures prosthesis. If the dentures were judged to be ill-fitting and unstable or there were none to begin with a new removable complete denture was fabricated. Then the dentures were placed in Polysiloxane impression material to create a mold, and the denture boxes were used as a flask. After removing the dentures, and with the use of a mixer gun, X-resin [CT DVT Material] was injected to fill the impressions spaces. The denture flasks were closed and pressed, excess was removed and were left on the bench to set. The newly fabricated RO templates were checked for irregularities, if any were present, they were adjusted or remade, then the excess material was removed. All patients underwent CBCT scanning with the newly fabricated RO template that was given to the patient to wear and bite against the mandibular denture or dentition to ensure maximum compression of soft tissue. The scan machine used was I-Cat Precise scanner [scan time was 4 seconds and voxel size 0.3, x-ray radiation emission with 120 KV and 5 mA]. The scanned data of all patients was collected as Digital Imaging and Communication in Medicine [DICOM] file formats, and imported into the CT processing 3D software [Mimics innovation suite 15.0], images were processed to create 3D virtual objects of the maxilla, localization of the nasopalatine nerve canal and 3D generation of the RO template.

3D virtual implants were sketched and modeled according to accurate manufacturer's scale of the Zimmer Swiss implant system (Fig.1) using the 3D modeling software tool [Solidworks Premium 2013, Dassault Systems]. Measurements of the projecting distance of the full sequence hub-less drills, starting from the lower aspect of the contra-angled low speed hand-piece head to the tip of the drills were taken in millimeter. Calculating implant length and soft tissue thickness, measured at prospective implant sites on the CBCT images, were subtracted from the projecting distance. Then the remaining was the length allowed in which the virtual sleeve height can be designed. The virtual sleeve is the fitting component of the metal sleeve where the surgical guides (SG) sequence fits. Using Solidworks Premium 2013 software these calculations were sketched and the 3D virtual sleeve was designed and attached to the virtual implant. The implants were virtually placed in the most suitable location in reference to the teeth position in the RO template as well as anatomy of the vital structures of the maxilla [content of the nasopalatine canal and floor of maxillary sinus] (**Fig.1**). Central incisors, lateral incisors or canines were prospective sites for the 2 vertical parallel anterior implants and 1st or 2nd premolar teeth for the 2 posterior distally tilted implants [degree of angulation: 28-40°], which were then revised and adjusted in all views of the CBCT images [Cross-sectional view, Sagittal plane, and Axial plane] and the 3D virtual view (**Fig.1**).

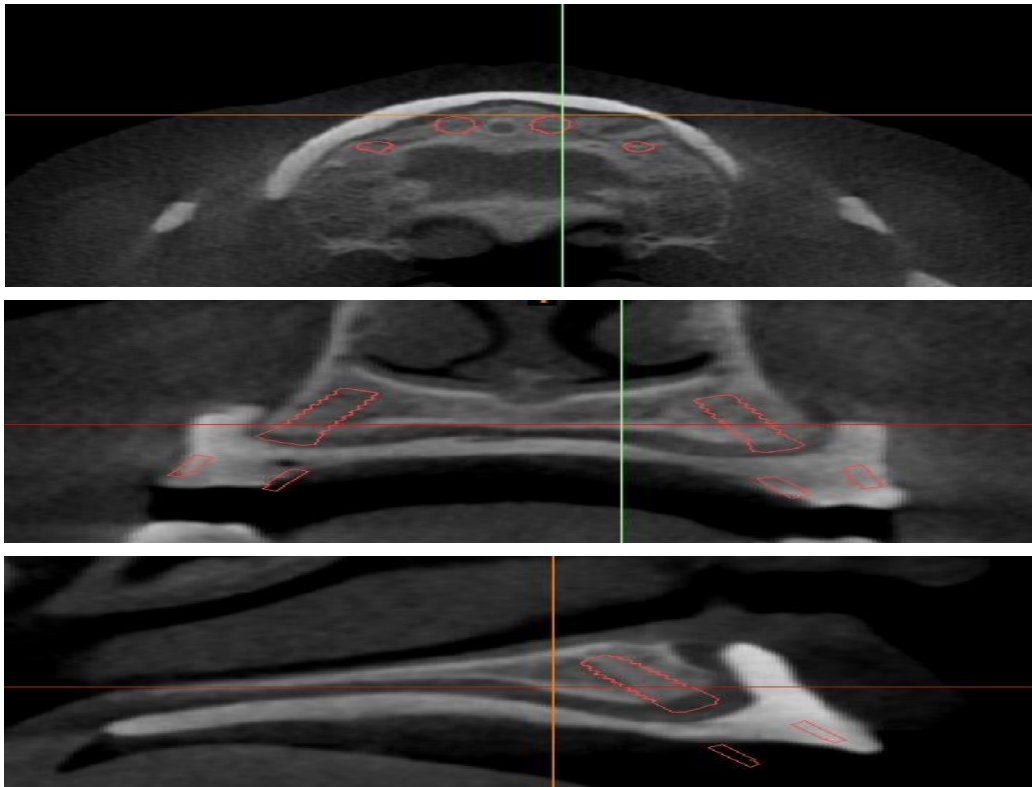
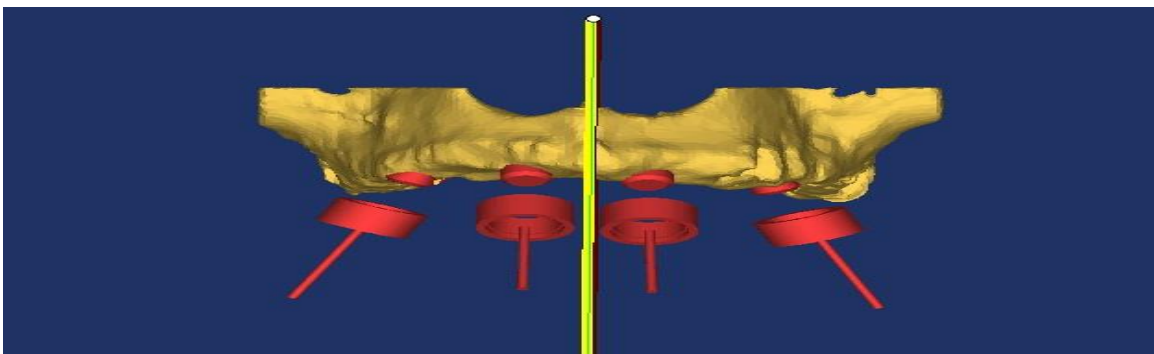


Fig. 1: virtual implant placement, and adjustments op implant positioning in regard to vital anatomical structures. Positions were revised on all CBCT planes [Cross-sectional view, Sagittal plane, and Axial plane].

The final SGT was designed by adding and merging the 3D objects of the virtual sleeves and the 3D RO template. Virtual mono-cortical fixation mini-screws with screw sleeves were included in the design for template stability (**Fig.2**).



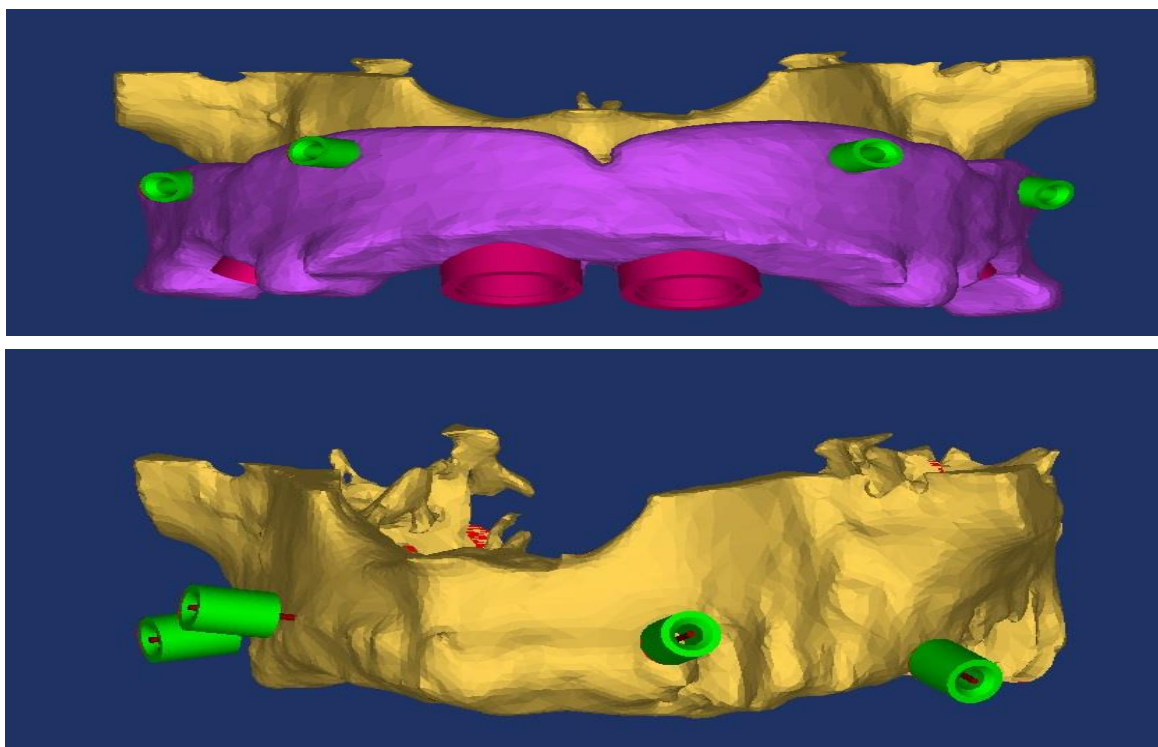


Fig. 2: a. Maxilla and virtual implants, metal sleeves (red) and screw guides (green) placed.



Fig. 3: the computer-generated final design 3D object of the SGT (Left), the 3D printed SGT with fused deposition modeling (FDM) technique of rapid prototyping.

The RO template was trimmed to allow SG and implant drill advancement as well as resting of the hand-piece head without any interference that may deviate the virtually planned drilling path. The template

was then exported as an STL file format (**Fig.3**), for 3D printing, fused deposition modeling (FDP) was the method of printing and the device used was MOJO desktop 3D Printer from Stratasys Company, printing material medical grade Acrylonitrile butadiene styrene (ABS) (**Fig.3**).

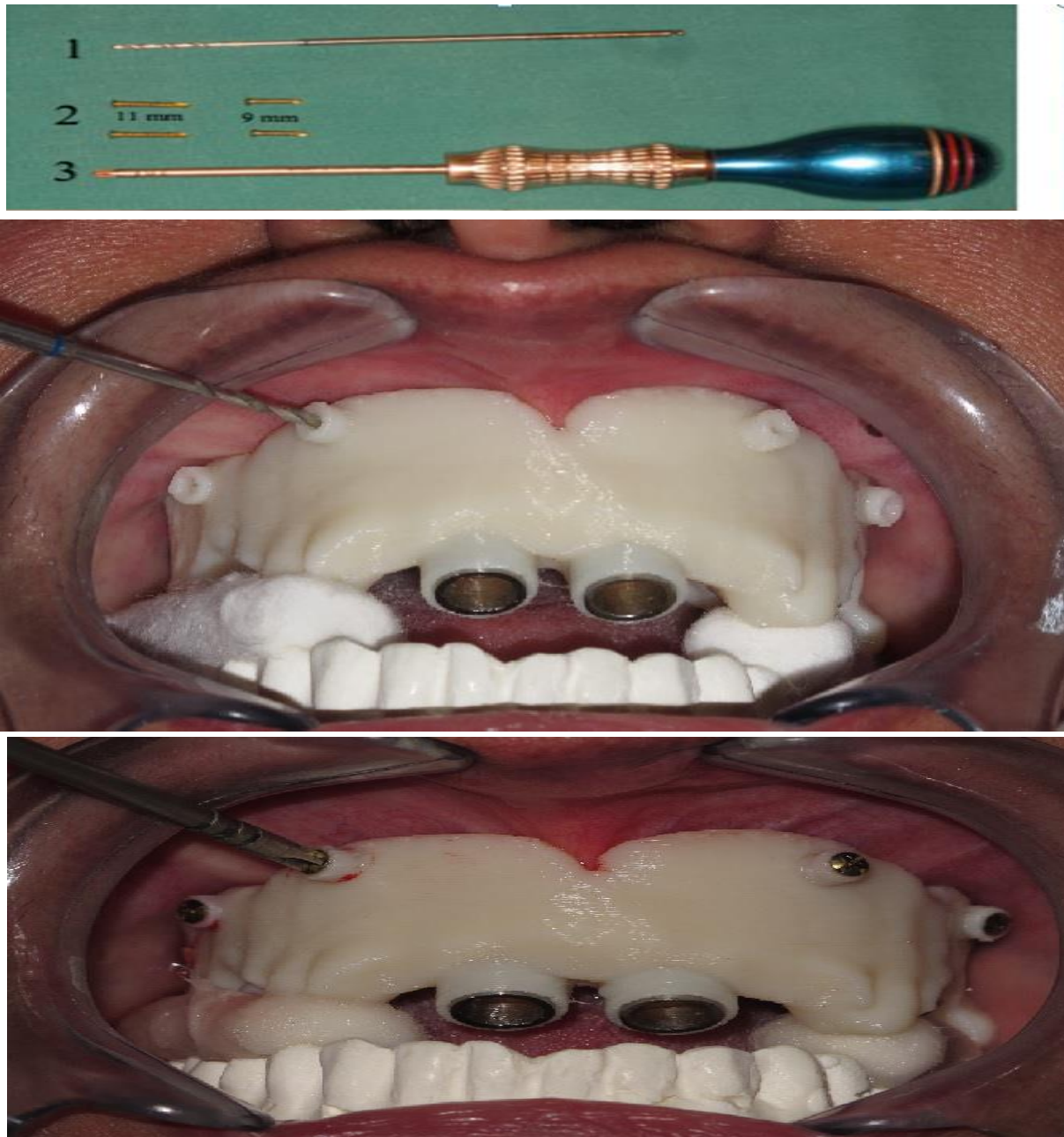


Fig. 4: showing fixation screws armamentarium, drill, mini screws, screw-driver, mono-cortical drilling procedure, screw placement and fixation.

Computer guided implant placement:

All implants were placed with flapless surgical technique, under local anesthesia. The SGTs and the opposing mandibular dentures were disinfected with 2% cydex solution. All patients were given Chlorhexidine mouth Rinse for preoperative disinfection of the oral cavity. SGTs were placed in occlusion against the mandibular dentition or denture to ensure maximum compression of soft tissues (Fig.4). SGTs were secured using mono-cortical mini-screws that were drilled and placed through screw guides that were previously placed during software planning procedure (Fig.4). Metal sleeves were placed in their fitting parts inside the SGT, the different sized custom-made surgical guides were interchanged according drill diameter and full sequence drilling diameter of each implant was performed (Fig.5)

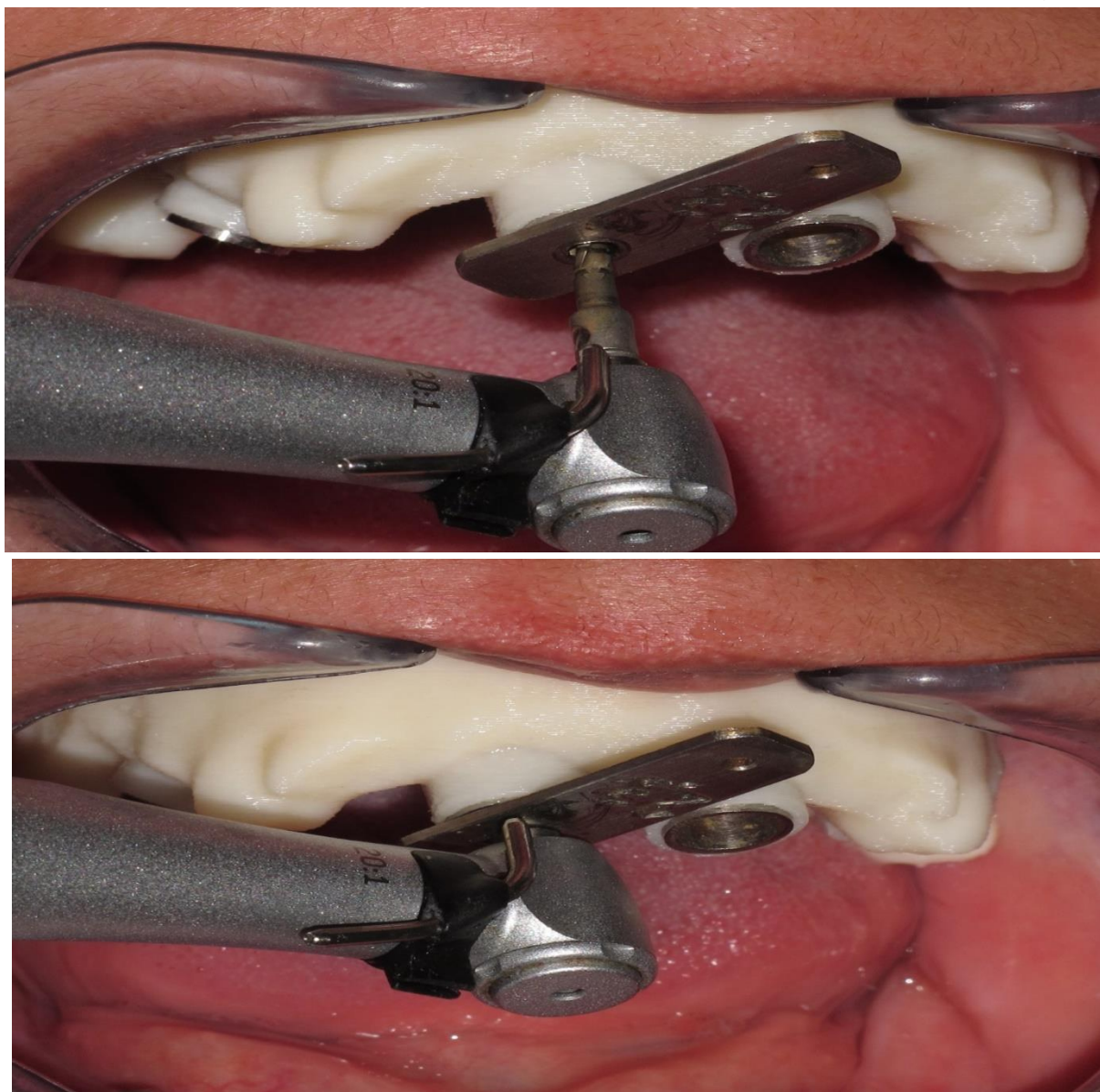


Fig. 5 showing implant site preparation and osteotomy, the drill is advanced through the surgical guide that is resting inside the metal sleeves.

according to the zimmer implant manufacturer's instructions. After the drilling process was concluded, the Mono-cortical mini screws were unscrewed, and the SGT was removed. Then the implants were placed and secured then the surgical field was irrigated with normal saline and cover screws were placed (Fig.6), and that concluded the implant placement surgical procedure.

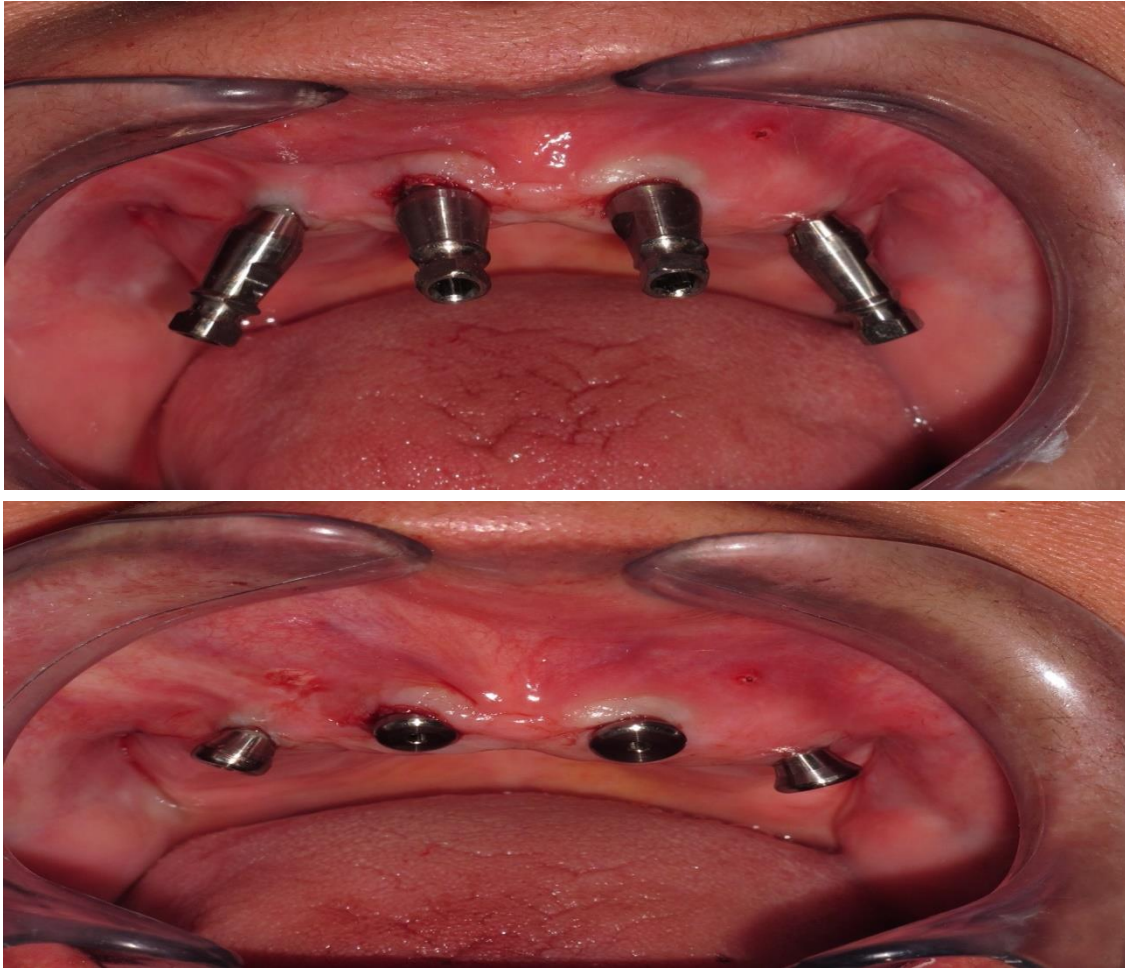


Fig 6: implants placed(above) and cover screws (below)

Postoperative management:

Postoperative OPG were taken for all cases immediately after surgery for preliminary evaluation of the placed implant positions relative to the vital anatomical structures (Fig.7). Patients were prescribed oral mouth Chlorhexidine 0.12% for maintenance of oral hygiene; patients were prescribed 75 mg Declofenac Sodium intra-muscular injection every 12 hours for the first 24 hours and then 50 mg Declofenac Potassium tablets every 8 hours for the 72 hours that followed for pain management. In some cases Antibiotic: ampicillin 825mg, clavulonic acid 125mg Tablets every 12 hours for 7 days were prescribed for patients with systemic conditions that required prophylactic antibiotic management. All patients were sent for immediate postoperative CBCT scans for postoperative accuracy assessment and

evaluation. The Second day after surgery all patients were recalled for clinical evaluation to check for any signs of swelling, redness or bleeding or loosening of the cover screws. Later after Three month, was the commencement of Prosthesis fabrication procedures. Delivery was approximately 1-2 weeks from the 3-month period.

