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*Research Article*

# Influence of 3D Printing Technology, Resin Type, and Occlusal Design on the Accuracy of Surgical Guides

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## Abstract

**Aims:** The present study aimed to assess the accuracy of surgical guides fabricated using two different 3D printers, two resins, and different occlusal designs (OS: original shape; GS: groove sealing).

**Materials and Methods**: Forty surgical guides were printed on a digital light processing (DLP) printer and a Liquid Crystal Display (LCD) printer, with two resin types (SG guide and V-guide) and two occlusal designs. The region where the implant was planned was digitally removed from the cast, allowing passive positioning of the implant through the guide. A scan body was inserted in the implant, and the cast was scanned with an intraoral scanner. The planned implant was compared with the actual implant position. Six measurements representing the accuracy of implant placement: (depth, angular, global apical, horizontal apical, global coronal, and horizontal coronal) deviations. Descriptive statistics and a multivariate analysis of variance (MANOVA) were conducted.

**Results**: The DLP printer and GS group exhibited lower mean deviation and standard deviation across all measured parameters. Printer type had a statistically significant multivariate effect (Wilks' Lambda = 0.015, $p< 0.001$, Partial $\eta^2 = 0.985$). The resin type had no multivariate effect on the combined dependent variables, as indicated by Wilks' $\Lambda = 0.727$, $p = 0.161$. Occlusal shape showed a significant multivariate effect (Wilks' Lambda = 0.015, $p<0.001$). The univariate tests revealed that printer type and the shape of the occlusal surface had a statistically significant effect on all six deviation parameters ($p < 0.001$ for all); however, resin type had a significant effect only on horizontal coronal deviation ($p = 0.018$).

**Conclusion**: The DLP printer was more accurate than the LCD printer. Also, the accuracy of a surgical guide can be improved by sealing the occlusal surface grooves directly before fabricating the guide. The accuracy of both SG and V-guide resins was the same.

**Keywords**: DLP printer, LCD printer, Deviation, Groove sealing.

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## INTRODUCTION

Implant-based rehabilitation can help those who have lost teeth. (1,2) Implant dentistry has focused on implant geometry and osseointegration. Implant success depends on surface topography, especially roughness, which improves osseointegration. (3-7). Modern implantology puts the most emphasis on osseointegration, cosmetic restoration, and tissue health. (8,9) If an implant is poorly designed, it might irritate soft tissue and induce bone loss around the implant. There may be a number of problems with dental care. (10,11) 3D digital technology can help with these problems by making things more accurate and better in the clinic. 12 Intraoral scanners can make 3D virtual models without the need for imprints. They also help keep digital data safe and make patients more comfortable. (13,14)

Additive manufacturing, which deposits layers of material consecutively, enables the fabrication of precision dental components. (15,16) The concept of prosthetically driven implant surgery entails that the desired final restoration must be initially designed and utilized as a reference for the placement of the dental implant. It is a multi-factorial approach that necessitates radiographic assessment, arch scanning, virtual creation of the treatment plan, surgical guide design and fabrication, and implant insertion with an implant drill kit. (17,18)

Digital surgical guidance enhances implant placement accuracy; however, errors in depth and angulation can still occur. (19) Implant displacement can result from issues with the accuracy of 3D-printed surgical guides, including variations in printing technology, printer type, and resin composition. (20) Furthermore, the occlusal surface often presents intricate anatomical features—such as fissures and grooves that can hinder the proper seating and adaptation of the surgical guide. (21)

The current study aims to compare the accuracy of implants placed with 3D-printed surgical guides made by two different types of 3D printers: DLP and LCD, compare the accuracy of the surgical guide made by two different resins, and evaluate the effect of groove sealing of the posterior occlusal surface on the accuracy of implant placement using a 3D-printed surgical guide. The null hypotheses were that there would be no significant differences in accuracy among the mentioned different variables.

## MATERIALS AND METHODS

### Ethical Approval

This study was reviewed and approved by the Research Ethics Committee of the College of Dentistry, University of Mosul (**Reference No.: UoM.Dent. 25/1010**). Ethical approval was granted on November 25, 2024. The study was conducted in accordance with the ethical guidelines and regulations of the University of Mosul, College of Dentistry.

**Inclusion and Exclusion Criteria for our patient (one patient)**

### Inclusion Criteria

- An adult whose age is ≥ 18 years.
- Patient with good oral hygiene.
- No systemic or local conditions present a contraindication to implant placement.
- Patient with a single missing tooth.
- Patient with good bone height and width.
- Patient with good gingival health.

### Exclusion Criteria

- An adult whose age is < 18 years.
- Patient with bad oral hygiene.
- Systemic or local conditions presenting a contraindication to implant placement.
- Patient with multiple missing teeth.
- Patient with low bone height and width.
- Patient with periodontal disease.

