EGYPTIAN
DENTAL JOURNAL

Vol. 64, 3713:3721, October, 2018

I.S.S.N 0070-9484

Fixed Prosthodontics, Dental materials, Conservative Dentistry and Endodontics

www.eda-egypt.org • Codex : 124/1810

ACCURACY OF IMPLANT PLACEMENT USING THREE DIFFERENT SURGICAL GUIDES

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ABSTRACT

Aim of the study: This study was done to evaluate and compare the accuracy of implant placement using three differently constructed surgical guides (3D printed, laser sintered and CAD/CAM milled surgical guides).

Materials and Methods: Eighteen implants were placed in partially edentulous patients having maxillary bounded edentulous areas. Based on the method of construction, patients were divided into three groups: group I, received 3D printed surgical guides, group II: received laser sintered surgical guides and group III: received CAD/CAM milled surgical guides. Implant placement evaluation included the difference between the planned and the actual implant sites regarding the point of implant insertion (coronal deviation), apex position (apical deviation), and implant angulation (angular deviation)

Results: The highest deviation values were obtained from group III (CAD/CAM milled surgical guides) followed by group II (laser sintered surgical guides), while group I (3D printed surgical guides) showed the least deviation values. There was a statistically significant difference between group I (3D printed surgical guides)) and group III (CAD/CAM milled surgical guides) regarding coronal deviation and apical deviation, also there was a statistically significant difference between group II (laser sintered surgical guides) and group III (CAD/CAM milled surgical guides) regarding coronal deviation and apical deviation, while there was no statistically significant difference between group I (3D printed surgical guides) and group II (laser sintered surgical guides), besides there was no statistically significant difference between the three groups regarding angular deviation.

Conclusion: 3D printed surgical guides had the best accuracy (minimal deviation) followed by laser sintered surgical guides and the least accurate were the CAD/CAM milled surgical guide

KEY WORDS: surgical guides, 3D printing, laser sintering, CAD/CAM milling, implant accuracy.

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INTRODUCTION

Many factors should be considered to obtain a successful implant such as osseointegration, as well as accurate implant placement and orientation to fabricate a dental restoration with optimal esthetic and function. Ideal placement facilitates the establishment of favorable forces on the implants and prosthetic components while ensuring an esthetic outcome. To increase the predictability of success, it is essential that the implants are accurately placed.[1]

There are many different types of surgical guides present in the field of implant dentistry, such as profile surgical templates, vacuum-formed surgical templates, and size-customized light-polymerized acrylic resin guides, some provide informations regarding the buccolingual and mesio-distal positions of the implant, but no information about its angulation, others provide informations about the position and angulation but not the depth. ,[2,3]

With the advancement of implant imaging and computer technology, software-guided implant treatment planning is often used to guide the surgeon for placing the implant in its planned position[4], important information could be obtained through computerized tomography (CT) for more accurately plan implant placement regarding the locations, angulations, and depths of implant sites.[5]

Surgical guide can be manufactured whether by additive or subtractive method, in general, there is a tendency for the subtractive method to provide more homogeneous objects with acceptable accuracy that may be more suitable to produce intraoral prostheses where high occlusal forces are anticipated. Additive manufacturing methods have the ability to produce large workpieces with significant surface variation and competitive accuracy. Such advantages make them ideal for the fabrication of facial prostheses.[6]

I- Additive Manufacturing (AM) is a term to describe set of technologies that create 3D objects by adding layer-upon-layer of material. Materials can vary from technology to technology. Then Additive Manufacturing (AM) device reads data from computer added design (CAD) file and builds a structure layer by layer from printing material, which can be plastic, liquid, powder filaments or even sheet of paper.[7]

The term Additive Manufacturing holds within such technologies like Rapid Prototyping (RP), Direct Digital Manufacturing (DDM), Layered Manufacturing and 3D Printing. There are different 3D printing methods that were developed to build 3D structures and objects.