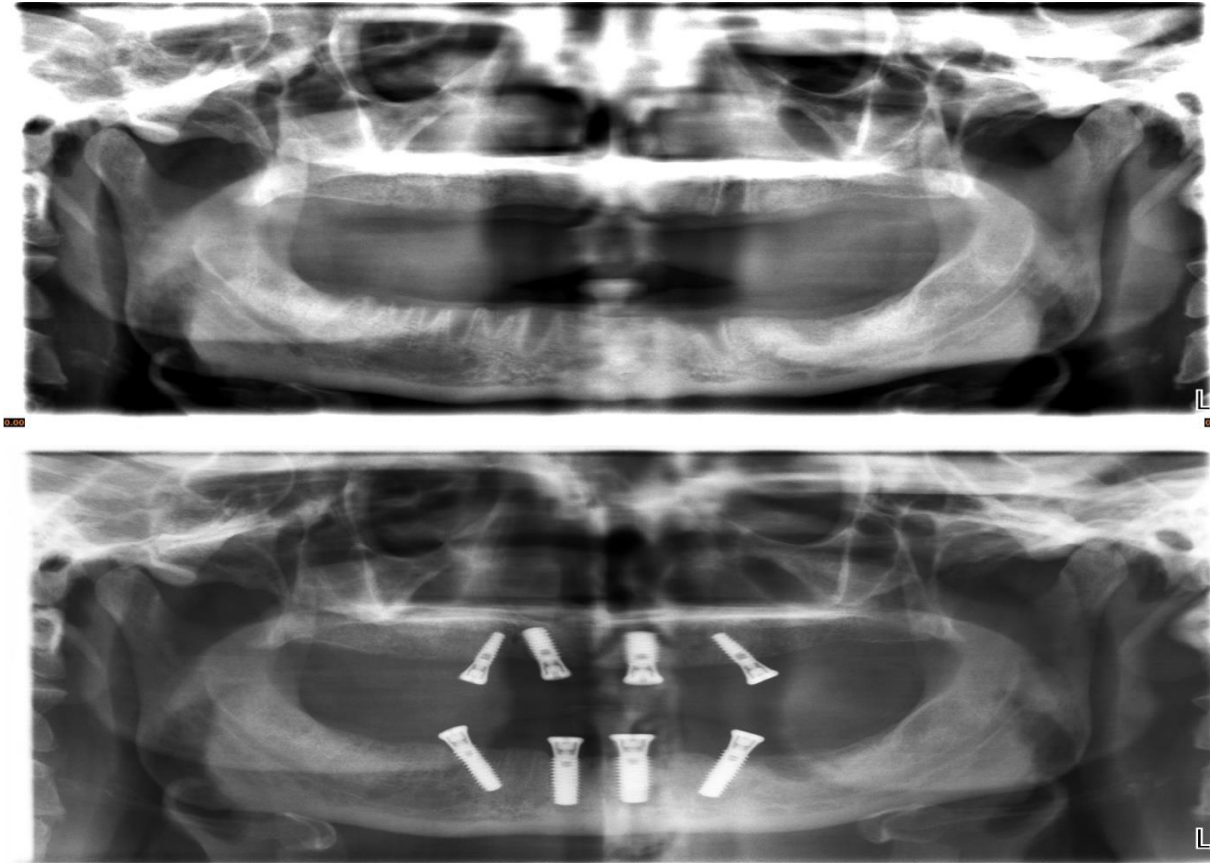


Fig. 7: showing preoperative OPG (Top) and postoperative OPG (below).

Image registration:

The postoperative CBCT scan data were collected in the form of DICOM file format and imported into [mimics innovation suite 15.0] software program. Superimposition of both the preoperative and postoperative data sets was done using an image registration feature called point registration, which relied on anatomical landmarks in the maxilla that was identified in both data sets (**Fig. 8**) This process was repeated for all patients. The superimposed images were then used to identify the preoperative virtual implants and the postoperative placed implants. Relying on radiopaque values of the placed implants, segmentation masks were identified and used to generate 3D objects of the postoperative implants (Fig.9). For each patient there was 2 sets [pre and post] of the implants 3D objects that can be viewed in the 3D environment window (**Fig.9**) as well as their outline in all CBCT views [sagittal, coronal, axial and cross-sectional views]. For each implant object [pre and post] virtual object axes were

identified, and intersection of these axes at the implant neck was identified as the coronal end, and at the apex as the apical end (**Fig.10**).

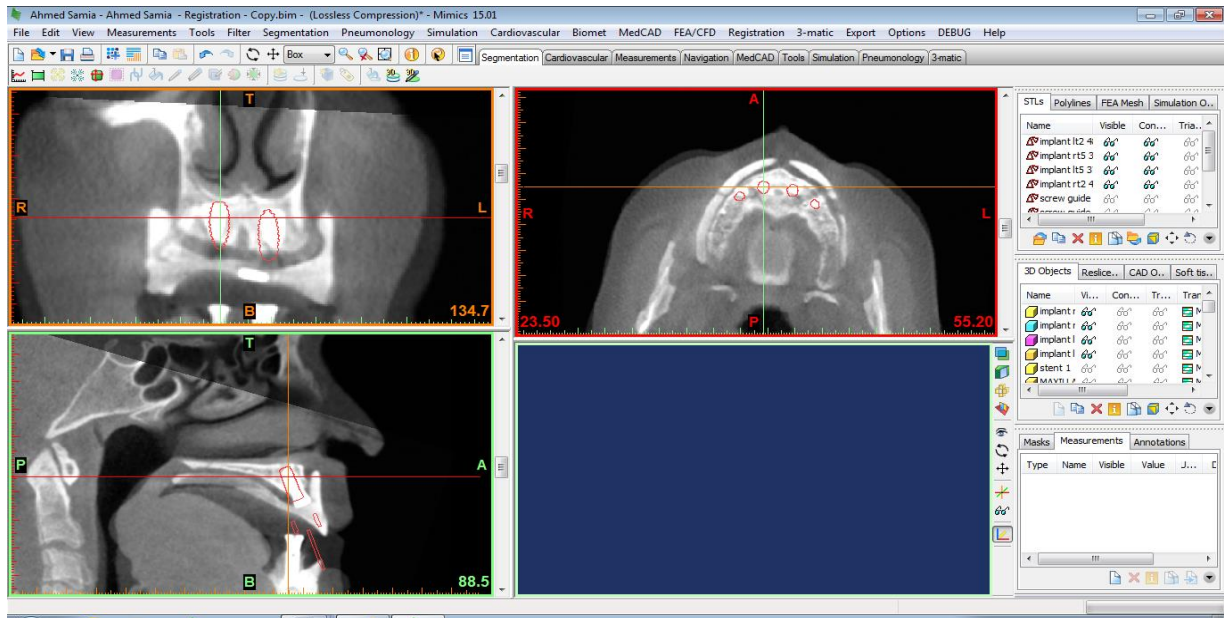


Fig. 8 Superimposition of the pre and postoperative CBCT scans showing the preoperative implants outline in red and postoperative implants position in coronal, sagittal and axial cuts, image caption from mimics software.

