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EFFECT OF TWO DIFFERENT DEPOSITION LAYER THICKNESSES ON THE RESOLUTION OF 3-D PRINTED IMPLANT SURGICAL GUIDES (*IN VITRO* STUDY)

Anas A. Omran[1*], Ghada Abdel Fattah Heussein[2], Nancy E. B. Rafla[3]

Department of fixed prosthodontics, Faculty of Dentistry, Ain Shams University, Cairo, Egypt.

Corresponding author: Anas A. Omran*
Department of fixed prosthodontics, Faculty of Dentistry, Ain Shams University, Abbassia, Cairo, Egypt. 11566.
Email: anasim1995@gmail.com

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ABSTRACT:
Objective: This research aimed to evaluate the effect of different 3D printing layer thicknesses (50-µm and 100-µm) on the accuracy of implant surgical templates fabricated by a digital light processing (DLP) printer.
Material and methods: The Nissin educational model was scanned three times (missing maxillary central incisor, missing maxillary canine, missing maxillary first molar). Each time will be scanned individually to generate a virtual STL model, which model will be imported into the planning software and virtual implant planning is completed and the virtual implant guide will be generated, and 3D printed using DLP 3D printer, the guides are printed in 2 different vertical resolutions (50-µm and 100-µm). Then all the printed implant surgical guides were scanned at an interval one week after printing, the scan STLs files will be superimposed to each design file to detect surface deviations from the original design file by Geomagic reverse engineering software.
Result: Data showed significant deviation in the first molar group for the 100-µm layer compared to the 50-µm layer ($p=0.002$). In the central incisor and canine groups, deviations were higher for the 100-µm layer but not statistically significant ($p=0.611$ and $p=0.176$, respectively).
Conclusion: Results show that implant surgical guides printed at 50-µm display overall lower deviations and smoother surface when compared to 100-µm implant surgical guides in both the fitting surface and the guide tube.

Keywords: 3Dprinting, surgical guides, DLP, implant.

1. INTRODUCTION

The rapidly progressing CAD/CAM (Computer Aided Design, Computer Aided Manufacturing) technology has been changing the dental practice in so many ways from patient education to healthcare delivery (Bhargav *et al*., 2018; Koch *et al*., 2016). Digital dental manufacturing is one part of these advanced technologies with high levels of productivity and accuracy. One of the most recent developments in the digital revolution is the integration of 3D printing technology for the manufacture of physical parts from digital files. Multiple layers are added during this procedure to create an item (Kantaros *et al*., 2023). Rapid prototyping or additive manufacturing are better terms to describe this technique. We have volumetric data in dentistry and surgery, including intra-oral or desktop optical surface scan data, computed tomography (CT) data, and cone beam computed tomography (CBCT) data. In comparison with other available technologies, additive manufacturing is more effective and reliable technique due to its ability to use readily available supplies, recycle waste material, and has no requirements for costly tools, molds, punches, scrap, or milling. In addition, this technology possesses the advantages of manufacturing large complex structures while reducing the polymerization shrinkage by gradual curing (Bhargav *et al*., 2018).

There are numerous uses for 3D printing in dentistry, including: Dental models for restorative dentistry: Scanned model data may be digitally archived, and only printed when needed, easing storage requirements. Crown copings and partial denture frameworks: In fixed and removable prosthodontics, treatment is planned and restorations designed in CAD software. Scan data and CAD design are used to mill or print crown or bridge copings, implant abutments, and bridge structures. Product design and instrument manufacture: 3D printing of several prototype designs for innovating new instrument and device designs.

Moreover, Surgical guides fabrication and digital implantology: Proper use of surgical guides can improve clinical outcomes in dental implant surgeries by facilitating detailed presurgical planning and precise placement of implant bodies. Using cone-beam computed tomography (CBCT) technology to assess osseous topography and identify critical structures, definitive prosthetic design can be employed during presurgical planning to choose the best position for the Osseo-integrated implant (Kola *et al*., 2015). Utilizing a guide during surgery can speed up the procedure and relieve physicians of some preoperative decisions (Sarment *et al*., 2003). In addition, guide use results in significantly more precise implant placement and have higher safety than freehand techniques (Afshari *et al*., 2022; Guentsch *et al*., 2021).

