JFCR

Journal of Fundamental and Clinical Research
https://jfcr.journals.ekb.eg/
ISSN 2735-023X
Vol. 4, No. 1, 30-41, June 2024

Comparing Accuracy of Surgical Guides Fabricated by Additive Method (3D Printing) versus Subtractive Method (Milling by CAD/CAM) for Prosthetically-Driven Implant Placement "An InVitro Study"

Mounir S. Stino[1], Tarek S. Morsy[2], Talaat Samhan[3]

ABSTRACT

Background*:** The accuracy of prosthetically driven implant placement relies heavily on the technique used for surgical guide fabrication. However, a significant challenge arises in accurately transferring the planned implant position to the surgical site. ***Aim of the study: the aim of this in vitro study is to compare the accuracy of additive (3D printing) and subtractive methods (CAD/CAM Milling) in surgical guides fabrication. ***Materials and methods***: cone beam computed tomography (CBCT) obtained from the dental implant software library of a demo case with missing mandibular first molar was used. The mandible was 3D printed to obtain the master cast. Prosthetically-driven implant planning was done, and surgical guides were fabricated using additive (3D Printing) and subtractive (CAD/CAM Milling) methods. Twenty-four duplicates of master cast were obtained by epoxy resin models. Models were divided into two equal groups according to the fabrication method. Implants were placed following guided surgery protocol using tooth-supported surgical guides, followed by digital scanning using scanning bodies connected to the implants. Supper imposition of planned and placed implants was performed using Geomagic software, and the degree of deviation was calculated at the point of entry, apical point, and angular deviation. The Mann-Whitney U test was used for comparison ($P \leq 0.05$). ***Results***: A statistically significant difference between SLA and milled groups was found for angular deviation ($P<0.001$). Overall, the SLA group showed lower deviations. ***Conclusion*:** The SLA 3D printing surgical guides were more accurate than milled surgical guides. Angular positions demonstrated higher deviation than the horizontal and vertical positions.

***Keywords*:** surgical guides, 3D printing, milling, prosthetically driven implant placement, stereolithography.

1-Postgraduate Researcher, Fixed Prosthodontics Department, Faculty of Oral and Dental Medicine, Misr International University, Cairo, Egypt.
2-Professor of Fixed Prosthodontics, Fixed Prosthodontics Department, Vice Dean of Postgraduate Studies and Research Affairs, Faculty of Oral and Dental medicine, Misr International University, Cairo, Egypt.
3-Lecturer of Fixed Prosthodontics, Fixed Prosthodontics Department, Faculty of Oral and Dental Medicine, Misr International University, Cairo, Egypt.

INTRODUCTION

In an era of supreme esthetic demands,[1] when a treatment methodology fails to deliver adequate esthetics on par with the patient demands, the result is often patient dissatisfaction and unacceptance. One treatment methodology recently becoming more predominant due to, its relative success rates[2] and teeth conservation from unwarranted reduction; is dental implants. For dental implants to prove to be esthetically pleasing, they must fulfill a certain criterion[1,3], of which proper prosthetic placement is of supreme concern.[1]

The concept of prosthetic implant placement has revolutionized the field of implantology by minimizing risks and possible intra-operative complications, while saving time and providing a more predictable esthetic outcome.[4] For a proper prosthetic implant placement protocol to be achieved, the process begins with a proper clinical examination, imaging using cone-beam computed tomography (CBCT), an oral digital scan as an optional step, an implant planning software, followed by a properly fabricated surgical guide, and a compatible surgical drilling kit.[5,6]

In a dental digital era, prosthetic implant placement has become more feasible and accurate, largely due to the role of computer-guided implant surgery.[7,8] Computer-guided implant placement allows for favorable esthetics, prosthetic, and functional outcomes, long-term soft and hard peri-implant tissue stability, optimum occlusion and dental implant loading, possibility of screw-retained prothesis fabrication, all through easy surgical navigation systems and surgical guide fabrication.[7]

A surgical guide is a customized template crucial for diagnosis, treatment planning, and precise implant placement within the alveolus. Due to the increasing demand for dental implants, various types of surgical guides have been developed. These guides fall into three common designs based on their surgical restriction level: nonlimiting, partially limiting, and completely limiting. Nonlimiting guides allow freedom in angulation and depth, indicating the ideal drilling location. Partially limiting guides restrict the first drill, leaving subsequent drilling freehand, while completely limiting guides restrict all drilling parameters except those preplanned by software. Surgical guides are categorized by factors like drilling freedom, support, extension, material, and fabrication method. Fabrication methods include cast-based (metal strip, Gutta-Percha, etc.) and digital

(3D printed or milled) options. This variety addresses the diverse needs of clinicians and patients in the realm of dental implant procedures.[9-11]

There has been a long controversy between 3D printed and milled guides, which holds supreme to the other. 3D printing technology is also termed additive manufacturing, a manufacturing method where an object is formed layer by layer through addition of material. While on the other hand, milling by CAD/CAM is also termed subtractive manufacturing, where an object is revealed in its final form by removing parts.[12] However, for both manufacturing methods, 3D printing or milling, a standard triangulation language (STL) file is required, collected through a CAD-CAM device.

Regardless of the manufacturing method, whether additive as 3D printing or subtractive as milling, each can have its own benefits and drawbacks, 3D printed guides carry less cost than their milled counterparts. Other than having higher material costs; milling machines and equipments are usually more expensive and have higher maintenance costs.[11,13] 3D printing also has a great advantage of less material waste, and quicker fabrication time than milling.[13]

On the other hand, some authors have reported on the higher accuracy of milled surgical guide models compared to other methods,[14] yet correspondingly other authors have demonstrated comparable accuracy between additive 3D printed surgical guides and conventional cast based surgical guides.[15]

In an attempt to reach a consensus on which fabrication method holds supreme to the other, this in vitro study will aim to compare the accuracy of 3D-printed surgical guides vs Milled surgical guides for dental implant placement to restore missing mandibular first molar. The null hypothesis was that there is no difference in accuracy between milled and SLA-fabricated surgical guides on the final placed implant position.

MATERIALS AND METHODS

From a demo case within the Blue Sky Bio software library, an STL file and a DICOM file were extracted, showcasing a missing mandibular first right molar. These files were digitally superimposed, and a virtual prosthetic restoration design was meticulously crafted to optimize functionality and aesthetics, aligning with a prosthetically-guided implant surgery protocol. Careful consideration was given to implant selection, focusing on bone height, width, proximity to adjacent teeth, and anatomical landmarks, and an implant of

5.5mm width and 11mm length met those criteria **(Figure 1).** This virtual plan was saved as an STL file for reference.

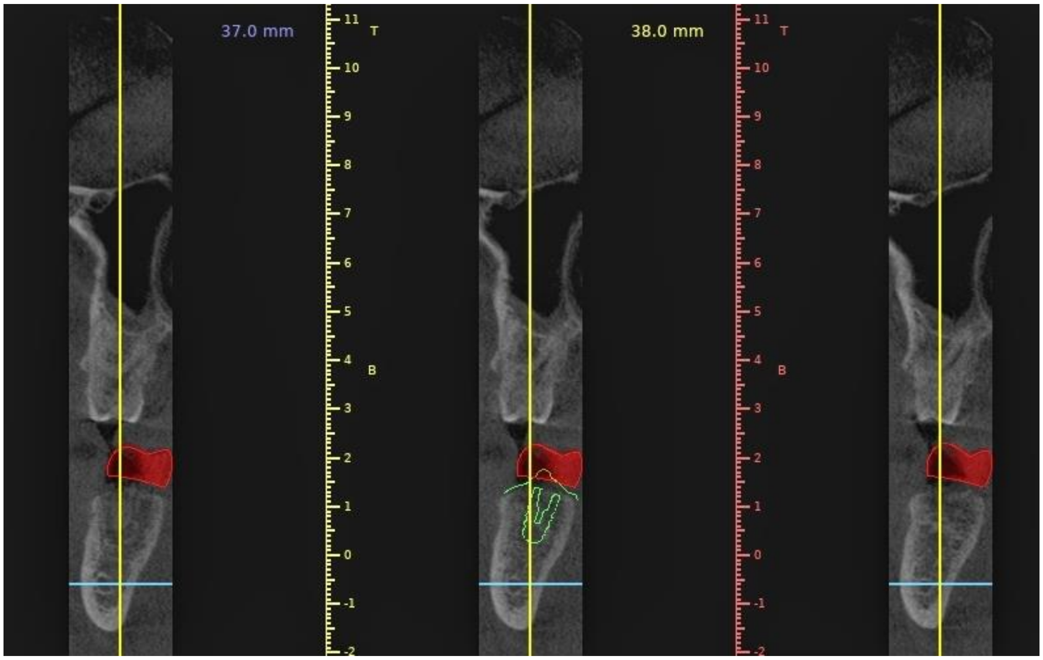

Figure (1): Prosthetically driven implant planning.

The master cast was created using a Formlabs Form 2 in-office 3D printer (Formlabs Inc, Massachusetts, USA) with Formlabs dental model resin (Formlabs Inc, Massachusetts, USA). A duplicate silicone mold (Dupliflex, Protechno, Girona, Spain) was fabricated from the master cast, enabling the construction of epoxy resin casts for implant placement. In total, 24 epoxy resin casts were produced, sequentially labeled from one to 24. A power analysis using vertical implant position deviation (mm) as the primary outcome. The effect size (d) = 1.207 was calculated based upon the results of Gjelvold B et al[16]. Using alpha (α) level of (5%) and Beta (β) level of (20%) i.e.power = 80%; the minimum estimated sample size was 12 implants per group for a total of 24 implants. Sample size calculation was performed using G*Power Version 3.1.9.2. The surgical guide design for the chosen implant size was developed using On Demand 3D implant planning software (Cybermed Inc, Seoul, Korea). The guide extension covered the area from the lower left canine to the lower left second molar, with a window strategically positioned on the mesial side of the lower left second molar. This design was directly exported as an STL file from the software for 3D printing and milling processes.

In this research, 24 surgical guides were used, and divided into two groups. Twelve were produced using SLA 3D printing, and the other twelve were crafted via CAD/CAM milling of PMMA discs. For the SLA surgical guides, Formlabs Form 2 printer (Formlabs Inc, Massachusetts, USA) was employed, with a layer thickness of 0.05 mm for precision. Formlabs surgical guide resin (Formlabs Inc, Massachusetts, USA) was used, and post-processing included rinsing with isopropyl alcohol and sandpaper refinement. For milled surgical guides, the SheraEco-mill milling machine (Shera Werkstoff Technologie, Germany) was used. Clear Yamahachi PMMA discs (Yamahachi Dental MFG, CO. Aichi-Pref, Japan.) were chosen for manufacturing. The CAM software facilitated the guide creation, with sprues attached to the outer surface of the guide and a cutting depth of 0.8mm for precision. Post-milling, the guides were manually detached from the sprues and finished with a fine-grit sandpaper. Fitting on epoxy casts was visually verified for both groups **(Figure 2)**. Dentaurum large sleeves, corresponding to the selected implant size, were inserted into the guides to ensure precise implant placement.

In total, 24 Dentaurum tiologic ST dental implants measuring 5.5x11mm were placed using the surgical guides, with 12 guided by SLA 3D printed guides and 12 guided by

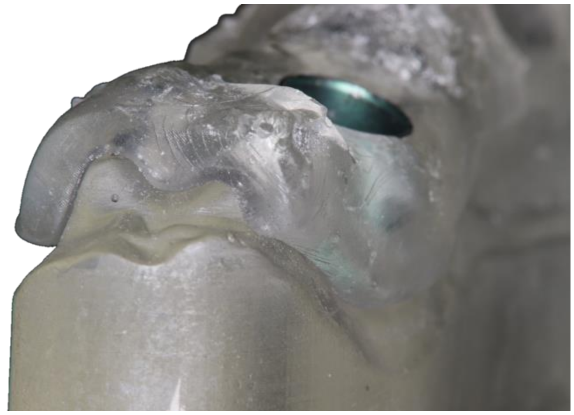

Figure (2): Visual inspection of surgical guide fitting over epoxy cast.

PMMA milled surgical guides. All implants were placed aided by the Dentaurum fully guided drilling system, and drill size 5.5 was used as the final drill. The implants were placed inside the osteotomy sites by the aid of a torque wrench till the desired position, where the implant mount lined up with the top rim of the metal sleeve in the surgical guide. After attaching a scan body to each implant, the translucent epoxy casts were sprayed with a scanning spray to facilitate the scanning process **(Figure 3)**. All casts were

Figure (3): