A THREE DIMENSIONAL INVITRO STUDY ON THE ACCURACY OF IMPLANT PLACEMENT USING SURGICAL STENTS FABRICATED USING THREE DIFFERENT 3D PRINTERS

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ABSTRACT

INTRODUCTION: Computer guided implant surgery is now widely used giving excellent results in placing implants accurately and safely, however understanding the impact of various 3D printers on the precision of the final implant position is still up for debate.

OBJECTIVES: The aim of this study is to determine the accuracy of 3 different 3D printers used in stent fabrication on the final implant position as compared to the planned position.

MATERIALS AND METHODS: A comparative invitro study included 30 surgical guides divided into 3 groups.10 surgical guides printed with SLA printer and 10 surgical guides printed with DLP printer and 10 surgical guides printed with an FDM printer.They were used to place 30 implants in 30 different models and the final implant position was compared with the planned implant placement by superimposition using CBCT and implant planning software. The deviation between the actual and planned implants was measured at angular deviation in degrees and horizontal and vertical deviations at both hex and apex.

RESULTS: Significant differences were found between the three study groups in regards to the angular deviation, vertical hexagon, and apex, with no significant differences in the horizontal hexagon and apex ($p= 0.07$ and 0.09 respectively). Regarding the angular deviation, the SLA group showed the lowest mean (SD) value (1.42 (0.35)), with a significant difference between SLA and FDM groups ($p= 0.02$). As for the vertical hexagon and apex, the FDM group showed significantly lower values than both DLP and SLA groups (mean (SD)= 0.30 (0.19) and 0.20 (0.16), for hexagon and apex, respectively). Conclusion: SLA printers provide more accurate implant placement when angular deviation is the main concern, while FDM printers has less vertical deviation at hexagon and apex. However all 3 3D printers showed clinically acceptable results.

KEYWORDS: Computer guided implant surgery, 3D printers, SLA printer, DLP printer, FDM printer, Surgical guides.

RUNNING TITLE: Invitro study comparing 3 different 3Dprinters in surgical guide fabrication.

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INTRODUCTION

Today, the rehabilitation of partly and totally edentulous jaws involves the common implantation of dental implants. Many long-term studies have showed positive outcomes after long-term follow-up (1-4).

Recent advancements in computer technology and radiographic three-dimensional (3D) imaging technique have largely been responsible for the development of the procedure for dental implants (5,6).

In the past 10 years, "prosthesis driven" implant placement has received extra focus in order to maximize the aesthetic result of the final prosthesis with optimal loading parameters and effective cleaning access. Preoperative planning and effective interaction between the patient, the surgeon, and the prosthodontist became possible with the help of 3D imaging, which depicts the alveolar bone in relation to the optimal tooth location, and planning software (7,8).

The best method for treating patients with dental implants is prosthetic-driven implant dentistry (9,10). To achieve the proper 3D implant position within the alveolar bone in relation to the intended prosthetic replacement, careful pretreatment planning is necessary (11).

Computed tomography (CT) or cone-beam computed tomography (CBCT) can be used to create a 3D model or digital file of the alveolar bone and associated oral anatomy (cone beam computed tomography). With the capacity to scan constrained fields of view, CBCT significantly reduces radiation dose (12). A further 3D model of the patient's oral state is produced by the addition of surface scanning technologies, either using intra-oral or extra-oral scanning procedures, and it can be superimposed on the radiographic data set to create a lifelike 3D virtual patient. On implant planning software, this virtual patient can be viewed including data on hard and soft oral tissue, suggested prosthetic treatments, and information on volume of the bone can be represented as various layers (13). Clinicians can do a virtual implant placement within the implant planning software while respecting the current anatomical circumstances and future prosthetic needs. This knowledge can be utilized to create surgical drill guides that help the doctor place the implants where they are intended to be.