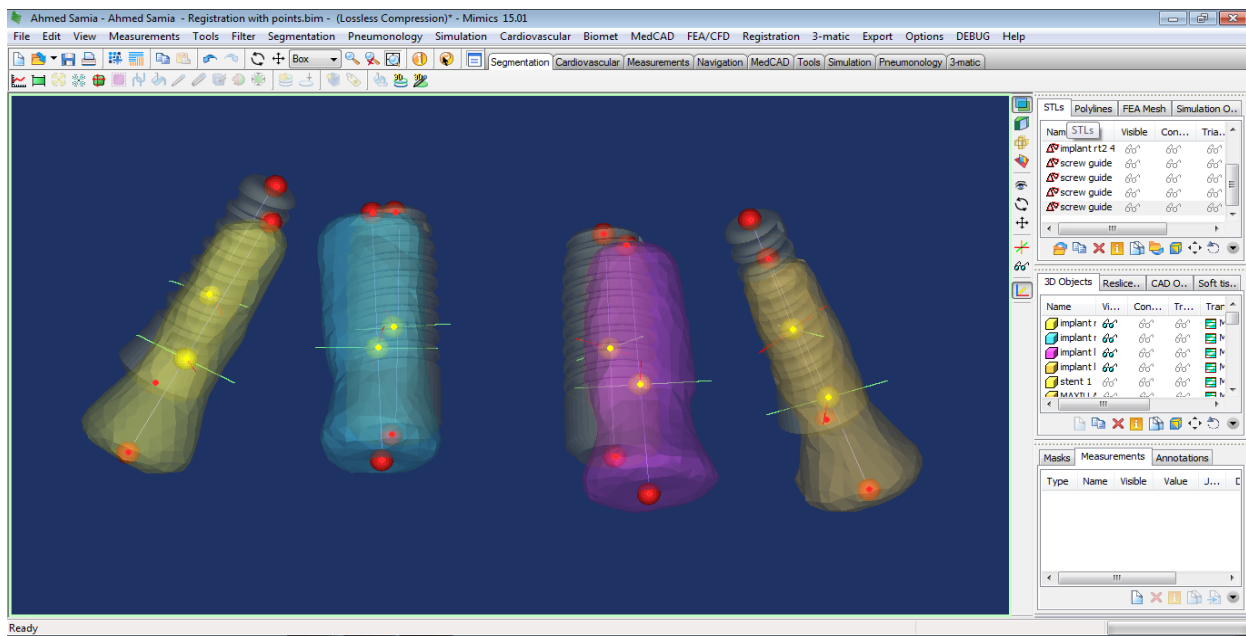


Fig. 9: Apical, coronal, center points and x,y and z axes were defined for each implant in the 3D environment, toggle transparency was enabled for a clearer display.

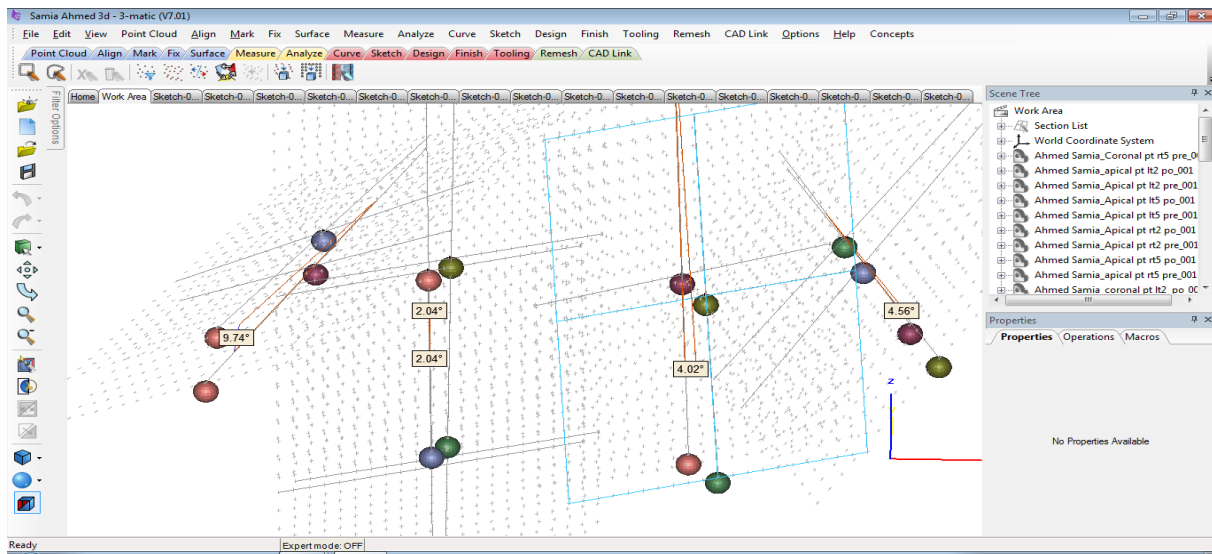


Fig.10: Image caption from 3-matic software to show the angular deviation between preoperative and postoperative implants axes

Data Collection and Accuracy Evaluation:

Different methods were assigned to determine the postoperative deviation of all each implant from its original preoperative counterpart:

- The first was axial deviation, measuring the angle between the pre and postoperative implant 3D object axes (**Fig.10**).
- Linear 2D measurement of each preoperative point to its postoperative counterpart on CBCT planes in 3 explicit planes (**Fig11,12**):
 - a. Coronal View: to determine Height Difference.
 - b. Sagittal View: to determine Anterio-Posterior displacement.
 - c. Cross-sectional View: to determine Bucco-lingual displacement.

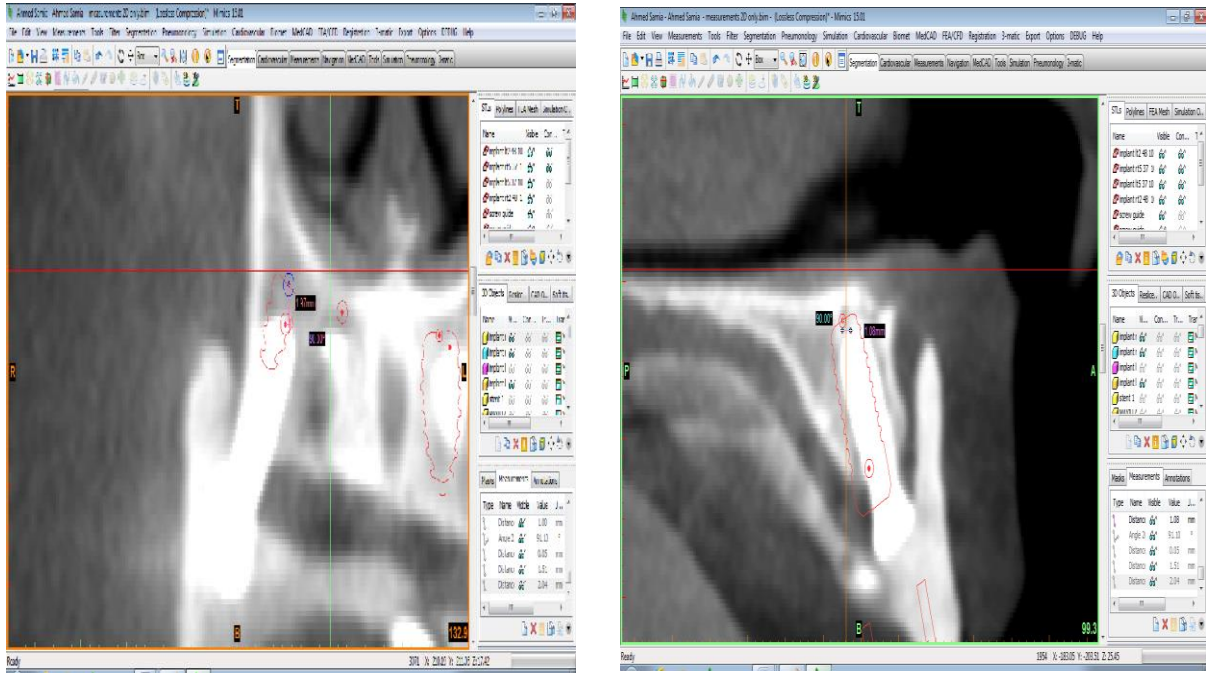


Fig.11 left, showing height difference of right posterior implant measured between two apical points in coronal view and right showing the Anteroposterior displacement of left anterior implant measured between two apical points in the sagittal view.