The most common 3D-printing technologies used to fabricate surgical guides in dental implantology are stereolithography (SLA), Digital Light Processing (DLP), inkjet and its derivative PolyJet. However, there are other AM technologies available such as Selective Laser Sintering (SLS), 3-dimensional Printing (3DP), and Fused Deposition Modeling (FDM). Although a variety of materials can be used with these technologies, plastics, resin or plastic-based materials are the most used materials for dental applications (Chen *et al*., 2019; L'Alzit *et al*., 2022).

Nowadays, there is a wide available array of 3D printing techniques with varying results and outcomes. Vat polymerization types are typically presented with higher accuracy and more convenience to the users. This technology utilizes a source of light to selectively cure or solidify layers of liquid photo-polymer resin from a tank to form physical parts (Piedra-Cascón *et al*., 2021). The digital light processing technique, which depends on a digital light projector as a light source, stands out among the vat polymerization technologies owing to its superior accuracy and faster manufacturing time (Chen *et al*., 2019).

Another fundamental factor in the accuracy of 3d printing process is the layer height. Layer height is the vertical height of each layer of a print material extruded, cured, or sintered by a

3D printer. The additive buildup technique creates a stair-step effect of the object surface which might result in dimensional deviations and a rough surface. Depending on the thickness of the layer, the object's surface is either more or less smooth or detailed. Moreover, the layer thickness may have an impact on the mechanical properties of the printed object (Etemad-Shahidi *et al*., 2020; Dalal *et al*., 2020).

This study aimed to evaluate the resolution of implant surgical guides fabricated by DLP technology utilizing two different printing profiles at 50-µm and 100-µm layer height with different edentulous spaces in comparison to the reference STL file design demonstrating the pattern of deviation in the X, Y, and Z axes. The null hypothesis is that different printing layer thicknesses do not affect the resolution of the printed surgical guides.

2. MATERIAL & METHODS

Sample selection and preparation

The study was designed as a comparative in-vitro study between three groups presented different edentulous spaces; the first group included a surgical guide for missing maxillary right central incisor, the second group included a surgical guide for missing maxillary right canine and the third group included a surgical guide for missing maxillary right first molar.

Each of these three groups was divided into two subgroups the first subgroup included implant surgical guides 3d printed at 50-µm layer height and the second subgroup included implant surgical guides 3d printed at 100-µm layer height.

The primary outcome was to assess the 3-dimensional deviations of the test groups from the original virtual surgical guide design in the three directions X, Y, and Z. Sample size (n) was a total of (42) samples i.e. (14) for each group and (7) for each subgroup. Sample size calculation was performed using G power version 3.1.9.2. based on a previous study by Hazeveld *et al*. (2014).

Methods

The Nissin educational model (Nissin, Kyoto, Japan) was scanned three times; the first scan was without maxillary right central incisor, the second scan was without maxillary right canine, and the third scan was without maxillary right first molar. The typo-dent was selected to have a full permanent dentition replica with intact surfaces (no voids or teeth fractures). Using a 3shape D850 desktop extra-oral scanner (3Shape, Copenhagen, Denmark), the typo-dent was 3d scanned to produce a digital representation of the model in the form of STL format. The file was then optimized for 3D printing by blocking extracted area, cropping gingival and typo-dent base areas.

