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Accuracy of Surgical Guides Fabricated Using Two Different 3D Printers for Prosthetically-Driven Implant Surgery "An in-Vitro Study"

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ABSTRACT

Background: Prosthetically driven implant surgery provides a higher level of precision in the placement of dental implants and leads to more predictable outcomes in prosthetic results when compared to implant surgery without guidance. ***Aim:*** To evaluate and compare the accuracy of implant placement when utilizing surgical guides that are 3D printed through Stereolithography (SLA) and Digital Light Processing (DLP) techniques. ***Materials and Methods:*** Eighteen epoxy resin models with a missing mandibular first molar were prepared. The positioning of the implant was planned virtually using 3D planning software. A total of nine surgical guides were manufactured using an SLA 3D printer and another nine guides were manufactured using a DLP 3D printer. A total of 18 dental implants (5.5×11 mm) were placed using tooth-supported surgical guides. Dental implants were digitally scanned using scan body. The differences between the planned and placed position of implants in terms of point of entry, apical point and angular deviation were assessed for both groups. For comparison, the Mann-Whitney U test was used ($P \leq 0.05$). ***Results:*** Statistically significant difference was observed between SLA and DLP in relation to the deviation at the entry point of the implants ($P=0.021$) and deviation at the apical point ($P<0.001$). Overall lower deviations were found for SLA 3D printed surgical guides. ***Conclusion:*** The SLA 3D printing technique was found to be more accurate than the DLP 3D printing technique for the fabrication of surgical guides. Vertical positions demonstrated higher deviation than horizontal positions.

Keywords: Surgical guides, Prosthetically driven implant, Stereolithography, Digital light processing, 3D printing.

INTRODUCTION

The current trend in dentistry is to shift from traditional treatments to computer-assisted technologies. Previously, dentists were supposed to place implants where the

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amount of bone is greatest with little care for the final placement of the definitive restoration. In the majority of cases, implant placement was less precise than predicted with many variations from proper placement that can cause problems in the fabrication of final prostheses.[1] Digital technology has recently been used in dentistry in both laboratory and clinical procedures. Dental clinicians have been interested in prosthetically driven implant surgery as correct implant positioning can lead to significant advantages such as optimal occlusion, functional, and esthetic benefits and better oral hygiene, resulting in a higher long-term implant survival rate.[1-3]

Prosthetically driven implant surgery concept means that the preferred final restoration should be first planned and used as a guide for positioning the dental implant. It is a multi-factorial procedure that requires radiographic examination, arch scanning, virtual designing of the treatment plan, surgical guide designing and manufacturing, and implant insertion using an implant drill kit.[4,5]

Cone beam computed tomography (CBCT) and digital software for implant planning have revolutionized dental implant procedures with computer-guided implant system providing accurate outcomes that improve the implant survival rate by up to 95% after 5 years.[6] However, any error in the radiographic examination or implant planning can negatively impact the overall accuracy of the procedure, potentially causing harm to surrounding vital structures, so it is essential to execute each step of the process with utmost care and precision. Surgical guide is the physical link between the planned treatment and the post-operative position. Surgical guides are used to ensure proper implant placement, including depth, position and angulation and to prevent any damage to neighboring anatomic structures, such as injury to the inferior alveolar nerve, injury to neighboring teeth, and perforation of a thin lingual plate of bone.[7,8] Surgical guides can be classified based on support into tooth-supported, bone-supported or mucosa-supported and classified based on fabrication process into self, or light cure acrylic resin, vacuum-formed polymers, milled using computer-aided design/computer-aided manufacture (CAD/CAM) or 3D printed using a 3D printer.[9-13]

Additive manufacturing, also known as 3D printing, is a manufacturing method that involves building a product by incrementally adding material layer-by-layer until the desired final shape is achieved. This approach was created and is being utilized to create high-quality dental models, restorations, and surgical guides.[12,13] A recent study found that it is possible to produce high-quality surgical guides using 3D printing technology, indicating the potential for accurate and reliable surgical planning and implementation.[14] Dentistry commonly uses stereolithography (SLA) and digital light processing (DLP) 3D printers. SLA 3D printers utilize ultraviolet laser light to solidify a liquid photopolymerizing resin in a layer-by-layer manner. On the other hand, DLP 3D printers employ projector technology to solidify the resin at a faster pace. However, it is important to note that the resolution of the printed objects may be affected depending on the quality of the projector and the type of material used. Therefore, further investigation is necessary to explore and assess the potential impact on resolution and quality in different printing scenarios.[12,13,15,16]