Static guidance systems are described as systems that use a rigid surgical implant template or guide to convey the preset virtual implant position to the surgical operative region (5). Such static guidance systems are increasingly sold to dental doctors with the expectation that they will deliver high levels of accuracy. However, concerns have been expressed over the dependability, accuracy, and precision of these static surgical drill guides to reproduce the intended implant position, despite the fact that these improvements appear to be promising. Since two previous ITI (international team for implantology) consensus articles on the accuracy of guided surgery were indecisive, it was acknowledged that each stage in this digital workflow, whether taken alone or in combination with others, may produce errors (14). The result may be compromised if the actual implant position differs from the hypothetical planned implant position (5, 14). The use of surgical guides offers various benefits, including a reduction in the manual errors associated with free-hand implant placement and the ability to do less invasive procedures. As a result, postoperative surgical issues are reduced, which benefits both the patient and the practitioner psychologically (13). Precision is another benefit because implants are prosthetic-driven components and any deviation can cause unexpected changes in performance. Implant placement has become more precise and secure thanks to surgical guidance. When placing implants in vulnerable areas of the mouth, safety is one of the most crucial considerations. Even a minor mistake can result in serious consequences, but with the use of surgical guides, such mistakes can be avoided and vulnerable structures can be safeguarded (14). The advantages of precise placement made possible by surgical guides are predictability, aesthetics, hygiene, and shorter implant operation times. Graft harvesting may be made possible by the use of specialised surgical guide types, such as bone reduction guides(13, 14). On the other hand, surgical guides prevent the dental implant from being placed in the predetermined position if any adjustments are needed during surgery, and any tissue changes (such as swellings and the loss of abutment teeth) may affect how the stent fits, which results in the failure of the dental implant placement. With dislocation occurring during surgery, When drilling is intended to penetrate strong bone, torsional stresses are applied to the sleeves, raising the guide off the drill bit. Another disadvantage is the higher learning curve and start-up costs related to 3D printing and software purchases (14).

Additive manufacturing (3D printing) may be utilized to produce surgical guides for oral and maxillofacial procedures, create customized tissue regeneration scaffolds, carry out operation simulation, give accurate diagnosis, and instruct patients (15-18). Adoption of additive manufacturing is dependent on variables like low production costs, treatment customization, shorter treatment times, and clinically acceptable precision (17, 19-21). Milling and additive manufacturing have grown in popularity for the manufacture of implant surgical guides used in static computer-assisted implant surgery (s- CAIS) (22). For milled surgical templates, satisfactory levels of implant location precision have been demonstrated (22). However, milled parts have drawbacks such as the reluctance to make complicated structures, expensive material and equipment costs, and significant levels of waste generated during the process, which is why 3D printed parts are preferred (22). The popularity of 3D printed surgical templates may have been influenced by the availability of reasonably priced desktop 3D printers, FDA-approved printing resin, and free open-source implant planning software (20). The accuracy of surgical templates is directly influenced by cone beam computed tomography (CBCT) data, imprinting material, digital scan precision, durability of the surgical template, type of supporting tissue, manufacturing precision, and the surgeon's experience (23-25). In order to reduce the amount of errors for s-CAIS, it is crucial to know what kind of equipment and printing technologies can provide clinically acceptable accuracy and precision levels in light of the growing popularity of intraoral scanners and inexpensive 3D printers.

Studies comparing the precision of 3D printers have concentrated on the printer's capacity to correctly reproduce the digital file's precise size and surface (21,24,26-30). Factors including orientation of the cast, thickness of printing layer, printed part size and geometry, and hardware capabilities can all have an impact on the accuracy of the parts (20-22,31,32). It is unknown, however, if these factors have a big influence on the printed device's overall performance. Studies comparing the accuracy of the definitive implant position using the 3D printing equipment and its technologies to preoperative digital implant placement are scarce. The accuracy of the digitally planned implant position in comparison to the postoperative position was evaluated using CBCT images obtained following surgery and digital imaging and communications in medicine (DICOM) files superimposed on the preoperative implant site (33). The aim of this in vitro investigation is to ascertain whether using different 3D printers will have a significant impact on the post operative implant position as compared to the digitally planned one and to determine if any of the three printers is superior to the others. The null hypothesis states that surgical guides made with various kinds of 3D printers would not have a significant impact on the final implant position.

MATERIALS AND METHODS

The study design is a comparative study that was conducted on thirty resin printed models of a partially edentulous patient with bounded edentulous area with the edentulous space sufficient for placement of an implant (kennedy class III).

Sample size was estimated assuming 5% alpha error and 80% study power. The mean±SD angular deviation for Stereolithography (SLA) 3D printer was 1.25±0.49 degrees and 0.99±0.57 degrees for Digital Light Processing (DLP) (34). Fused Deposition Modeling (FDM) showed deviation of 3.22±1.55 degrees (24). Using F test and the largest SD (1.55) to ensure adequate power, sample size was calculated to be 9 surgical guides per group, increased to 10 to make up for processing errors. Total sample size = number per group × number of groups = 10 × 3 = 30 guides. Sample size was based on Rosner's method (35) calculated by G*Powe 3.0.10 (36). Models with no surface discrepancies and obvious flaws were selected for this study. The study included 3 groups which are:

Group A

Included ten implants placed using surgical guide printed and fabricated by Stereolithography (SLA)(Formlabs2, USA) 3D printer.