Extra-oral and cone beam computed tomography scans were obtained from a subject who needed an implant replacement, The full arch scanning protocol using the 3shape D850 desktop extra-oral scanner (3Shape, Copenhagen, Denmark). A surgical guide was designed to include two adjacent teeth at least on each site of the guide to maximize the guide stability that may influence implant placement deviations using implant treatment planning software 3Shape Implant Studio (3Shape, Copenhagen, Denmark) and seating windows were added to allow fit verification. After the surgical guides planning, the STL file was transferred to 3d slicer software chitubox (ChiTuBox V1.9.5; ChiTuBox, Guangdong, China) for adjustment and alignment before printing. Three guides were printed in a separate print job, one of each group. The fitting surfaces were adjusted to face downward while the occlusal surface was facing upward towards the printing platform where print supports were attached to the occlusal surface of guides, all support parameters were the same for all groups. all guides were tilted to have a 30° between the base and the print platform. Using DLP Microdont 1pro 3d printer (Mogassam, Cairo, Egypt) was used to print 42 implant surgical guides. 21 guides

printed at 50-µm layer thickness and 21 printed at 100-µm layer thickness (7 guides on each subgroup).
The ready-to-print files were transferred to the 3d printer and then the tank was filled with NextDent SG resin (NextDent, Soesterberg, Netherlands) as dental implant surgical guides printing resin. After finishing the manufacturing procedure, the specimens were carefully detached from the build platform using a spatula (Fig.1, Fig.2), and the supports were removed from the occlusal surface of the guides. Subsequently, the de-novo printed specimens were fully submerged in an ultrasonic bath (TriClean Ultrasonic Cleaner U-10LHREC; BrandMax, Alpharetta, GA) with 99% isopropyl alcohol (IPA) (Isopropyl alcohol 99%; Cumberland Swan, Smyrna, TN) for 3 minutes, followed by a second ultrasonic bath with clean 99% IPA solvent for 2 minutes. Afterwards, specimens were rinsed with water and positioned in a paper towel for drying (Fig.3). Specimens were then polymerized in the UV-polymerization machine (PCA-100; Envisiontec) for 2 minutes. All the specimens were numbered from 1 to 7 in each group and then stored in a black container until scanning for measurements was completed. The whole procedure was applied for all groups. Using the same desktop scanner, all the printed implant surgical guides from all groups were scanned at an interval one week after printing, Scan spray powder (Renfert-Scan spray, Renfert GmbH, Munich, Germany) with a particle size of 5 µm was applied by an experienced user to aid in the digitization and counteract the translucent reflective nature of the printed implant surgical guides before scanning. The exported STL files were named after the same number of the correspondent printed guide.

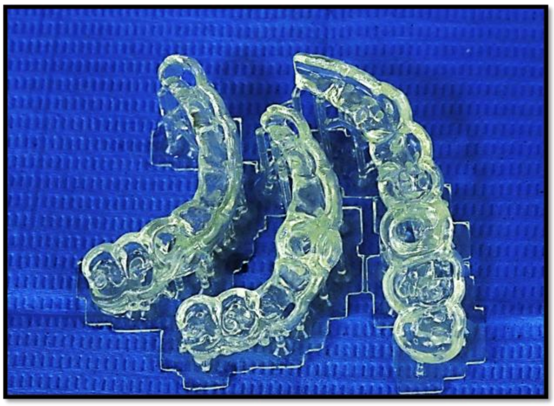

Fig. 1: guides after finishing the 3d printing process

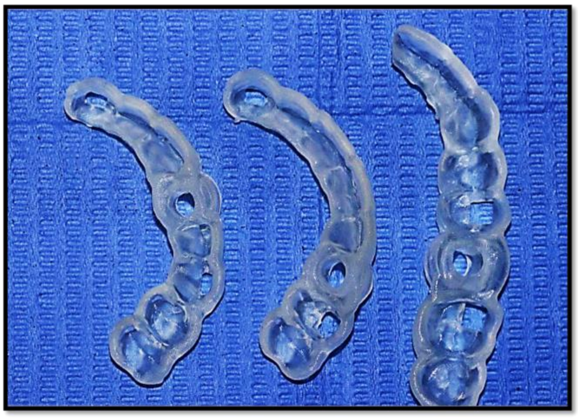

Fig. 2: guides after rinsing and drying on a paper towel.

The scan STLs files will be superimposed to each design file to detect surface deviations from the original design file. Geomagic reverse engineering software (control X 2018, Geomagic, 3Dsystems, NC, USA) was employed to superimpose the reference STL file obtained from the 3Shape D850 desktop scanner to each printed implant surgical guide STLs in every subgroup.

The reference STL data was imported scan, then the measurement first STL file (no. 1 in first subgroup) was imported which is one of the STL files of the corresponding scanner. The initial alignment feature with enhancement of the accuracy of the alignment was selected then the best fit alignment was selected to ensure the 2 guides data sets are positioned in one common coordinate system with the least possible mean deviation. The reference guide was re-segmented according to planes to thousands of segments then the area of interest was merged with the merge tool to ensure a precise superimposition. The 3D comparison was done only for the merged areas (fitting surface and tube) which is the area of interest with the shortest projection of deviation and auto maximum deviation. A color map was drawn with maximum deviation range of 0.1 mm and -0.1 mm minimum deviation and no specific tolerance. The green meant perfectly matching surface, the red mean test guide surface was positively positioned relative to reference STL guide and the blue mean test guide surface was negatively positioned relative to reference STL guide.

$$\text{RMS} = \sqrt{\frac{\sum_{m=1}^{n}(x_{1,m} - x_{2,m})^2}{n}}$$

That is when two scans were superimposed, the square of the phase difference between several points in 3-D space was calculated (x-, y-, and z-axis). The sum of these squares was divided by the number of points, and RMS was calculated as the square root of this value. This may be a more reliable and accurate value than general arithmetic means because the difference between each data point is represented by both a positive value (red in the color-difference map and a negative value blue in the color-difference map). The reliability of arithmetic means is limited in cases of simple sums. PDF and Excel reports were created with all the calculated data collected from the superimposition process. All these steps were performed 7 times for every subdivision to compare it with its reference scan and a total of 42 reports were generated to collect data from them.

Statistical analysis

Numerical data were presented as mean with 95% confidence intervals (CI), standard deviation (SD), minimum (min.) and maximum (max.) values. They were explored for normality and variance homogeneity by checking the data distribution and using Shapiro-Wilk's and Levene's tests, respectively. Other data were normally distributed with homogenous variances. Data were analyzed using two-way ANOVA followed by Tukey's post hoc test. Simple effects comparisons were made utilizing the ANOVA error term with p-values adjustment using the False Discovery Rate (FDR) method. The significance level was set at $p<0.05$. Statistical analysis was performed with R statistical analysis software version 4.3.3 for Windows1.

3. RESULT

1- Main effects:

A- Effect of tooth:

There was no significant difference between values measured in different teeth ($p=0.059$). The highest deviation was found with the central incisor (264.80±61.55) (µm), followed by the first molar (252.48±52.10) (µm), while the lowest deviation was found with the canine (223.93±54.32) (µm).

B- Effect of layer height:

Deviation measured with the 100-µm layer (266.03±51.24) was significantly higher than that measured with the 50-µm layer (221.79±56.71) (p=0.004).

2- Interactions:

A- Effect of tooth:

- **50 µm:**

There was no significant difference between different teeth (p=0.118). The highest deviation was found in the central incisor (256.90±68.06) (µm), followed by the first molar (207.80±18.53) (µm), while the lowest deviation was found at the canine (199.24±67.35) (µm).

- **100 µm:**

There was no significant difference between different teeth (p=0.070). The highest deviation was found in the first molar (297.16±29.64) (µm), followed by the central incisor (270.73±60.28) (µm), while the lowest deviation was found at the canine (237.64±43.98) (µm).

B- Effect of layer height:

- **Central incisor:**

100-µm layer (270.73±60.28) (µm) had a higher deviation than the 50-µm layer (256.90±68.06) (µm), yet the difference was not statistically significant (p=0.611).

- **Canine:**

100-µm layer (237.64±43.98) (µm) had a higher deviation than the 50-µm layer (199.24±67.35) (µm), yet the difference was not statistically significant (p=0.176).

- **First molar:**

100-µm layer (297.16±29.64) (µm) had a significantly higher deviation than the 50-µm layer (207.80±18.53) (µm) (p=0.002).

4. DISCUSSION

Electronic, digital, and advanced manufacturing technologies have revolutionized dentistry, leading to a significant trend toward digitization in prosthodontics (Jeon *et al*., 2018). When used appropriately, surgical guides enhance clinical outcomes in dental implant surgeries by facilitating detailed presurgical planning for definitive prosthetic design and precise implant body placement (Kola *et al*., 2015).

The introduction of three-dimensional (3D) printing has been transformative in the dental industry (Dawood *et al*., 2015). However, achieving consistent accuracy in 3D printing is challenging due to the diverse range of available technologies, each with unique outputs and performance characteristics. Variations in 3D printer types are influenced by specialized engineering, optics, materials chemistry, and overall design. A systematic review conducted by Etemad-Shahidi in 2020 highlighted the widespread use of SLA (stereolithography) and DLP (digital light processing) 3D printers in dental literature, underscoring the complexity of achieving uniform standards of accuracy across different printing technologies (Etemad-Shahidi *et al*., 2020).

While comparing the most common printing technology in dentistry, accuracy can vary significantly. For SLA printers, reported accuracy ranges from 3 µm to 579 µm, while for DLP printers, it ranges from 16 µm to 446 µm. In this study (Etemad-Shahidi *et al*., 2020), we focused on evaluating the accuracy of the DLP Microdont 1pro printer, which despite its popularity in Egypt, lacks documented accuracy data in the literature. Layer height is a critical factor influencing the precision of printed implant surgical guides. The thickness of each layer affects the smoothness and detail of the object's surface, potentially impacting dimensional stability (Yousefi *et al*., 2021; Zhou *et al*., 2000). Our research aimed to assess the resolution of implant surgical guides produced via 3D printing at layer heights of 50 µm and 100 µm, comparing these outcomes across three different edentulous scenarios with reference STL files.

The study examined several factors influencing the accuracy of 3D-printed implant surgical guides. Firstly, it found no significant difference in accuracy between different types of teeth when comparing 50 µm and 100 µm layer heights. Regarding layer height, while the overall comparison showed a slightly higher deviation with the 100 µm layer compared to the 50 µm layer, this difference was not statistically significant across most groups. However, significant deviations were observed in the first molar group, where the 100 µm layer exhibited notably higher deviation. This is attributed to the larger volume of molar teeth, leading to increased resin consumption and subsequent expansion and shrinkage effects (Son and Lee, 2020).

Our findings conclusively demonstrated that printing at a 50 µm layer thickness outperformed the 100 µm layer in terms of accuracy. This aligns with broader research indicating that thinner layers result in smoother, more detailed surfaces due to increased point density, whereas thicker layers exhibit greater stair-stepping effects. Clinically, the higher accuracy achieved with thinner layers enhances fitting surface stability and printing consistency, which are critical for successful implant placements.

Despite the production motivation among clinicians and technicians to opt for larger layer heights, such as 100 µm or more, for faster printing, this approach compromises guide accuracy. Additionally, factors like printing orientation (e.g., 90°) for mass production should be carefully considered, as they can negatively impact accuracy (Shendy *et al*., 2024).

The interaction between layer height and tooth type also warrants attention, with significant deviations observed in larger molar teeth due to increased resin consumption and subsequent expansion and shrinkage effects. Furthermore, scanners exhibit varying accuracy across different tooth types, performing better with anterior teeth compared to posterior teeth, likely due to anatomical differences (Son and Lee, 2020).

Etemad-Shahidi in 2020 study results indicated that a 50-µm layer thickness is superior to a 100-µm layer thickness in terms of accuracy. This aligns with the general understanding of 3D printing, where the accuracy of DLP technology improves when the layer thickness is reduced from 100 to 50 µm. DLP technology functions by curing resin layer by layer using light. The layer thickness determines the number of distinct points and triangles that form the STL printable object. Reducing the layer thickness results in more distinct points and triangles, leading to a smoother and more detailed surface, thereby increasing the print's precision. Conversely, a thicker layer has fewer distinct points and greater distances between them, causing a noticeable stair-stepping effect at the edges, which impacts overall accuracy (Etemad-Shahidi *et al*., 2020).

Our findings align with a study by Dalal *et al*. (2020), which examined the interaction between build angle and layer thickness in implant surgical guides. Printing surgical guides at a layer height of 50 µm showed superior performance compared to 100 µm in terms of internal surface stability, printing consistency, and tube deviations. However, the clinical implications of these improvements in fitting surface stability and printing consistency remain unclear. In cases where precise tube deviations are critical, such as in guides for multiple implant sites, using a printing layer of 50 µm and printing between 0° and 45° angles may help reduce these deviations. Although both placement angulation and layer thickness statistically affect the angulation and linear deviations of the surgical guide tube. However, for single anterior implant guides, variations in surgical guide fitting surface and tube deviations resulting from different printing angles and layer thicknesses do not appear to clinically affect implant placement deviations (Dalal *et al*., 2020).

Clinicians and laboratory technicians often prioritize faster production by using thicker layers like 100 µm or more. Additionally, printing guides at a 90° angle can increase efficiency by allowing more guides to be printed simultaneously. It's important to note that these practices may compromise the accuracy of printed guides (Dalal *et al*., 2020).

Different results were obtained by Sherman *et al*. (2020), who examined the efficacy and accuracy of a DLP printer for clinical purposes with various settings and modifications. They found no statistically significant difference between layer thicknesses of 50 µm and 100 µm, suggesting the use of DLP technology for high-speed printing at a 100 µm setting (Sabbah *et al*., 2021).

Sabbah *et al*. (2021) conducted a study using DLP technology and found no statistically significant difference between three distinct layer heights of 25 µm, 50 µm, and 100 µm. Our findings did not align with those of Sabbah *et al*., which can be attributed to different approaches to assessing deviation (Sabbah *et al*., 2021).

Our findings were consistent with a study by Ko *et al*. (2021), which examined the interaction between build angle and layer thickness. They reported deviations ranging from 0.08 to 0.09 mm at a 50 µm layer height and approximately 0.1 mm at a 100 µm layer height. These deviation readings at a 50 µm layer thickness were slightly greater than ours, possibly because our study used a 45° build angle, which was not one of the angles analyzed in Ko *et al*.'s study. Consequently, a 45° build angle might be recommended over 30° or 60° (Ko *et al*., 2021).

This study has some limitations that should be discussed. First, only one type of 3D printer and one material were used here. In this study, the printer (DLP Microdont 1pro, mogassam) (NextDent SG resin). second, this study focused only in the guide fitting surface representation of the original design without considering different fitting in humans and the placement of guide sleeve as well as implant placement. Fitting and adjustment in the printed or conventional dental cast or a patient’s mouth may have a large effect on guide’s adaptation and tube deviations.

5. CONCLUSION

Printing implant surgical guides for single-tooth implant placement can result in deviations in both the fitting surface and the guide tube. To minimize these deviations, printing with a 50 µm layer thickness provides better overall guide dimensions than printing with a 100 µm layer thickness. When minimizing tube deviations is crucial, such as in cases involving implant in the posterior area or multiple implant sites in one guide, using a 50 µm layer thickness and printing at angles between 0° and 45° can potentially reduce tube deviations and produce high-resolution object but this setting increases the 3D printing duration significantly.

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