Accuracy of implant placement refers to measuring deviation between the planned and placed implant position. Achieving high accuracy in 3D printed surgical guides is of utmost importance for the successful outcome of implant placement. Errors or inaccuracies in the guide can significantly increase the risk of implant failure. Therefore, ensuring accuracy, precision, and reliability in the fabrication of surgical guides is essential to minimize potential complications and optimize the overall success of implant procedures. Various methods are used to evaluate the accuracy of implant positions, such as a postoperative CBCT examination of a patient or using digital scan technology to register the final implant position.[17-22]

The aim of this study was to assess the accuracy of SLA and DLP 3D printed surgical guides by measuring the deviation between the planned and final placed implant position using digital superimposition software following prosthetically driven implant protocol. The null hypothesis of this study was that there is no difference in accuracy between SLA and DLP fabricated surgical guides on the final placed implant position.

MATERIALS AND METHODS

A demo case with a missing lower left first molar from Blue Sky Plan implant planning software's library (BlueSkyBio, LLC, Grayslake, IL, USA) was used. Digital imaging and communications in medicine (DICOM) and standard triangulation language (STL) files were clearly present and separately exported. Superimposition between both files was done digitally, followed by virtual designing of prosthetic restoration according to optimal functional and esthetic outcomes to achieve the prosthetically driven implant surgery protocol. Proper implant selection regarding the height and width of the available bone, proximity to neighboring teeth, and anatomical landmark was considered **(Figure 1)**.

epoxy resin casts were obtained and numbered from one to 18. Sample size was calculated according to power analysis using vertical implant position in µm as the primary outcome. The effect size (dz) = 1.145 was calculated based upon the results of Gjelvold B et al.[23] Using alpha (α) level of (5%) and Beta (β) level of (20%) i.e., power = 80%; the minimum estimated

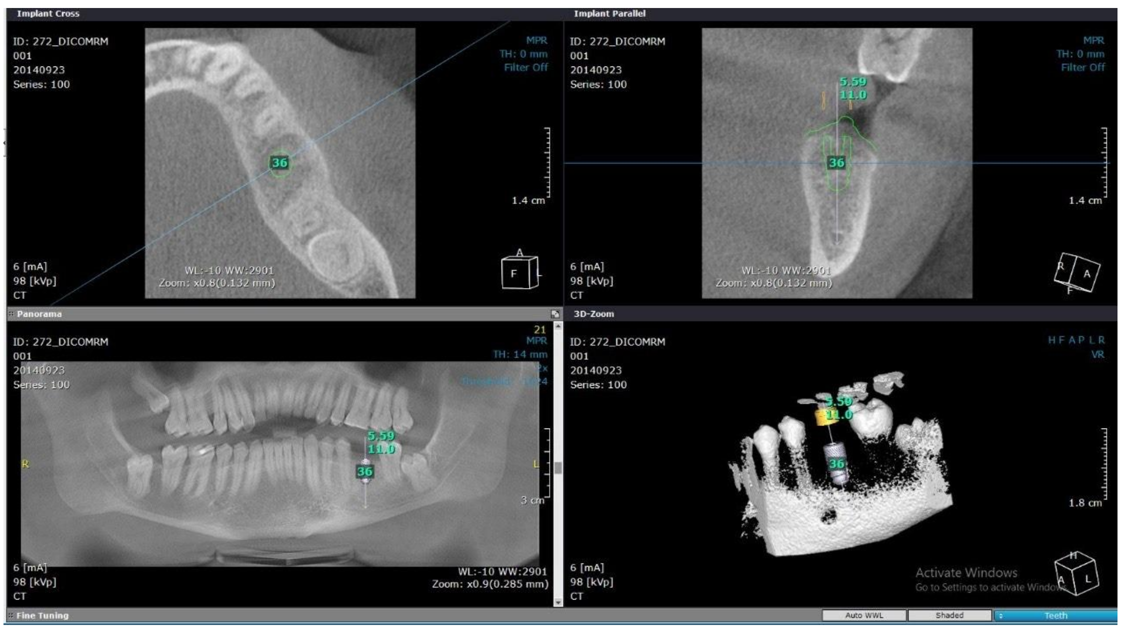

Figure (1): Virtual implant planning.