### Study design

Samples (40 implants and 40 surgical guides) were categorized into two groups based on the type of 3D printer (DLP and LCD). Within each 3D printer category, they were further divided into two groups according to the resin material (SG guide and V-guide). Subsequently, each group was split into two subgroups based on the sealing of grooves on the occlusal surfaces of posterior teeth: (A) original shape (OS) and (B) groove sealing (GS).

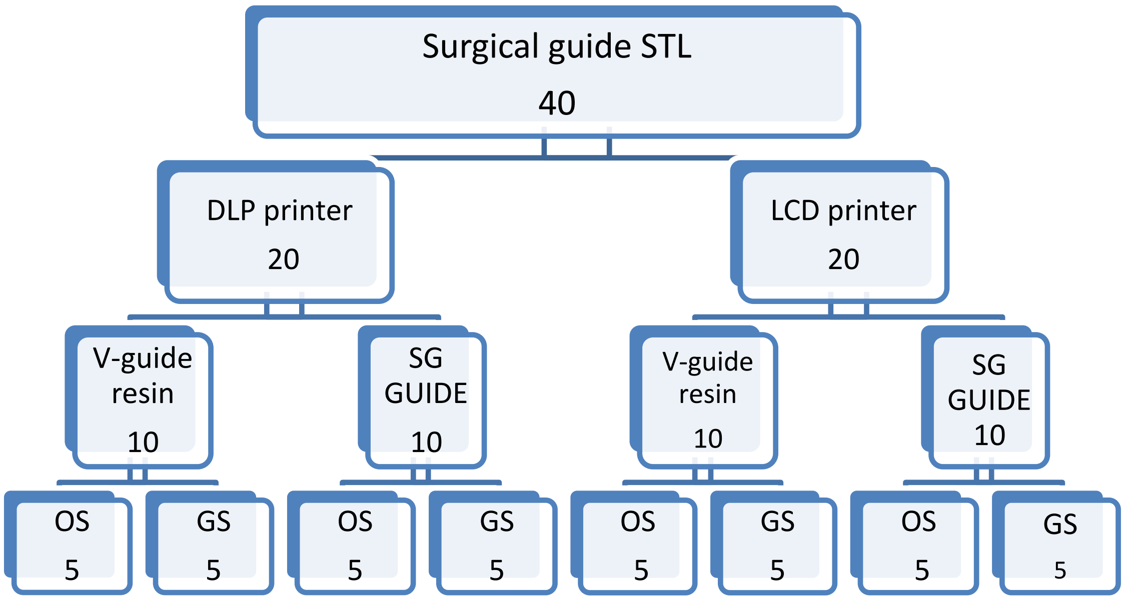


**Figure (1):** Study design.

**Preparation of the Experimental Model**

A cone-beam computed tomography (CBCT) scan and an intraoral scan by (MD-ISO300, Medit i700, bf2203100023, made in Korea) were obtained from a patient who presented to the Department of Prosthodontics at Mosul University Dental Clinics with a single missing lower left first molar (tooth no. 36). The diagnostic images used in this in vitro study were collected after obtaining informed consent and ethical approval (Reference No.: UoM.Dent. 25/1010). Two digital designs of the surgical guide were created. In the first design, the STL file preserved the original occlusal anatomy of the posterior teeth, whereas in the second, the occlusal surface was digitally sealed using *Exocad 3.1 Rijeka* software, as shown in Figure 2. The implant site was virtually outlined and segmented from the same digital model to avoid any effect of the drilling process on the final implant position and to allow easy removal of the implant after placement for subsequent scanning (22). Finally, twenty resin casts with sealed occlusal surfaces and twenty casts maintaining the original occlusal morphology were fabricated using 3D printing technology. As this study was in vitro, CBCT and the oral scanner of one patient were enough to plan and print 40 casts for implant placement.

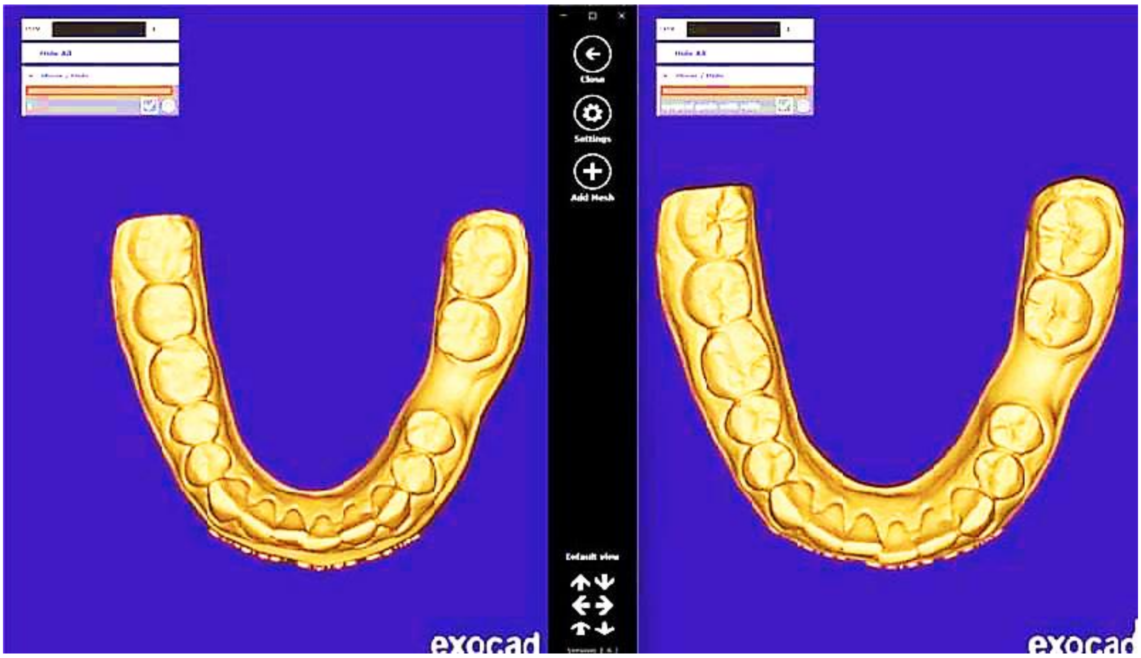


**Figure (2):** A. STL file that had the occlusal surface of posterior teeth with groove sealing, B. STL file that had the occlusal surface of posterior teeth with the original shape.

**Implant planning**

The Digital Imaging and Communication in Medicine (DICOM) files obtained from the CBCT scan and the Standard Tessellation Language (STL) files generated from the intraoral scan were imported into the implant planning software and accurately aligned using a best-fit alignment algorithm (23). The virtual implant planning was conducted with Blue Sky Bio Plan 4 software (Blue Sky Bio, LLC, USA) as shown in Figure 3. Taking into account both the prosthetic requirements and the patient's anatomical conditions, an implant of appropriate dimensions was virtually positioned within the software environment (24). A C-TECH implant (C-TECH Implant, Italy; Lot no. EL-6070) with a diameter of 4.3 mm and a length of 11 mm was selected for this study.

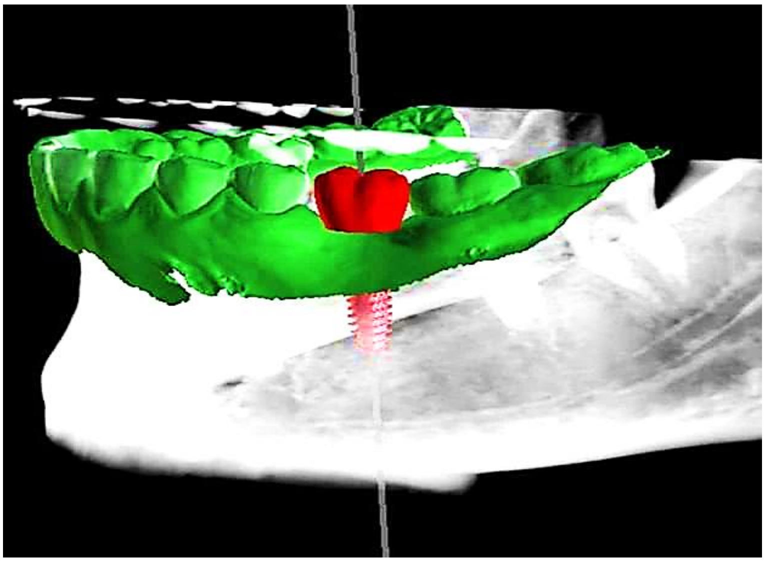

**Figure (3):** Implant planning and alignment of the implant with the crown.

**Surgical guide design**

The design parameters for the master surgical guide were standardized to ensure precision and consistency. The guide was created with a wall thickness of 3 mm, an offset of 0.5 mm from the adjacent teeth, and a sleeve offset of 0.05 mm. A guide tube with a diameter of 5.9 mm was intended for the chosen implant system, which meant that a guide hole of 6.2 mm needed to be printed. To make it easier for doctors to check that the seating was correct, each template had viewing windows that were placed symmetrically, so that the guides' fit could be seen directly during placement (25). Surgical guides were used for fully guided implant placement and covered the whole arch.

**Printing**

Forty surgical guides were made and split evenly based on the 3D printing technology. A DLP printer (Phrozen Luimi 8K, Phrozen Technology, China) made twenty (n = 20) guides, and an LCD printer (Creality HALOT-MAGE Pro 8K, Creality, China) made another twenty (n = 20). Two separate resins were employed for each printing technology: V-GUIDE resin (Crown for Dental and Medical Supply, USA) and SG GUIDE resin (Senertek, Turkey; Batch No. 9342EEC). 10 samples were printed with the first resin, and 10 samples were printed with the second resin for each printer.

There were two design subgroups for each resin group, one for each cast design: OS and GS. Thus, for every resin type, five (n = 5) OS-design and five (n = 5) GS-design guides were fabricated, resulting in a balanced design across printer types, resin materials, and guide designs.

Both systems used the same printing settings to make sure the comparison was fair. The layer thickness, lifting height, lifting speed, and light-off delay were all adjusted to 0.04 mm, 5 mm, 5 mm/s, and 1 s, respectively, for the Phrozen Luimi 8K (DLP) and Creality HALOT-MAGE Pro 8K (LCD) printers. To help the samples stick together better while printing, all of them had three bottom layers.

DLP and LCD technologies use different ways to project light (digital micromirror device vs. masked LCD illumination). To make sure the selected resin materials polymerized properly, the exposure times for both the first and second layers were changed according to each manufacturer's instructions. This method is based on earlier studies that looked at DLP and LCD printers for dental use. In those studies, most of the printing settings were the same, but the exposure settings were changed to account for differences in light intensity and projection efficiency. (23,26) After printing, using an ultrasonic cleaning device (Digital Ultrasonic Cleaner, China), the 3D-printed surgical guides were carefully taken off the build platform and cleaned twice in 99% isopropyl alcohol (IPA) for 5 minutes each. This was done to get rid of any uncured resin residues. The Phrozen Post-Curing Unit (Phrozen, China) was used to post-cure samples printed using the DLP printer (Phrozen Luimi 8K, Phrozen Technology, China). This unit uses 405 nm LEDs to cure the samples.

The Anycubic Wash & Cure Plus machine (Anycubic, China) was used to wash and cure the samples made using the LCD printer (Creality HALOT-MAGE Pro 8K, China). It has a single chamber and a 405 nm LED light source. According to the manufacturer's instructions, printed guides were air-dried for 10 minutes and then cured for 15 minutes on each side in both systems.

**Implant placement**

To make sure the fit was right, each surgical template was carefully seated onto its corresponding master cast. A guided implant mounter with a stop-width that connected with a ratchet connection was used to set the final position of the implant. This made sure that the insertion depth and stability were controlled during installation, as illustrated in Figure 4. The implants utilized in this investigation (C-TECH Implant, Italy; Lot no. EL-6070) were held in place on the master cast with a medium-viscosity elastomeric A-silicone material (Silginat, Kettenbach GmbH & Co. KG, USA; Lot no. 1382611). Before further investigation, this process made sure that each implant was correctly indexed to its cast.

**Figure (4):** The final implant position was achieved with the assistance of a guided implant Mounter with a stop width that connected with a Ratchet connection.

**Accuracy evaluation**

To assess the precision of the final implant placement, scan bodies were affixed to the placed implants in each printed model. This study used the EL Scan Body, which is made of PEEK and titanium (C-TECH Implant, Italy; Lot no. EL-6070). Each model with its attached scan body was scanned using an intraoral scanner (*MD-ISO300, Medit i700, BF2203100023; Medit Corp., Korea*), generating a digital representation of the cast and implant position. The scan body was then digitally aligned with the corresponding library file within the software environment (11).

An intraoral scanner was selected over an extraoral scanner because the Medit I500 intraoral system has demonstrated higher accuracy in transferring implant positions compared to the Rainbow extraoral scanner (27). The preoperative virtual plan and the postoperative implant positions were superimposed (28) using Blue Sky Bio software to assess positional deviations (29). The overall accuracy of the 3D-printed surgical guides was analyzed following international standards and previously validated methodologies (23,30,31).

Trueness was evaluated by measuring the linear deviation (in millimeters) between each virtually planned implant and its corresponding actual implant position using Blue Sky Plan software (Blue Sky Bio, USA). The printed models were superimposed on the reference STL files through the software's built-in alignment function, and deviation values were calculated using a digital caliper in the software at the selected reference points at the coronal, apical, and angular positions (11).

Six deviation metrics were recorded for each sample that represent trueness: angular deviation (°), depth deviation (mm), horizontal coronal deviation (mm), global coronal deviation (mm), horizontal apical deviation (mm), and global apical deviation (mm). To find the precision, we found the standard deviation (SD) of the deviation values in each subgroup ($n = 10$). A smaller SD meant that the printing process was more repeatable when the conditions were the same. After that, we used both the mean deviation and the SD data to evaluate the dimensional accuracy of the two printing technologies (DLP vs. LCD), two resins (SG and V-guide), and the two occlusal guide designs (OS vs. GS).