Group B

Included ten implants placed using surgical guide printed and fabricated by Digital Light Processing (DLP) (Asiga Max, Australia) 3D printer.

Group C

Included ten Implants placed using surgical guide printed and fabricated by Fused Deposition Modeling (FDM) (Creality3D Ender-3 V2, China).

A patient with an edentulous area that has a bounded saddle with one missing tooth was selected and patient arch was recorded using addition silicon impression material and the cast was scanned using an extra-oral desktop 3D optical scanner (Ineos, Sirona, Germany) to obtain a Standard Tessellation Language (STL) file for the model (Fig 1).

The STL file was used to print 30 resin model replicas using an SLA 3D printer (Formlabs2, USA) (Fig 2). The resin model was then scanned with a CBCT machine (icat2, Kavo, Germany) to obtain DICOM (Digital Imaging and Communications in Medicine) data and the resin model was scanned with an extra-oral desktop 3D optical scanner (Ineos, Sirona, Germany).The DICOM data and the scanned resin cast (as STL file) were imported in an implant and surgical guide planning software (Blue sky bio software, USA). Once the planning was completed and approved, digital plan was sent as Standard Tessellation Language (STL) file to the manufacturer for 3D printing and fabrication of a fully guided surgical guide using three different printing technologies (10 each) but with the same settings adjusted. The layer thickness was set to 0.1 mm and the print resolution was 100 microns with the same orientation used and automatic supports were created with all other settings set according to manufacturer's recommendations. The 3D printers were calibrated with the software by printing guides with multiple guide holes each hole with a different diameter and fitted with the guided surgery drills to determine the optimum measurements used on the software. This procedure was repeated for all three printers and the optimum (best fitting) measurements were used.

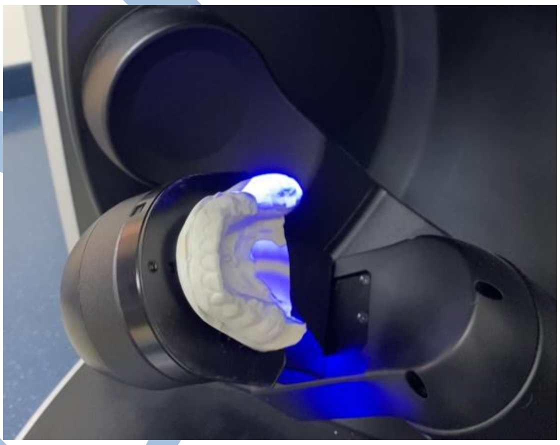

Figure (1): Model scanning.

Figure (2): Printed resin model.

An SLA printer use the additive manufacturing process where surgical guides are constructed by a printer that use a laser as light source for curing photo reactive polymers layer by layer while a DLP 3D printer use the additive manufacturing process and surgical guides are constructed by a printer that uses a digital light projector (DLP) as the light source to cure photo-reactive polymers and an FDM printer selectively deposits liquefied material in a pre-set path layer by layer.

Placement of implant was carried out following the implant manufacturer’s instructions by one experienced surgeon. All the implants were carried out by the same operator using a fully guided surgical kit (Dentium, South Korea) (Fig 3). After placement a cone beam scan was acquired with similar acquisition parameters of the pre-placement scans to verify the implant’s final position; these images (preoperative and postoperative) were superimposed via blueskybio software (Bluesky bio, USA) to match the planned and actual implant locations and axes (Fig 4).

Figure (3): Implant placement using dentium fully guided kit.

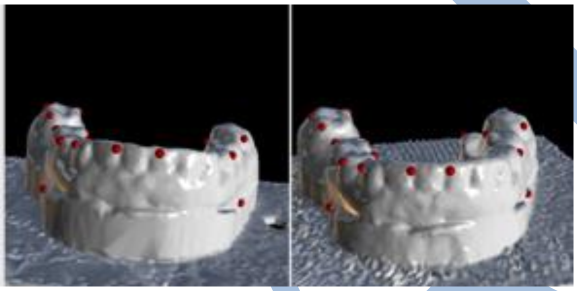

Figure (4): Superimposition on blueskybio software.