The master cast was 3D printed using Formlabs Form 2 in-office 3D printer (Formlabs Inc, Massachusetts, USA) with Formlabs Dental Model Resin (Formlabs Inc, Massachusetts, USA), and a mold of the master cast was fabricated using duplication silicone material (Dupliflex, Protechno, Girona, Spain) to construct epoxy resin models for implant placement. A total of 18

sample size was 9 implants per group. Sample size calculation was performed using G Power software version 3.1.9.2. Designing the surgical guide for the chosen implant was done using On Demand 3D implant planning software (Cybermed Inc, Seoul, Korea) and it was directly exported from the planning software to the 3D printer as an STL file.

This study included 18 surgical guides with 9 surgical guides fabricated using each 3D printing technique. The SLA surgical guides were printed using a Formlabs Form 2 in-office 3D printer. The process involved selecting the guide material from the 3D printer's software, choosing a layer thickness of 0.05 mm for optimal resolution and accuracy, importing the designed STL file, and orienting the guide on the built platform according to manufacturer's instructions. The SLA guides were printed using Formlabs Surgical Guide Resin (Formlabs Inc, Somerville, Massachusetts, USA) and were then post-processed by rinsing them with isopropyl alcohol and using fine-grit sandpaper to smooth any rough surfaces. The DLP surgical guides were printed using an Asiga Max 3D printer (Asiga, Sydney, Australia). For DLP 3D printing, the same workflow for SLA 3D printing was followed. The DLP guides were printed using Power Resins Surgical Guide Resin (Promarket Tasarım ve Teknoloji A.Ş, Istanbul, Turkey) and were then post-processed in the same way as the SLA guides. In addition, the DLP guides were post-cured by exposing them to Asiga Max UV curing unit (Asiga, Sydney, Australia) for 60 minutes to ensure optimal mechanical properties and full curing. Both the SLA and DLP surgical guides were then checked for fit by placing them over their respective epoxy resin models **(Figure 2)**. Dentaurum large sleeves were inserted into the guides to support a fully guided technique.

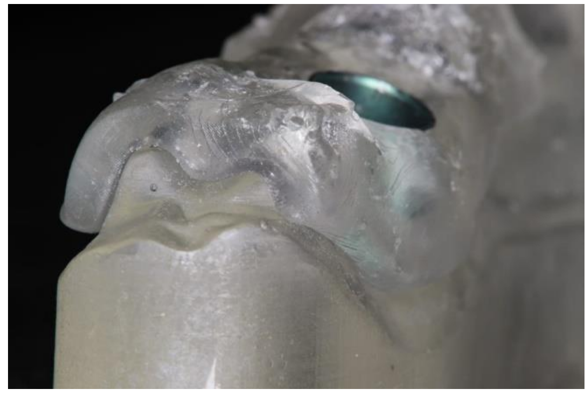

Figure (2): Visual inspection of the surgical guide over its respective model.

A total of eighteen 5.5mm diameter X 11mm length Dentaurum tioLogic ST dental implants (Dentaurum GmbH & Co. KG, Germany) were placed in the duplicated models in each group (9 implants/ group) using a surgical guide, and a fully-guided drill kit. Implant drill bur size 5.5 was used to reach the prescribed stop position. A torque wrench was employed to align the implant hexagon with the indication marking on the surgical guide for proper adjustment. After placing each implant a scan body was placed on the implant, and a scanning spray was used to aid in scanning **(Figure 3)**. Afterward, the cast was scanned utilizing the inEos X5 extraoral scanner (Sirona Dental System GmbH, Germany)

Figure (3): Scan body placement on the implant prior to scanning.

and an STL file of the model was obtained after the scanning process. Using GeoMagic Control X software (Geomagic, NC, USA), the exported STL files were superimposed onto the reference planned 3D model where irrelevant areas from alignment between data sets beyond the field of interest were withdrawn to make the superimposition more precise. Deviation values after superimposition were presented in a colored heat map, and the deviation measurements were evaluated and analyzed by Blender software (Blender Foundation, Amsterdam, Netherlands) version 2.93.

The measurements were performed at two main points: the point of entry and the apical point which were analyzed at three different planes: bucco-lingual (ΔX) plane, mesio-distal (ΔY) plane and apico-coronal (ΔZ) plane **(Figure 4)**.

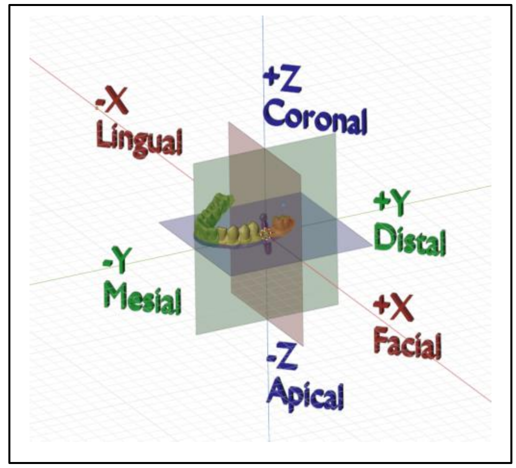

Figure (4): X, Y and Z planes.

The deviations were measured in micrometers (µm) and presented as point of entry deviation (µm) and apical deviation (µm) at the X, Y and Z coordinates. Additionally, the angular deviation (degrees) was measured by marking reference dots at the cross-sections of bucco-lingual and mesio-distal regions of planned and placed implant positions **(Figure 5)**.

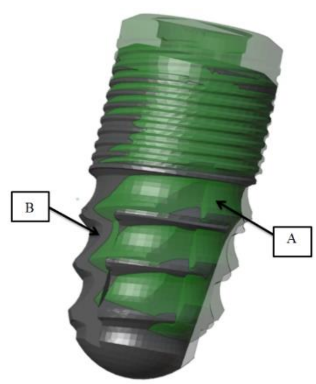

Figure (5): Illustrative diagram demonstrating deviation between (A) planned & (B) placed implant positions.

Statistical Analysis

Numerical data were presented as mean with 95% confidence intervals, standard deviation (±SD), median, minimum, and maximum values. They were explored for normality by checking the data distribution and using Shapiro-Wilk test. Root mean square (RMS) values were assessed using this formula: RMS= $\sqrt{(\Delta X + \Delta Y + \Delta Z)}$ and were normally distributed and analyzed using an independent t-test. Other data were non-parametric and were analyzed using Mann-Whitney U test. The significance level was set at $p \leq 0.05$. The statistical analysis was conducted using R statistical analysis software.

RESULTS

The surgical guide fabrication and implant placement were carried out smoothly without any unexpected incidents, and 18 dental implants were successfully placed. The angular deviation, entry point and apical point deviation were measured, and RMS was calculated. Angular deviation showed that DLP fabricated surgical guide had a statistically significantly higher value of deviation (5.09±0.47°) than SLA fabricated surgical guide (0.89±0.12°) (p<0.001). The mean values for deviation at the entry point were higher for the DLP group than the SLA group in all three directions where DLP fabricated surgical guide had a statistically significant higher value of deviation for placed implant position (1443.98±271.62µm) than SLA fabricated surgical guide (1077.23±186.26µm) (p=0.021). The mean values for deviation at apical point were higher for the DLP group than the SLA group in all three directions where DLP fabricated surgical guide had a statistically significantly higher value of deviation for placed implant position (2016.88±268.49µm) than SLA fabricated surgical guide (1347.57±60.23µm) (p<0.001). The statistical analysis conducted on the deviations observed in dental implant position between SLA and DLP groups is summarized in **Table (1)** and **Figure (6)**.

Table (1): Deviation difference between SLA and DLP surgical guides (Mann-Whitney U test).