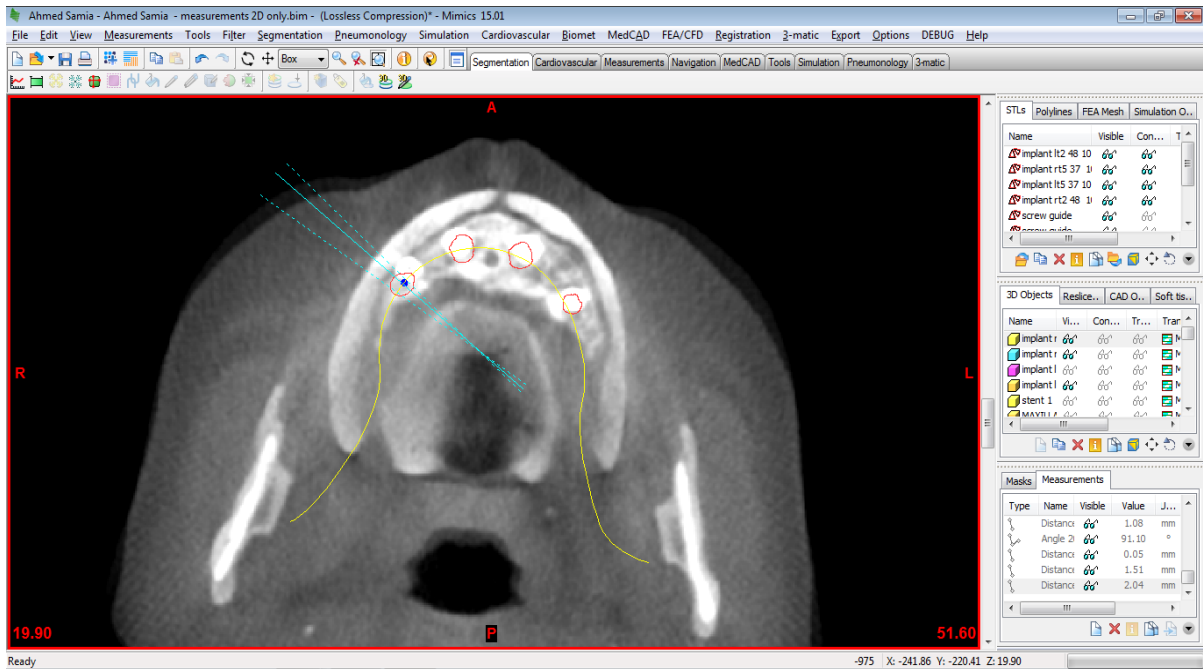


Fig.12 showing the Buccolingual displacement of all implants in the axial view, online resilience enabled (yellow outline), area of interest (blue outline) at the right posterior implant.

Statistical Analysis:

Data was collected, tabulated and assessed by Microstat7 for windows statistical package (Microstat Co) the following statistical tests were made to assess the accuracy of computer guided implant placement. Independent student “t” was used to compare between selected parameters, Two-way ANOVA was used to compare virtual and actual values in different levels followed by LSD calculation for paired comparisons. Difference was considered statistically significant when $p < 0.05$.

Results:

1. Clinical results:

No implants failed, no peri-implant pathology in all cases, all implants healed properly. The purpose of computer guided Implant placement plan to avoid vital anatomical structures was a 100% success as there was no injury to nasopalatine canal or maxillary sinus perforation.

2. Statistical results:

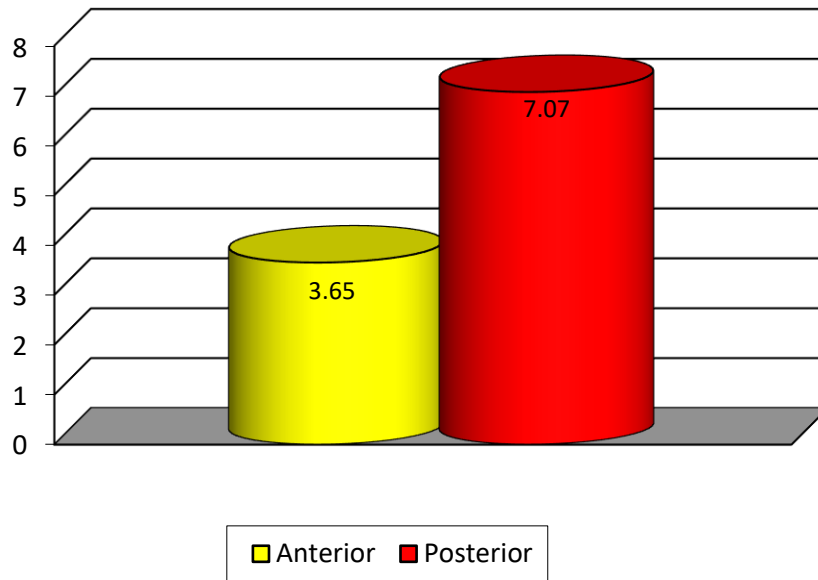
- A total of six patients with completely edentulous maxillae were selected from the outpatient clinic, Removable Prosthodontics Department, faculty of oral and dental medicine, Cairo University.
- Patient’s age ranged from 55-75 years.
- A total of 24 implants were placed, 4 for each patient (2 anterior axial implants and 2 posterior tilted implants).
- Clinically, the success rate of implants was 95.8%, where 1 of 24 implants failed to osseointegrate and was lost after three months. In the postoperative CBCT of this patient all implants showed bodily deviation to one side suggesting the cause of error is improper surgical stent positioning which caused buccal plate perforation and subsequent failure of this implant. Free hand insertion of implant was planned after three months of healing for this patient and prosthetic preparations were done.

Summary of the results:

I. Angular deviation:

The angular deviation showed a mean of 5.36° regardless of the implant site (anterior or posterior) and with a mean of 3.65° And 7.07° for the anterior axial implants and the posterior tilted implants respectively.

Angular Deviation	Anterior		Posterior		"t"	Probability
	Mean	St Dev	Mean	St Dev		
	3.65	1.54	7.07	3.29	3.264	0.002 *



Bar chart showing mean values of angular deviation at the anterior and posterior areas.

II. Linear deviation:

1. Comparing the results of the 24 implants with regard to the implant end and regardless of CBCT Plane:

The overall deviation produced regardless of the implant site (Anterior or posterior) in all the CBCT views (coronal, sagittal and axial) showed a mean of 1.18mm (SD 0.9) and 1.24mm (SD 0.92) for coronal and apical ends respectively which show statistically insignificant difference.

2. Comparing the results with regard to the implant end in different CBCT planes regardless of the site (Anterior or posterior):

The height discrepancies from linear measurements measured in the coronal plane showed a mean 1.37mm and 1.53mm in coronal and apical ends respectively

The anteroposterior displacement measured in the sagittal plane showed a mean 1.13mm and 1.37mm in coronal and apical ends respectively.

The Buccolingual displacement measured in the axial plane showed a mean of 1.04 mm and 0.9mm in coronal and apical ends respectively.