1- Three-Dimensional Printing (3DP)

3D printing is also known as additive manufacturing (AM), rapid prototyping, layered manufacturing or solid free form fabrication. It is the process in which multiple layers of material coming from the supply chamber to the top of fabrication chamber and added one by one under computer control to create three-dimensional object. The idea of this method is that the three dimensional model is sliced into many thin layers and the manufacturing equipment uses this geometric data to build each layer sequentially until final desired product is completed. It all starts with creation of a virtual design of the object. Scanner is used to produce a 3D model which sliced and uploaded into a 3D printer, the object is ready to be 3D printed layer by layer. The 3D printer reads every slice and creates a 3D object. Objects of any geometry can be made by this technology, after completion, the object should be removed from the chamber and the excess powder brushed off.[8]

Materials used in this technique could be Plaster, sand, corn starch and acrylic, with infiltration materials as resins or cyanoacrylates. Advantages of 3D printing technique are the speedy fabrication, low material and system cost and it is possible to print colored parts. On the other hand, limitation of surface finish, material availability, with the fragility of the resultant restoration are considered as the main drawbacks of this technique [7, 9]

2- Laser sintering

In this technique, a fine material powder is fused by scanning laser, to build up structures incrementally. As a powder bed drops down, a new fine layer of material is spread uniformly over the surface. The laser then traces out the layer to selectively melt and weld the grains together to form a layer of the object. The work platform moves down by the thickness of one layer and the roller then moves in the opposite direction. The process repeats until the part is complete. Excess powder is simply brushed away and final manual finishing may be carried out. It takes a considerable cool-down time before the part can be removed from the machine. Large parts with thin sections may require as much as two days of cooling.[10] Advantages include ease of autoclavability of the materials, wide range of material selection, complexity isn't an issue as long as the not sintered powder could be removed and finally large sized restorations can be constructed accurately, while disadvantages may be due to porosity of the fabricated parts and/or its rough surface depending on the materials used, polymer parts are easily distorted by heat which causes shrinkage and warpage of fabricated parts, the finishing and accuracy is not as good as stereolithography, moreover, powders are messy with increased inhalation risk, technology is expensive, and significant climatic conditions such as compressed air are required [11], [12]

II- Subtractive manufacturing methods is one of various processes in which a piece of raw material is cut into a desired final shape and size by a computer-controlled material-removal process. The computer added manufacturing (CAM) software automatically translates the computer added design (CAD) model into tool path for the computer numerical control (CNC) machine. This involves computation of the commands series that dictate the CNC milling, including sequencing, milling tools, tool motion direction and magnitude[13].

Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM)

Treatment planning decisions can be conducted through reading and interpreting cone beam computerized tomography CT (CBCT), performing measurements, and evaluating anatomic relationship by placing virtual images on the screen. The materials used for milling could be metals, ceramics, resins, or waxes. Advantage of milling is ensuring the durability of the restoration. On the other hand, most of the cutting power will turn into thermal energy and raise the milling tool temperature, which can reduce its life, moreover, the surface temperature rise will be accentuated if the milled material is of low thermal conductivity, thus, constant cooling is required to prevent overheating of the milled material. Moreover, brittle materials could develop surface damage in the form of surface microfractures, chipping defects, and altered surface quality [14], [15], [16] to reduce such complications, milling is better accomplished in two steps: a first rough milling is done at a low feed rate and high cutting force while the final fine milling is performed at a higher feed rate and reduced cutting forces[17]. The fine milling will reduce the chip thickness and minimize surface roughness. [18]

This study was conducted to evaluate the accuracy of 3D printed surgical guides, laser sintered surgical guides and CAD/CAM milled surgical guides regarding coronal, apical and angular deviation between the planned and the actual implant positions.

MATERIALS AND METHODS

Partially edentulous patients having maxillary bounded edentulous areas were selected according to the following criteria:

- The absence of any relevant systemic diseases that would contraindicate implant placement as osteoporosis.

- The presence of sufficient bone height and width for the placement of implant fixtures without using regenerative techniques.

Smokers and diabetic patients were excluded from the study.

A preoperative CBCT (scaora 3D X. Filand) was taken to evaluate and measure the available bone width and height and to determine the virtual implant location regarding coronal, apical, angular positions. Parallelism of the implants was also controlled and corrected. (Figure 1)

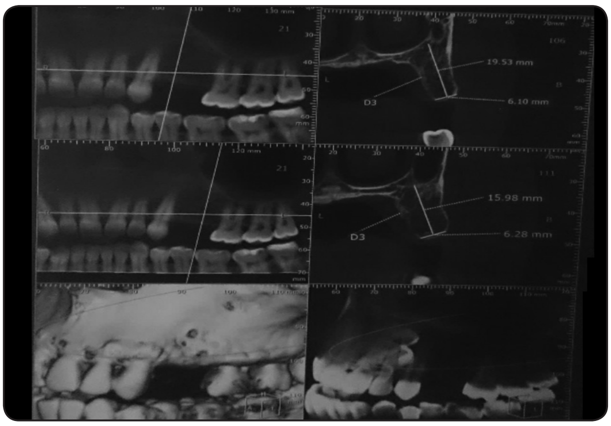

Fig. (1): Preoperative CBCT

Surgical guides construction:

After an informed consent document had been signed by the patient, treatment plan was completed, primary impressions were made using alginate impression material (Alginate- Cavex- Holland) for both arches in properly selected and modified stock tray and poured in dental stone (Durguix , Hard natural stone, Spain) to obtain study cast which were mounted on a fixed condylar path articulator (Magic Art-2 Alphadent, korea) using inter-occlusal wax record (Modelling wax, Cavex, Holland), to evaluate the remaining teeth, inter-arch distance, and to detect and correct any occlusal discrepancies.

Then the study casts were scanned using optical scanner (shera eco-scan 7 scanner) to produce a virtual 3D model which either uploaded into a 3D printer machine (rapid prototyping machine P380, EOS, Munich, Germany), or to a laser sintering machine (FORMIGA P 10 EOS), or to CAD/CAM machine (shera-eco-mill 5x, software 2251, av letournex montrea Quebec H1V 2N9 CANADA) (Figure 2,3,4) The surgical guides of the three groups were constructed from polymethaylmethacrylate (PMMA).(Ivoclar Vivadent Inc. USA).

Fig. (2): 3D printed surgical guides

Fig. (3): lased sintered surgical guides

Fig. (4): CAD/CAM milled surgical guides

Fig. (6): Drilling through the guide.

At the time of implant placement, flapless surgery was performed under local anesthesia, surgical guides were fixed in its position by the support of the remaining neighboring teeth.

The drill holes with metal sleeves made with an appropriate diameter that allow insertion of guide sleeves with successive diameters (including rotary tissue punch drill) (Figure 5). After the required mucosa were removed with a rotary tissue punch, drilling procedures were performed according to implant system's recommendations (Figure 6) and implants (II active, neobiotech. USA) were inserted in its preplanned position and angulation (Figure 7).

Fig. (7): Implant placement.

Fig. (5): Rotary tissue punch drill.

After implant insertion, a postoperative CBCT of the patients was carried out and the data were brought into the implant 3D software. The implants were clearly observed, without any artifacts (Figure 8). To perform analytic measurement calculations, virtual implants of the same size were placed on the present implants. These 3D data were transferred to Ondimand software along with the preoperative 3D treatment plan data. After the superimposition of the preoperative treatment data and the postoperative implant data, the apical and coronal points of the actual and the planned implants were recorded. Then analytic calculations were performed to evaluate coronal, apical and angular deviations. (Figure 9)

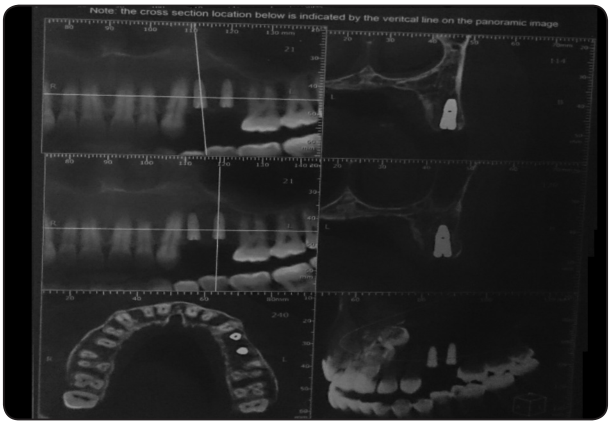

Fig. (8) postoperative CBCT

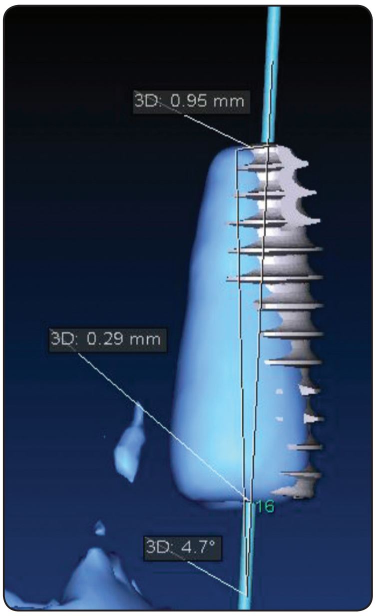

Fig.(9): Superimposition of preoperative treatment data and the postoperative implant data and deviations measurement.

RESULTS

Statistical analysis was performed using IBM SPSS Statistics Version 2.0 for Windows. Data was presented as mean, median, standard deviation (SD), minimum, maximum and 95% Confidence Interval (95% CI). The significance level was set at P ≤ 0.05. Kolmogorov-Smirnov and Shapiro-Wilk tests were used to assess data normality.

One-way ANOVA followed by Tukey's post-hoc test were used to compare the coronal deviation (point of insertion) and angular deviation (angulation) between the planned and the actual implant sites of the three surgical stent fabrication methods. Kruskal-Wallis test followed by Mann-Whitney test were performed to compare the apical deviation between the planned and the actual implant sites of the three surgical stent fabrication methods.

The highest deviation values were obtained from group III (CAD/CAM milled surgical guides) followed by group II (laser sintered surgical guides), while group I (3D printed surgical guides) showed the least deviation values.

There was a statistically significant difference between group I (3D printed surgical guides)) and group III (CAD/CAM milled surgical guides) regarding coronal deviation and apical deviation,

TABLE (1): Mean ± Standard Deviation (SD) and P value for the comparison between the three fabrication methods regarding coronal, apical and angular deviation.

Grouping / Difference in deviation	Group I 3D Printed	Group II Laser Sintered	Group III CAD/CAM Milled	P-value
	Mean ± SD			
Difference in point of insertion (Coronal deviation)	0.19 ± 0.05 [A]	0.27 ± 0.05 [A]	0.47 ± 0.17 [B]	0.002*
Difference in apex position (apical deviation)	1.43± 0.46 [A]	1.47 ± 0.53 [A]	2.60 ± 0.57 [B]	0.003*
Difference in implant angulation (angular deviation)	5.0 ± 0.74	5.15 ± 0.80	6.58 ± 0.91	0.083

: Significant at P ≤ 0.05Means with different superscript letters within the same row are significantly different at P ≤ 0.05

also there was a statistically significant difference between group II (laser sintered surgical guides) and group III (CAD/CAM milled surgical guides) regarding coronal deviation and apical deviation, while there was no statistically significant difference between group I (3D printed surgical guides) and group II (laser sintered surgical guides), besides there was no statistically significant difference between the three groups regarding angular deviation.