Variable	SLA		DLP		*P*-Value
	Median	Mean ±SD (min-max)	Median	Mean ±SD (min-max)	
RMS Deviation at entry point (µm)	1038.34	1077.23±186.26 (808.90-1315.52)	1368.59	1443.98±271.62 (1179.17-1840)	0.021*
RMS Deviation at apical point (µm)	1335.18	1347.57±60.23 (1275.40-1449.19)	2068.94	2016.88±268.49 (1606.10-2388.86)	<0.001*
Angular deviation (degrees)	0.99	0.89±0.12 (0.69-1)	5.16	5.09±0.47 (4.27-5.53)	<0.001*

***RMS**, Root Mean Square; **DLP**, Digital Light Processing; **SD**, Standard Deviation; **SLA**, Stereolithography.*
**Statistically Significant at P<0.05.*

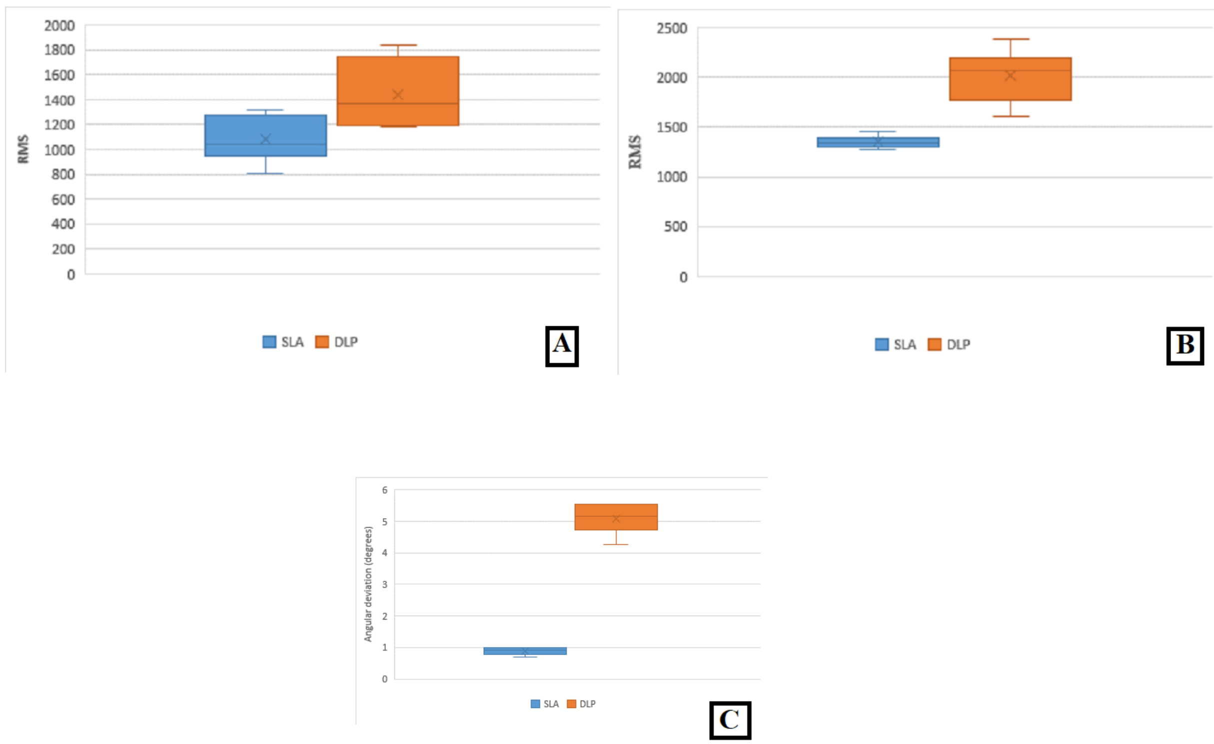

Figure (6): Box plots of mean 3D deviation between SLA and DLP groups: **(A)** 3D deviation at entry point, **(B)** 3D deviation at apical point and **(C)** Angular deviation.

DISCUSSION

The null hypothesis was rejected as the results of this study indicated statistically significant differences favoring SLA 3D surgical guides over DLP 3D surgical guides in terms of accuracy of the final implant position.