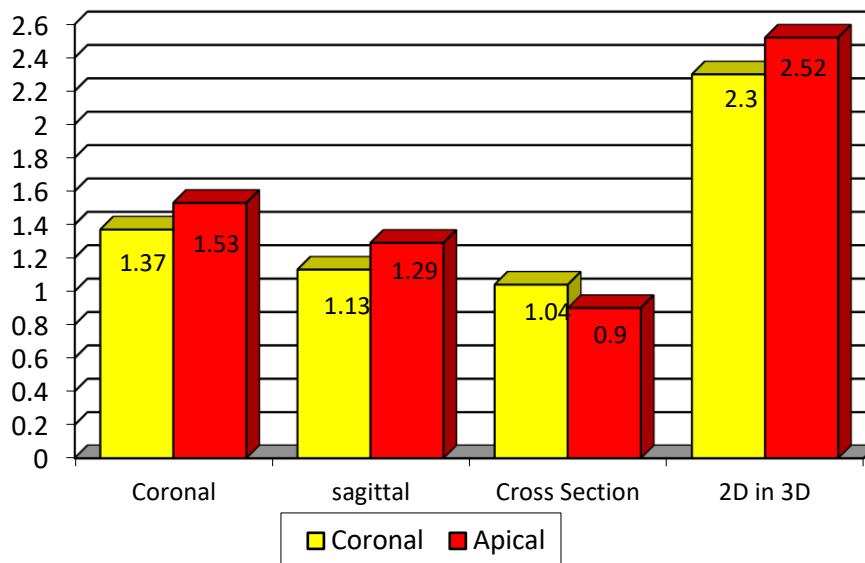
Error in linear deviation measured in the 3D environment showed a mean of 2.3 mm and 2.52mm for the coronal and apical end respectively.

3. Comparing the results with regard to the implant end (coronal and apical) and implant site (Anterior and posterior) in all CBCT views (coronal, sagittal and axial views):

The height discrepancies from linear measurements measured in the coronal plane for the anterior implants showed a mean of 1.65mm (SD1.41) and 1.8mm (SD1.38) for the coronal and apical ends respectively, and for the posterior implants a mean of 1.08mm (SD0.64) and 1.25mm (SD0.57) for the coronal and apical ends respectively.

The anteroposterior displacement measured in the sagittal plane for the anterior implants showed a mean of 1.02mm (SD0.66) and 1.11mm (SD0.75) for coronal and apical ends respectively, and for the posterior implants showed a mean of 1.24mm (SD1.02) and 1.46mm (SD0.98) for the coronal and apical ends respectively.

The Buccolingual displacement measured in the axial plane for the anterior implants showed a mean of 0.94mm (SD0.77) and 0.94mm (SD0.73) for the coronal and apical ends respectively, and for posterior implants showed a mean of 1.14mm (SD0.60) and 0.86mm (SD0.70) for coronal and apical ends respectively.



Bar chart showing mean values of all coronal, sagittal, cross section, 3D measurements regardless of the implant area.

Discussion:

The use of minimally invasive technique (flapless technique) is to maximize patient comfort by avoiding traumatic injury to the tissues and by eliminating the flap elevation and possible consequences of infection, dehiscence and necrosis and meanwhile providing dental implant success rates equal to conventional techniques as reported by Shibli et al, (2008) in his study [10].

Although Flapless implant surgery has several advantages which include preservation of soft tissue architecture, hard tissue volume at the region, reduced surgical time, improved patient comfort and accelerated healing, the approach has some disadvantages which include the surgeon's inability to visualize anatomic landmarks and vital structures, the increased risk of malposed angle or depth of implant placement which were eliminated by the use of computer guided implant placement for presurgical analysis and 3d virtual implant planning .

In terms of safety and accuracy, the clinical application of Computer assisted surgery was found to enhance both aspects in dental implantology [11-13] where Virtual planning permits three-dimensional analysis of implant position thus optimizing intra- and postoperative outcomes, reducing surgical morbidity and improving the predictability of the proposed treatment plan.

The treatment plan previously established on the computer software was transmitted to the three dimensional printing system that creates the stereolithographic guide template which provide benefits in the insertion of multiple implants particularly in totally edentulous jaws where no anatomical landmarks exist for the surgeons reference, especially when applied in a flapless fashion, via the mucosa supported guides, a significant drop in the surgery duration and postoperative complications was observed.

Six patients with completely edentulous maxilla were selected for the study, each patient received four implants with a total of 24 implants. They were placed using a computer guided approach using a CBCT-derived mucosa supported stereolithographic (SLA) surgical guide stent.

As the production of SLA guides is performed on the basis of a segmentation procedure according to the tomographic gray density, any compromise of the image quality may jeopardize the reliability of the actual surgery by inducing deviations in the physical transfer of the planned virtual implants following the maneuver of Dhore et al, (2009)¹⁴ As the SLA guide itself is a digital copy of the scan prosthesis.

In this respect the CBCT-derived mucosa supported guide used in this study was produced using a flat panel detector which allows better segmentation and three-dimensional model reconstruction capability for SLA guides¹⁵. Great improvement in data acquisition efficiency, spatial resolution, and spatial resolution uniformity are the advantages of the use of flat panel detector.

CBCT provides a volumetric data acquisition where the whole volume of the scanned object is acquired through a pyramid or cone-shaped beam of X-rays (cone beam) [16] resulting in high accuracy 3D image with high accuracy in linear measurements [17] submillimeter resolution [18] and other advantages as compared to CT including significant lower radiation exposure, increased spatial resolution and better versatility of software [19].

In an attempt to make the pre and postoperative radiographic data uniform, patients were adjusted on the same machine using the head restraint technique, where the seat, head restraint, chin rest and vertical and horizontal laser lines are adjusted according to each patient. This eliminated the possible errors of the data extracted during the planning of surgery; however, one of the limitations on the CBCT image was the artifacts produced from metallic restorations⁶, which was not a factor of concern in this study since all patients were completely edentulous and had no metallic restorations.

A critical factor that was carefully evaluated during planning in order to eliminate error and deviation, was the existence of adequate interarch space of at least 40 mm. This is important to ensure proper instrumentation, and accordingly patients who did not fulfill this requirement were excluded from the study.

The Surgical guide templates used in this study were 3D printed from an STL formatted file using the fusion deposition modeling, a technique of prototyping that provides accurate results as found in literature [21] using ABS material, a homogenous readymade radiopaque material called X-resin (barium sulphate-acrylic mixture).

In a study conducted to evaluate the accuracy of prototyped models by Poukens et al, (2003) [22] who simulated osteotomies and placement of distraction devices performed on rapid prototyped models in distraction osteogenesis for the correction of cranio-maxillofacial deformities in the midface, mandible and alveolar ridge using surgical guides to transfer the surgical planning to the patient in the operating theatre. Accuracy, reduced operating time and superior preoperative treatment planning was concluded. Another study conducted to evaluate the accuracy of prototyping in implant surgery was conducted by Gateno et al, (2003) [23], who studied the fit precision of stereolithographic surgical splints and that of conventional acrylic resin splints, their results indicated that stereolithographic splints had a high degree of accuracy of seating, thus enabling transfer of virtual treatment plans directly to the patient during surgery.

According to Perez et al., (2012) [24] Fusion deposition Modeling materials such as ABS suffered damage from high heat and autoclave machines used for sterilization, then glutaraldehyde solution was the suitable alternative used in this study for disinfection of temperature sensitive materials like that.

Referring to the use of preoperative antiseptic mouth wash solution before surgeries like chlorohexidene 0.12%, proved to have a substantial effect in reducing the number of bacteria [25], it was used in this study as a preoperative antiseptic.

Referring to data analyzed by Schneider et al. (2009) 26 in a systematic review to assess the accuracy and clinical applications of guided implant surgery, early surgical complications were observed in 9.1% of 428 patients or 2.5% of 1581 implants, by comparing to our study only one of the twenty-four implants placed did not osseointegrate and was lost after three months from surgery, presenting a 4.2% clinical failure rate. In the postoperative CBCT of this patient all implants showed bodily deviation to one side suggesting the cause of error was improper surgical stent stabilization which caused buccal plate perforation and subsequent failure of this implant.

The reliability of CBCT –derived mucosa supported surgical guides in terms of linear and angular deviations between the planned and placed implants was analyzed in this study.

The evaluation method carried out in this study was the measurement of deviation in the postoperative virtual implant position from the preoperative virtual implant planning concerning the coronal and apical linear deviation and the interimplant angle. That was done by superimposing the CBCT images of pre-operative virtual planning with the postoperative actual implants placed in the patient's mouth. Image registration used in this study was a landmark based intrinsic method provided by the software (mimics innovation suite 15.0) called point image registration, it depends on determining fixed points in the skeletal anatomy of the both pre and postoperative sites in the axial, coronal and sagittal plane [32-33].

Alternative methods such a non-image-based registration method which depends on matching the preoperative machine setting to the postoperative setting offers higher accuracy but is only available through the use of another software that was not available for us to use.

The results of this study showed anteroposterior displacement measured as a linear deviation in the sagittal sections showing a mean of 1.13mm and 1.29mm for implants' coronal and apical ends respectively. Buccolingual displacement measured as a linear deviation in the reformatted crosssectional axial view of maxilla showed a mean of 1.04mm and 0.9mm for coronal and apical ends respectively. Height discrepancies from linear in the coronal sections showed a mean of 1.37mm and 1.53mm for coronal and apical ends respectively.

Overall linear deviation in this study regardless of the site (Anterior or posterior) and regardless of plane (coronal/sagittal or axial) was found to be 1.18mm for the coronal end and 1.24mm for the apical end.

Deviation in angle between placed and planned implants was measured in 3D environment using 3matic software was found to be 3.65° in the anterior implants and 7.07° in the posterior implants. the overall Deviation in angle between planned and placed regardless of their site was 5.37°.

Metal sleeves were used to control the direction and depth of drill and minimize deviations, they were made to fit tightly in the surgical stent with a 0.2mm tolerance. As for the the surgical guides they were made to fit but can be interchanged during surgery inside the metal sleeves so they can be removed with force but not enough to disturb the surgical stent, the amount of clearance was 0.7mm. But for the drills, a 0.5mm tolerance existed between them and the surgical guides thus Care was given to initiate the osteotomy in parallel with the guides' metal sleeves because a nonparallel start has been shown to be suspected in the angular deviation error. Which was 5.37° in our current study (3.65° in the anterior region and 7.07° in the posterior

According to a systematic review in year 2009²⁷, eight studies were analyzed regarding accuracy and clinical application in computer guided template-based implant dentistry, the mean error deviation regardless of type of stent used (tooth supported/ bone supported /mucosa supported) or study design (human/model /cadaver) was 1.07mm for the coronal end and 1.63mm for the apex, and 5.26 ° angular deviation. when evaluating the studies only conducted on human, the results were a mean of linear deviation 1.16mm at the coronal end and 1.96mm at the apical end and 5.73° angular deviation, our study revealed comparable results in overall linear deviation in the coronal end being 1.18mm (SD0.9) and overall angular deviation 5.37° and showed improved accuracy results in linear deviation in the apical end being 1.24mm (SD0.92).

In a similar study, Ozan et al, (2009²⁴, inserted 110 implants, 30 implants were placed using tooth supported SLA surgical guides for single-crown restoration, 50 implants were inserted using bone supported SLA guides in partially and completely edentulous patients while 30 implants were placed using mucosa –supported SLA guides in completely edentulous patients, he concuded that tooth supported surgical guides were more accurate than bone or mucosa supported surgical guides. The angular deviation of the placed implants with the tooth supported, bone supported and mucosa supported surgical guides were 2.9°,4.63° and 4.51°. by comparsion to our results, significant difference exists when comparing angular deviation value (5.37°) of this study to the tooth supported guide results and this could be best explained due to the micromovements and soft tissue flexibility in our case and subsequent expected errors.

When comparing our results to the study conducted by, Ozan et al, (2009)²⁴, to match the errors encountered by the mucosa supported SLA guides only, 4.5° (SD 2.1°), and linear deviation at the neck

and apex of 1.06mm (SD 0.6mm) and 1.6 (SD 1 mm) respectively, they found to show insignificant difference when compared to our study.

Van Assche et al., (2007)²⁵ examined the accuracy of the mucosa supported SLA surgical guide and emphasized that ex vivo and cadaver studies yielded best results compared to clinical studies, he used a flat panel CBCT device to produce similar surgical guides and placed a total of 12 implants to human cadaver jaws and reported mean of 2° (SD 0.8°) angular deviation and 1.1mm (SD 0.7mm) and 2mm (SD 0.7mm) linear deviation in the implant shoulder and tip respectively. Their superior accuracy concerning the angular deviation compared to our study which revealed a 5.37° in the same parameter could be best explained by the intrusion of the additional confounding factors in clinical studies compared to cadaver studies such as restricted mouth opening and visibility and physiological motions during execution of the actual surgery because the fact that surgical guide was not directly attached to jaw bone results in micromovements of the surgical guides because of the soft tissue flexibility.

The result of our study concerning the height deviation being less than 2mm between the planned and placed implants in all cases was in line with what Worthington [26] stated “2mm cutoff point was set for a clinically relevant deviation because it is generally maintained that 2 mm is the recommended safety margin around vital structures”, it is then assumed a nonclinical relevant difference between planned and actual implant height.

Evaluation of the difference in linear deviation with regard to region (Anterior/Posterior), in coronal, sagittal and axial planes to evaluate the height difference, Anteroposterior displacement and buccolingual displacement respectively showed statistically insignificant values in both coronal and apical side of all implants placed in this study, not comparing to other studies since no previous studies compared the computer guided accuracy results with regards to region.

Another observation concluded from the 3D measurements evaluating the angular deviation between the axes of planned and placed implants showed an acceptable range of 5.37° for all implants when compared to literature as discussed before, but statistical and clinically significant difference existed between the angular deviation in anterior (3.65°) and posterior (7.07°). This could be attributed due to difference in bone density in posterior region, poorer accessibility of the instruments, the preparation of osteotomy of a tilted implant is more complicated than an axial osteotomy. There were no studies that discuss the angular deviation in regard to the region (anterior /posterior) to refer to.

Surgical guide template stability is a critical step, the use of anchor pins was implemented by several studies [25,27,24,28], and in those studies SLA guides were fixed by monocortical screws as a method of rigid fixation of the stent to reduce the errors that could have arisen from stent micromovements during surgery.

Our study showed more accurate results compared to a study conducted by Di Giacomo et al, 2005 [28] who placed 21 implants using SLA surgical guides but without fixation. The match between actual and virtual implant axes was 7.25° angular deviation, linear deviation errors were 1.45mm at the coronal end and 2.99mm at the apical end. On the other hand, our study revealed 5.37° angular deviation, 1.18mm and 1.24mm linear deviation in coronal and apical ends respectively, this emphasizes the effect of using rigid screw fixation to enhance the stability of the surgical guide and consequently the accuracy of the template.

Generally, the result of this study taken together with previous studies highlights the fact that clinical accuracy of the presently utilized SLA guides can be minimized no further than a certain level because of various technical and physiological causes and mostly due to mechanical errors such as mucosal resiliency [29], tolerance within the SLA guide [30], and radiographic distortion [32].

The minor variations between planned and actual implant placement in this study showed that computer-based treatment plans can be reliably transferred to the operative environment by means of the guided surgery technique.

Furthermore, another key advantage of this procedure is the possibility of immediate loading of functional prostheses. Implant planning and positioning should not only take into account successful intraosseous implant placement, but also ensure that the future prosthesis is passively and securely seated on its fixtures.

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