DISCUSSION

Investigators have reported that implant placement with conventional surgical guides made from virtual planning with CBCT data results in less variation between the planned and actual implant positions at the implant platform and apex than those using a freehand method.[19]

In this study, all groups showed deviation between the planned and the actual implant positions, this may be attributed to the lack of horizontal fixation of the surgical stent, however, the results indicated that the deviation is and within the limits of the other studies [20, 21, 22,23]

Considering that the main drawback of the surgical guide was its possible movement during surgery, a recent clinical study [24] demonstrated that implants placed using mucosa supported surgical guides showed the lowest deviations compared with bone- and tooth-supported guides. Ersoy et al [25] aimed to evaluate the match between the position and axes of the planned and placed implants using virtually planned surgical guides, they found angulation deviations between planned and placed implants, which may have resulted from micro-movements when the surgical guides were not screwed to the jawbone. Therefore, it is important to stabilize surgical guides otherwise, clinical variability such as soft tissue fit and compressibility and implant insertion in less dense bone might be the main source of the discrepancies [26].

Distortions could also occur during the construction of 3D images from multi-slice radiographs. Despite this, the discrepancies observed goes with the clinical recommendation that these techniques do not eliminate the importance of surgeon experience, awareness of critical anatomical features, and the maintenance of a safe zone of 2mm from critical features such as adjacent teeth when planning implant placement. Overall, the accuracy of the surgical guides could be improved by fabricating them to fit the alveolar bone instead of soft tissue and by the use of fixation screws [27].

In this study, the highest deviation values were obtained from group III (CAD/CAM milled surgical guides) followed by group II (laser sintered surgical guides), while group I (3D printed surgical guides) showed the least deviation values. This variations may be due to the technical sensitivity and difference in the method of construction of each group. The cutting power used to construct CAD/CAM milled surgical guides and the laser used to construct the laser sintered surgical guides produced thermal energy that may affect the accuracy of the resultant guides.[10,14,15,16]

There was a statistically significant difference between group I (3D printed surgical guides)) and group III (CAD/CAM milled surgical guides) may be due to Due to brittle nature of the PMMA microscopic cracks that could be introduced during the process of machining which would affect the accuracy of the surgical guide. Moreover, another study showed the advantages of 3D printing over CAD CAM technology including the large amount of raw material is wasted because of unused portions of the mono-blocks which are discarded after milling and recycling of the excess ceramic is also not feasible, also, milling tools are prone to heavy abrasion and wear which shortens their cycling time. [28]

There was a statistically significant difference between group II (laser sintered surgical guides) and group III (CAD/CAM milled surgical guides) regarding coronal and apical deviation, this result is similar to that obtained from a study conducted to compare the accuracy of fit between laser sintered and CAD/CAM milled tooth supported frameworks, the results showed that the frameworks produced by laser sintering is better than those produced by milling [29]

This may explain why the deviation values in group II (laser sintered surgical guides) were lower than that of group III (CAD/CAM surgical stents)

Accuracy of laser sintering technique can be adjusted by controlling particle diameter (30 μm) and layer thickness (50–200 μm each) [30]. The smaller the dimensions, the greater the accuracy and the density of the final product. As increasing laser intensity and melting time is desirable to increase the density of the workpiece, this should be weighed against the increase in dimension error that can occur as a result. Although the distortion of each layer is minimal, the accumulated error for all the layers can cause a measurable error[31]. The manufacturer should therefore control the processing parameters, to ensure ideal parameters for a given application.

A study was done to evaluated the accuracy of intraoral implant placement positions using surgical implant guides produced by stereolithography and it was revealed that, accuracy was in the range of 0.4–2.0mm, and angulations were in the range of 2–5°, [32] and this differences would not affect implant position accuracy.

CONCLUSION

Within the limitation of this study, the three techniques of surgical guides construction were of acceptable accuracy and the minimal differences between the deviation values didn't affect the final treatment outcome, moreover, computer-aided flapless implant surgery seemed to provide several advantages to the clinicians as compared to the standard procedure; however, linear and angular deviations are to be expected. Therefore, accurate pre-surgical planning taking into considerations that anatomical variations and prosthetic demands are mandatory to ensure a successful treatment and better prosthetic outcome.

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