**Statistical Analysis**

Statistical analyses were performed using SPSS version 25 (IBM Corp., Armonk, NY, USA). Descriptive statistics included the mean (M), standard deviation (SD), and sample size (N). Multivariate analysis of variance (MANOVA) was used to evaluate the effects of occlusal surface design, resin material, and printer type on the six dependent variables. Univariate analyses were subsequently conducted to identify the specific dependent variables significantly affected by each factor. Statistical significance was set at $P \leq 0.05$, with $P \leq 0.01$ considered highly significant.

## RESULTS

Table 1 shows descriptive statistics for all six parameters—angular, depth, horizontal coronal, global coronal, horizontal apical, and global apical— for printer type, resin type, and occlusal design.

A multivariate analysis of variance (MANOVA) was performed to investigate the effect of printing technology (Printer), resin material (Resin), and occlusal surface design (Occlusal) on six dependent variables indicative of implant placement accuracy: depth deviation, angular deviation, global apical deviation, horizontal apical deviation, global coronal deviation, and horizontal coronal deviation.

Table (1): mean deviation values (trueness) and standard deviation values (precision) for the DLP and LCD printers, occlusal design (OS and GS), and Resins (V-GUIDE and SG guide) across six parameters: angular deviation, depth deviation, horizontal coronal deviation, global coronal deviation, horizontal apical deviation, and global apical deviation.

| **Descriptive statistic** | | | **angular deviatior** | **depth deviation** | **horizontal coronal deviation** | **global coronal deviation** | **horizonti apical deviatior** | **global apical deviation** |
|---|---|---|---|---|---|---|---|---|
| **Printer type** | DLP | Mean (trueness) | 1.7920 | 0.6000 | 0.4255 | 0.7965 | 0.9980 | 1.3865 |
| | | N | 20 | 20 | 20 | 20 | 20 | 20 |
| | | Std. Deviati (precision) | 0.04225 | 0.05749 | 0.07487 | 0.04452 | 0.05845 | 0.09505 |
| | LCD | Mean (trueness) | 1.9825 | 0.6890 | 0.5080 | 0.8760 | 1.2195 | 1.5510 |
| | | N | 20 | 20 | 20 | 20 | 20 | 20 |
| | | Std. Deviati (precision) | 0.07078 | 0.05675 | 0.07481 | 0.04828 | 0.10169 | 0.09629 |
| | Total | Mean | 1.8873 | 0.6445 | 0.4668 | 0.8363 | 1.1088 | 1.4688 |
| | | N | 40 | 40 | 40 | 40 | 40 | 40 |
| | | Std. Deviati | 0.11232 | 0.07218 | 0.08486 | 0.06100 | 0.13886 | 0.12593 |
| **Occlusal design** | OS | Mean (trueness) | 1.9340 | 0.6965 | 0.5330 | 0.8780 | 1.1820 | 1.5590 |
| | | N | 20 | 20 | 20 | 20 | 20 | 20 |
| | | Std. Deviati (precision) | 0.11278 | 0.04913 | 0.05823 | 0.04467 | 0.14047 | 0.08879 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | GS | Mean (trueness) | 1.8405 | 0.5925 | 0.4005 | 0.7945 | 1.0355 | 1.3785 |
| | | N | 20 | 20 | 20 | 20 | 20 | 20 |
| | | Std. Deviati (precision) | 0.09259 | 0.05087 | 0.04639 | 0.04442 | 0.09248 | 0.08671 |
| | Total | Mean | 1.8873 | 0.6445 | 0.4668 | 0.8363 | 1.1088 | 1.4688 |
| | | N | 40 | 40 | 40 | 40 | 40 | 40 |
| | | Std. Deviati | 0.11232 | 0.07218 | 0.08486 | 0.06100 | 0.13886 | 0.12593 |
| **Resin** | V- GUID | Mean (trueness) | 1.8830 | 0.6435 | 0.4575 | 0.8365 | 1.1050 | 1.4630 |
| | | N | 20 | 20 | 20 | 20 | 20 | 20 |
| | | Std. Deviati (precision) | 0.11051 | 0.08035 | 0.08441 | 0.06580 | 0.14051 | 0.13127 |
| | SG-guid | Mean (trueness) | 1.8915 | 0.6455 | 0.4760 | 0.8360 | 1.1125 | 1.4745 |
| | | N | 20 | 20 | 20 | 20 | 20 | 20 |
| | | Std. Deviati (precision) | 0.11681 | 0.06509 | 0.08647 | 0.05753 | 0.14075 | 0.12348 |
| | Total | Mean | 1.8873 | 0.6445 | 0.4668 | 0.8363 | 1.1088 | 1.4688 |
| | | N | 40 | 40 | 40 | 40 | 40 | 40 |
| | | Std. Deviati | 0.11232 | 0.07218 | 0.08486 | 0.06100 | 0.13886 | 0.12593 |

N: number of specimens, OS: original shape of occlusal surface, GS: groove sealing of occlusal surface.

Table 2 shows that Wilks' Lambda was used to measure the multivariate effect. The results showed that printer type had a statistically significant multivariate effect on the combined dependent variables. The kind of resin did not have a multivariate influence on the combined dependent variables. Occlusal shape exhibited a significant multivariate effect.

Table (2) presents the multivariate analysis of variance (MANOVA) results using Wilks' Lambda to evaluate the overall effects of printer type, Resins type, and occlusal shape.

| **Effect** | **Wilks' Lambda** | **F** | **Hypothesis df** | **Error df** | **Sig.** | **Partial Eta Squared** |
|---|---|---|---|---|---|---|
| Printer | 0.015 | 301.124 | 6.000 | 27.000 | 0.000 | 0.985 |
| Resin | 0.727 | 1.692 | 6.000 | 27.000 | 0.161 | 0.273 |
| Occlusal | 0.015 | 293.729 | 6.000 | 27.000 | 0.000 | 0.985 |

**: highly significant at P ≤ 0.01.

The univariate tests (as in Table 3) revealed that the printer type exerted a statistically significant influence on all six deviation measures ($p < 0.001$ for all). The corresponding

Partial Eta Squared ($\eta^2$) values ranged from 0.794 to 0.957, showing that all parameters had large effect sizes. The univariate analysis demonstrated that resin type significantly influenced horizontal coronal deviation (p = 0.018), indicating a modest impact size. There were no significant changes (p > 0.05) for angular, depth, global coronal, horizontal apical, or global apical deviations. The univariate tests (as in Table 3) showed that the shape of the occlusal surface had a statistically significant effect on all deviation parameters (p < 0.001).

Table (3): presents the univariate tests of between-subjects' effects for the variable printer type, occlusal design, and resin type on each of the six deviation parameters

| variable | Deviations | F-value | sig | Partial Eta Squared |
|---|---|---|---|---|
| Printer type | angular deviation | 363.812 | 0.000** | 0.919 |
| | depth deviation | 196.795 | 0.000** | 0.860 |
| | horizontal coronal deviation | 123.469 | 0.000** | 0.794 |
| | global coronal deviation | 187.267 | 0.000** | 0.854 |
| | horizontal apical deviation | 713.633 | 0.000** | 0.957 |
| | global apical deviation | 598.017 | 0.000** | 0.949 |
| Occlusal design | angular deviation | 87.642 | 0.000** | 0.733 |
| | depth deviation | 268.720 | 0.000** | 0.894 |
| | horizontal coronal deviation | 318.481 | 0.000** | 0.909 |
| | global coronal deviation | 206.585 | 0.000** | 0.866 |
| | horizontal apical deviation | 312.178 | 0.000** | 0.907 |
| | global apical deviation | 720.006 | 0.000** | 0.957 |
| Resin type | angular deviation | 0.724 | 0.401 | 0.022 |
| | depth deviation | 0.099 | 0.755 | 0.003 |
| | horizontal coronal deviation | 6.209 | 0.018 | 0.162 |
| | global coronal deviation | 0.007 | 0.932 | 0.000 |
| | horizontal apical deviation | 0.818 | 0.372 | 0.025 |
| | global apical deviation | 2.923 | 0.097 | 0.084 |

**: highly significant at $P \leq 0.01$.

## DISCUSSION

Possible deviations between the preoperative plan and the postoperative implant positions require attention because they may lead to undesirable clinical consequences. Deviations at the shoulder of the implant can significantly affect prosthetic planning, and deviations at the apex of the implant can lead to the violation of important anatomic landmarks and perforations (32).

The null hypothesis was rejected for printer type and occlusal surface design, and accepted for resin type.

**Effect of Printer Type (DLP vs LCD)**

The results indicated that the kind of printer exerted a statistically significant multivariate effect on the combined dependent variables. This shows that the type of 3D printer (DLP or LCD) had a big impact on the overall accuracy findings, with a big effect size ($\eta^2$ = 0.985). This indicates that the type of 3D printer (DLP or LCD) significantly influenced the overall accuracy results, exhibiting a substantial effect size ($\eta^2$ = 0.985). The univariate tests demonstrated that the printer type exerted a statistically significant influence on all six deviation measures ($p < 0.001$ for each). The Partial Eta Squared ($\eta^2$) values, ranging from 0.794 to 0.957, indicated that all parameters had substantial impact sizes.