In the past, implant surgeries focused on inserting the implant in a bone region that supported a functional prosthesis, but prosthetic restorations did not always meet esthetic standards. To address this defect, prosthetically driven implant surgery was introduced, which involves planning the implant placement based on the final prosthesis. However, the implant position still deviates from the planned position due to various factors.[15,16,24-26] Achieving accuracy in 3D printed surgical guides is crucial for the successful placement of dental implants. Two commonly utilized types of surgical guides are DLP and SLA. The aim of this study was to compare the accuracy of implant position using DLP and SLA surgical guides in an in-vitro setting to determine if there are significant differences in accuracy.

All steps were performed by one experienced operator. Despite standardization, deviations between planned and placed implant position still existed. The findings of this study indicate that there were observed differences in the accuracy of implant placement between the SLA and DLP fabricated surgical guides. SLA guides had a lower degree of deviation than DLP guides at the entry point, apical point, and angular deviation. The findings were consistent with those of previous researches, which showed mean deviations of 1 mm variation at both the apical and coronal positions, along with an angular deviation of 5 degrees.[24,27-30] In previous studies[15,29,30], the vertical positions frequently demonstrated higher deviation than the horizontal positions, and that was also observed in this study.

The variations in implant position precision observed in this study may be attributed to several operator-related factors. These factors include the tolerance between the guiding tools, the length of the dental implant used and the separation between the guide sleeve and implant site. In addition, the hexagon location was visually aligned during installation requiring the operator to mark the reference position which may contribute to large rotational deviation and data with a wide spread. As guided surgery technologies continue to advance such variations may be reduced. Moreover, the precision of implant position can be influenced by the surgeon's level of experience, as experienced clinicians demonstrated reduced variation in placement accuracy. Due to the need to block out undercuts for complete seating of the surgical guide, it may not have been as stable as intended, leading to some of the deviation observed. During osteotomy preparation holding the surgical guide and the cast simultaneously can be challenging resulting in inconsistent surgical guide positioning.

The variances observed in the DLP printed surgical guides could be attributed to printing-related factors such as the offset values necessary for the cylinder sleeve and space between the guide and teeth, leading to difficulties in mounting the sleeve and seating the guide. Additionally, the DLP printer used had a lower degree of photo polymerization than the SLA printer necessitating a post-polymerization process that could cause deformities in the guide. Other factors that could influence the final implant position include the presence of a metal sleeve, the resolution of the 3D printer, the surface polish of the material used, the reproducibility of the printing process, the accuracy of offset settings, the effectiveness of post-processing techniques and the calibration of the equipment. Moreover, the epoxy resin used to create the models has a different density, elasticity and hardness than natural bone, which may affect the accuracy of the implant drills, leading to heat generation and bur clogging. However, epoxy resin is still commonly used in research as a bone simulant.

In their systematic review, Van Assche et al[31] found that tooth-supported surgical guides had an average error of 0.99 mm at the coronal center and 1.24 mm at the apical center, with an angular deviation of 3.81°. Turbush et al[10] reported similar findings, with SLA surgical guides having a mean error of 1 mm at the coronal center and 1.15 mm at the apical center and DLP surgical guides having a mean error of 1.4 mm at the coronal center and 1.75 mm at the apical center and an angular deviation of 2.26° and 3.54°, respectively. The results of our study were consistent with these earlier investigations. However, Gjelvold et al[23] reported contradictory results in their in-vitro study, with no significant difference between the SLA and DLP surgical guides for horizontal position deviation and better results for vertical and angular deviations with DLP surgical guides. This could be due to various factors such as the type of printer and resin used, and offset values.

The limitations of this study include a lack of biological variability as artificial models and materials were used, which do not accurately replicate the biological variability seen clinically, also it was of simplified models which may not accurately replicate the complexity of the clinical situation. This investigation failed to consider certain variables such as saliva, soft tissue, humidity, and patient motion within the oral environment. Moreover, the epoxy model material differs from bone, enamel, and soft tissue in its physical properties, potentially leading to variations in guide placement and implant insertion during actual clinical procedures.

CONCLUSIONS

Within the limitations of this in-vitro study, the following points were concluded:

1. The SLA 3D printing technique was found to be more accurate than the DLP 3D printing technique for the fabrication of surgical guides.

2. Vertical positions demonstrated higher deviation than horizontal positions.

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CONFLICTS OF INTEREST: The authors have no conflicts of interest to declare.

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