Linear and angular discrepancies between the actually implanted and virtually designed implant locations were examined in 3D during radiographic assessment (x, y, and z axes).

a. Linear horizontal deflection was recorded at the midpoint of the apex and midpoint of the hexagon of the implants in millimeters (Fig. 5A) (37).
b. Apical implant depth deviation, which was used to measure vertical deviations, is measured in millimeters. (Fig. 5B) (37).
c. The actual implant position and virtually intended implant position's principal axis' angle discrepancy was measured in degrees. (Fig. 5A) (Fig 6) (37).

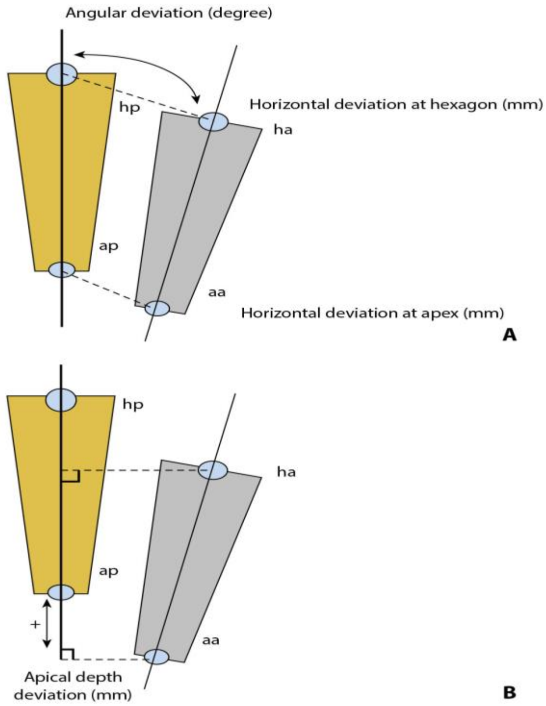

Figure (5): Measurement deviation calculation. A, At level of hexagon, apex, and angular deviation. B, Depth between virtually planned implant and implant placed after surgery. aa, apex actual; ap, apex planned, ha, hexagon actual; hp, hexagon planned.

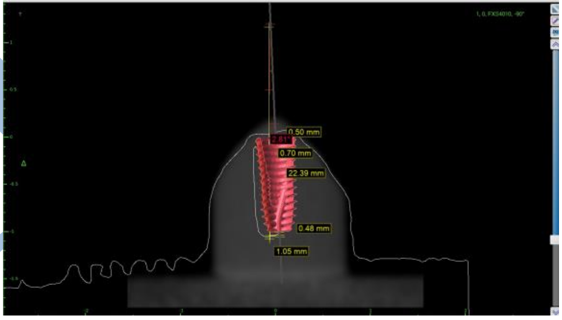

Figure (6): Measurements between actual and planned implants.

In order to analyze the data, IBM SPSS for Windows was used (Version 23.0). Descriptive statistics, normality tests, and plots were used to test the normality of all the variables (histograms, Q-Q plots, and boxplots). Since none of the variables had a normal distribution, non-parametric analysis was used. All variables' means, medians, standard deviations, and interquartile ranges were computed. The Kruskal Wallis test was used to compare the three research groups. If the results were significant, repeated pairwise comparisons using the Bonferroni adjusted significance level were then performed. At a p value of 0.05, significance was deduced.

RESULTS

The present study results reported that there were significant differences between the three study groups regarding the angular deviation, vertical hexagon, and apex, with no significant differences in the horizontal hexagon and apex as shown in tables 1and 2. Regarding the angular deviation, the SLA group showed the lowest mean (SD) value (1.42 (0.35)), while the highest value was observed in the FDM group (1.93 (0.55)) with a significant difference between the two groups (p= 0.02). As for the vertical hexagon and apex, the FDM group showed significantly lower values than both DLP and SLA groups (mean (SD)= 0.30 (0.19) and 0.20 (0.16), for hexagon and apex, respectively). Regarding the horizontal hexagon and apex, the FDM group showed the highest mean (SD) values, followed by SLA and DLP groups, with no significant differences existing between the three groups (p= 0.07 and 0.09, for hexagon and apex, respectively).

Table (1): Differences in angular deviation, horizontal and vertical hexagon and apex between the three study groups

		DLP (n= 10)	**FDM (n= 10)**	**SLA (n= 10)**	**P value**
Angular deviation (degrees)	**Mean (SD)**	1.85 (0.54)***ab***	1.93 (0.55)***a***	1.42 (0.35)***b***	H= 6.09 P= 0.048*
	Median (IQR)	1.85 (1.53, 2.14)	1.89 (1.70, 2.15)	1.42 (1.18, 1.76)	
Horizontal hexagon (mm)	**Mean (SD)**	0.56 (0.10)	0.72 (0.22)	0.60 (0.20)	H= 5.40 P= 0.07
	Median (IQR)	0.55 (0.46, 0.65)	0.73 (0.62, 0.86)	0.57 (0.51, 0.69)	
Horizontal apex(mm)	**Mean (SD)**	0.76 (0.21)	1.00 (0.32)	0.70 (0.26)	H= 4.90 P= 0.09
	Median (IQR)	0.78 (0.57, 0.96)	1.13 (0.80, 1.22)	0.57 (0.50, 0.90)	
Vertical hexagon (mm)	**Mean (SD)**	0.56 (0.27)***a***	0.30 (0.19)***b***	0.55 (0.28)***a***	H= 6.69 **P= 0.04***
	Median (IQR)	0.60 (0.34, 0.78)	0.21 (0.13, 0.46)	0.46 (0.36, 0.71)	
Vertical apex (mm)	**Mean (SD)**	0.50 (0.20)***a***	0.20 (0.16)***b***	0.43 (0.21)***a***	H= 11.51 **P= 0.003***
	Median (IQR)	0.55 (0.32, 0.67	0.12 (0.08, 0.30)	0.36 (0.29, 0.53)	

H: Kruskal Wallis test was used
SD: Standard Deviation, IQR: Interquartile Range
*statistically significant at p value <0.05
a,b: different letters signify statistically significant differences between groups using Bonferroni adjusted significance level

Table (2): Post-hoc pairwise comparisons of angular deviation, vertical hexagon and apex between the three study groups

	Group	Compared to	P value
Angular deviation (degrees)	DLP	FDM	1.00
		SLA	0.19
	FDM	SLA	0.02*
Vertical hexagon (mm)	DLP	FDM	0.02*
		SLA	0.81
	FDM	SLA	0.035*
Vertical apex (mm)	DLP	FDM	0.003*
		SLA	1.00
	FDM	SLA	0.04*

*statistically significant differences between groups using Bonferroni adjusted significance level

DISCUSSION

In dentistry, surgical guides must be of high quality in order to avoid important anatomical structures and guarantee a restoration that is both functionally and aesthetically pleasing (38).

Furthermore, choosing what to use for the creation of surgical templates is not simple due to the abundance of corporations and additive manufacturing choices. Clinicians should think about aspects including cost, platform size, printing duration, post-processing requirements, and production quality when selecting a 3D printer for the creation of surgical templates. No significant difference was detected regarding the horizontal hex and horizontal apex in the final implant position using the 3 different 3D printers.

The goal of the current study was to evaluate whether the use of different 3D printing techniques would impact the ultimate implant's position's precision, while Our research demonstrated that using different additive manufacturing techniques resulted in adequate accuracy and mean discrepancies between the planned and actual implant locations ranging from 1.42 (0.35) to 1.93(0.55) degrees for angular deviation, 0.56(0.10) to 0.72(0.22) mm for horizontal hex, 0.70(0.26) to 1.00(0.32) mm for horizontal apex, 0.30(0.19) to 0.56(0.27) mm for vertical hex and 0.20(0.16) to 0.50(0.20) mm for vertical apex. According to the Third EAO Consensus meeting, these values are within the range of the mean system error, which is 0.5 mm for the vertical direction and 1.2 mm for the horizontal surface (15). Likewise to how the suggested 2-mm safety zone is typically taken into account during planning, the final implant position is within this zone (19). This means that a number of factors, such as guide support, drill sleeve degree of freedom, drill length, scanning method and digital file registration may be involved in the occurrence of large variations.

In the present study regarding the angular deviation, the SLA group showed the lowest mean (SD) value (1.42 (0.35)degree), while the highest value was reported in the FDM group (1.93 (0.55) degree) with a significant difference between the two groups (p= 0.02) indicating that SLA printers have a slightly superior angular accuracy when compared to FDM printers suggesting better option when angle deviation is critical for example in multiple splinted implants or close proximity to neighboring teeth and roots.

As for the vertical hexagon and apex, the FDM group showed significantly lower values than both DLP and SLA groups (mean (SD)= 0.30 (0.19) and 0.20 (0.16), for hexagon and apex, respectively) implying that FDM printer might be printer of choice when dealing with implants in close proximity to critical anatomical structures, for example the maxillary sinus, mental foramen, or inferior dental canal, to prevent accidental damage.

No statistical difference was found between the SLA and DLP printers in all parameters tested however, Gjelvold et al (34) reported a statistically significant difference between the DLP and SLA printers for deviation at the entry point (P=.023) and in vertical implant position (P=.009), with a lower mean deviation in the DLP group which might be due to difference in superimposition of the data sets in which he used best fit algorithm rather than manual point by point superimposition and also this difference might be explained that due to a lower degree of photopolymerization during 3D printing, surgical guides from the SLA printer have to undergo a lengthier postpolymerization process than the DLP guides (34). Slight deformities brought on by handling during the postpolymerization procedure may have hindered the guide from fitting properly. The final implant location can be impacted by factors linked to the production of surgical guides, such as the integration of the master sleeve, 3D printer resolution, material surface polish, machine consistency, offset values, post-processing, and 3D printer calibration (34).

Regarding the horizontal hexagon and apex, the FDM group showed the highest mean (SD) values (0.72(0.22) and 1.00(0.32) mm for horizontal hex and apex respectively), followed by SLA and DLP groups, with no significant differences existing between the three groups (p= 0.07 and 0.09, for hexagon and apex, respectively), suggesting no printer is superior when horizontal hex and apex are of concern.

In another study Herschdorfer et al (39) reported a mean deviation in SLA printed guides of 1.44 ±0.61 degrees for angular deviation, 0.24 ±0.19 mm at entry point (hex) and 0.40 ±0.23 mm(101) at apex as compared to our results for SLA guides with a mean deviation of 1.42 (0.35) degrees for angular deviation, 0.60 (0.20) mm for horizontal hex, 0.70 (0.26)mm for horizontal apex, 0.55 (0.28)mm for vertical hex and 0.43 (0.21)mm for vertical apex showing very similar results between the two although the measurments where taken by two different techniques.

In another previous study, Sun et al (24) reported similar results for FDM printed surgical guides stating a mean of 3.22 degrees for angular deviation, 0.91mm for 3D deviation at implant hex and 0.41 mm for 3D deviation at implant apex with our results showing a mean of 1.93 degrees for angular deviation,0.72 and 1.00 mm for horizontal hex and apex respectively and 0.30 and 0.20 for vertical hex and apex respectively showing compareable accuracy between the 2 studies with a slightly superior result when it comes to angular deviation which might be due to different specs and models between the 2 FDM printers but both results are clinically acceptable.

Many factors may have an impact on clinical accuracy. Soft tissue, saliva, patient movement, or moisture in the oral cavity were not taken into account in this investigation. The material utilised for the surgical models also differs biologically from bone, enamel, and soft tissue, which could affect how the guide is seated and how the implant is placed in a clinical environment however this study is an in-vitro study and though lacking all these factors which is a drawback, our goal was to remove or minimize the variables as possible to observe the effect of the different 3D printing technologies on the final implant position and thus more studies should be done clinically. Another restriction was the absence of reference items in the model design. The adoption of a high-accuracy scanner would also help to reduce scanning-related mistakes, while more research is needed to understand whether the scanner's caliber might as well have an impact on the final implant location. Although we used the same CBCT machine with the same parameters in all cases for standardization, CBCT flaws may still be having an impact on the results. It should be emphasized that template-guided implant placement accuracy is typically higher in in-vitro research than in in-vivo clinical investigations (14).

The null hypothesis was rejected because the three different types of additive manufacturing technologies had a significant impact on the final implant location's angle deviation, vertical hex, and vertical apex although all deviations were within the clinically accepted parameters and hence more research is recommended on patients in order to overcome this study’s limitations and broaden the scope to include the long-term effects of implant misplacements or the effects of errors that add up over time.

CONCLUSIONS

Within the limitations of the present work; the following could be concluded that no single 3D printer is superior in all aspects, however SLA printers are slightly more accurate when it comes to angular deviations and FDM printer had lower mean deviation when it comes to vertical hex and apex, although all results were within clinically acceptable parameters. Moreover invitro results are more accurate than invivo ones in assessing surgical guide accuracy.

Tooth supported surgical guides are an accurate method for placing dental implants.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

FUNDING STATEMENT

The authors received no specific funding for this work.

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