The fundamental difference between DLP and LCD printers is how the light source is set up. Using only one digital micromirror device, DLP printers show the whole layer at once. In contrast, LCD printers employ a pixel-based mask that is illuminated by UV LEDs, which may result in uneven light distribution and distinct curing at the print area's edges. This increases the size and polymerization stability of the DLP system. Because DLP printers project light precisely, they are incredibly accurate. Each of the DMD's millions of tiny mirrors can be manipulated to direct light in a specific direction. Because the UV projector is more powerful than LCD printers, you can precisely control the curing process, which smooths the surfaces (26).

The results of the present investigation agree with those of Sim et al. (33), who concluded that DLP and SLA printers were more accurate, with DLP performing better in both linear and angular deviations. Generally speaking, DLP printers were more accurate than LCD printers. The high-resolution LCD4s performed the best among the LCDs. DLP 3D printers are also more accurate than LCD 3D printers, according to Moon et al. (31) and Tsolakis et al. (34) as well.

A mean angular deviation of 3.58° (SD = 0.2), a mean vertical deviation of 0.12 mm (SD = 0.23), a mean apical horizontal deviation of 1.41 mm (SD = 0.1), and a mean coronal horizontal deviation of 1.12 mm (SD = 0.08) were reported by Balaguer-Martí et al (35).

The DLP printer's mean horizontal coronal deviation in this study was 0.797 mm, while the LCD printer was 0.876 mm. The LCD printer's mean apical horizontal deviation was 1.220 mm, while the DLP printer was 0.998 mm. The DLP and LCD printers had angular deviations of 1.792° and 1.983°, respectively. These values were comparable to the findings of Dabbous et al. (36), where the mean angular, coronal, and apical deviations were 3.1°, 0.98 mm, and 1.1 mm, respectively. Hussein et al (37) had an average angular deviation of 2.86°- 4.26°. The average total coronal deviation was 1.6 mm - 1.75 mm. The average total apical deviation was 1.71 mm- 1.73 mm. The average deviations in this study fall within these ranges, which means that the printed guides from DLP and LCD were good enough. The current findings validate that the dimensional precision of 3D-printed surgical guides is significantly affected by the printer type. The DLP printer's excellent accuracy and precision make it perfect for tasks that need precise positioning, such as making surgical guides for implants. This study disagrees with Kim et al. (38), who suggested that, for dental casts, all 3D printers analyzed performed similarly.

**Effect of resin type (SG guide and V-guide)**

The type of resin did not have a big effect on the aggregated accuracy metrics, as shown by the results of the multivariate analysis of variance (MANOVA). There was no significant difference between the two resin groups when all types of deviation were looked at together.

The univariate tests, on the other hand, showed a small effect size (partial $\eta^2$ = 0.162) and a big difference in the horizontal coronal deviation ($F$ = 6.209, $p$ = 0.018). This suggests that the resin type may have influenced the coronal level lateral precision, possibly due to slight variations in mechanical rigidity, light transmission, or polymerization shrinkage between the two materials.

The angle, depth, global coronal, horizontal apical, and global apical deviations didn't alter much ($p > 0.05$). It demonstrates that both resins effectively preserved precise measurements during the construction of the surgical guide, as the majority of features are identical. These results are consistent with a recent study by Tsolakis et al. (26), which indicated that resin material does not influence overall accuracy and precision when similar printing processes and post-processing methods are utilized.

This study disagrees with Keßler et al. (20), who concluded that the resin material affected the precision of 3D-printed surgical guides.

**Effect of sealing Occlusal Surface**

The OS group showed slightly bigger mean deviations for most of the metrics, such as an angular deviation of 1.934° and a global apical deviation of 1.559 mm. When compared to the GS group (1.840° and 1.378 mm, respectively), however, the differences were quite small, which means that the precision and repeatability of implant placement were about the same for both occlusal designs. High precision is indicated by the small standard deviation values in both groups.

A significant multivariate effect was observed in the occlusal design. The results of the univariate tests showed that all deviation parameters were statistically significantly impacted by the occlusal surface's shape ($p < 0.001$). Angular, depth, horizontal, and global coronal and horizontal and global apical deviations were all significantly different. All Partial Eta Squared values (0.733–0.957) showed large effect sizes, and the F-values ranged from 87.642 to 720.006, indicating that the shape of the occlusal surface explained a significant amount of the variance in deviation values, which is consistent with Lim et al (38), who concluded that taking occlusal groove sealing into consideration before designing and manufacturing a 3D-printed surgical guide can greatly increase its accuracy and fit. Sealing the grooves does the following: simplifies the anatomy and occlusal morphology of the model; simplifies the design as the fitting surface will less corrugated features. Eventually, producing a fitting surface via 3D printing to fit on simplified anatomy is much more predictable than on a more detailed anatomical model (39) . This study agrees with Dong et al. (21), who concluded that the occlusal surfaces of posterior teeth displayed greater deviations than other regions, especially in pits and fissures.

## CONCLUSIONS

Within the limitations of the current study, it is possible to conclude that:
The DLP printer was more accurate than the LCD printer, but all of the printed guides were accurate within an acceptable range. Also, the accuracy of a surgical guide can be increased by immediately sealing the grooves of the occlusal surface of the back teeth before making the surgical guide. Both resins (SG guide and V-guide) had the same level of accuracy, which means that the type of material used doesn't have a big effect on the printing process while the same conditions are kept.

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**Authors' Contribution**
The author Hasan RH designed the study and supervised the work. Ismael IH conducted the experiments, collected data, performed the data analysis, and wrote the manuscript. Abduo J contributed by providing scientific information and assisting in the study.

**Ethical statement**: This study was reviewed and approved by the Research Ethics Committee of the College of Dentistry, University of Mosul (**Reference No.: UoM.Dent. 25/1010**). Ethical approval was granted on November 25, 2024. The study was conducted in accordance with the ethical guidelines and regulations of the University of Mosul, College of Dentistry.

**Conflict of interest**
The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

**Availability of data and materials**: All data generated or analyzed during this study are included in this published article and its supplementary information files.

**Declaration of Generative AI and AI-assisted technologies**
The authors declare that no generative AI or AI-assisted technologies were used in the preparation of this manuscript. The authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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## تأثير تقنية الطباعة ثلاثية الأبعاد ونوع الراتنج وتصميم الإطباق على دقة الأدلة الجراحية

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**الملخص**

**الأهداف**: هدفت هذه الدراسة إلى تقييم الدقة من حيث الصحة والتكرارية للأدلة الجراحية المصنعة باستخدام نوعين مختلفين من الطابعات ثلاثية الابعاد، ونوعين من الراتنجات، وتصميمين مختلفين للسطح الاطباقي: (الشكل الأصلي للسطح الإطباقي (و)إغلاق الأخاديد الإطباقية. **المواد وطرائق العمل**: تم تصنيع أربعين دليلًا جراحيًا باستخدام طابعة تعتمد تقنية المعالجة الضوئية وتقنية شاشة الكريستال السائل مع استخدام نوعين من الراتنجات (SG guide و(V-guide، وتصميمين مختلفين للسطح الإطباقي. تمت إزالة المنطقة المخطط لوضع الزرعة فيها رقميًا من النموذج، مما أتاح تموضعًا سلبيًا للزرعة من خلال الدليل الجراحي. ثم تم إدخال (scan body) في الزرعة ومسح النموذج باستخدام ماسح داخل الفم. بعد ذلك، تمت مقارنة موضع الزرعة المخطط له مع موضع الزرعة الفعلي. ثم اعتماد ست قياسات تمثل دقة وضع الزرعة، وهي انحراف العمق، الانحراف الزاوي، الانحراف القِمّي الكلي، الانحراف القِمّي الأفقي، الانحراف الإكليلي الكلي، الانحراف الإكليلي الأفقي تم إجراء الإحصاءات الوصفية وتحليل التباين متعدد المتغيرات **النتائج**: أظهرت مجموعة طابعة DLP ومجموعة GS متوسطات انحراف وانحرافات معيارية أقل عبر جميع المعايير المقاسة .كان لنوع الطابعة تأثير متعدد المتغيرات ذو دلالة إحصائية (Wilks' Lambda = 0.015, p<0.001, Partial $\eta^2$ = 0.985). أما نوع الراتنج فلم يُظهر تأثيرًا متعدد المتغيرات على المتغيرات التابعة مجتمعة، كما يتضح من (Wilks' Λ = 0.727, p = 0.161). بينما أظهر شكل السطح الإطباقي تأثيرًا متعدد المتغيرات ذا دلالة إحصائية (Wilks' Lambda = 0.015, p<0.001). وكشفت الاختبارات الأحادية المتغير أن نوع الطابعة وشكل السطح الإطباقي كان لهما تأثير معنوي إحصائي على جميع معايير الانحراف الستة (p < 0.001 لجميعها)، في حين أن نوع الراتنج أظهر تأثيرًا معنويًا فقط على الانحراف الإكليلي الأفقي (p = 0.018). **الاستنتاجات**: كانت طابعة DLP أكثر دقة من طابعةLCD كما يمكن زيادة دقة الدليل الجراحي من خلال إغلاق أخاديد السطح الإطباقي مباشرة قبل تصنيع الدليل الجراحي. ولم يظهر اختلاف في الدقة بين راتنجي SG وV-guide.

**الكلمات المفتاحية:** طابعة DLP، طابعة LCD، انحراف، ختم الأخاديد.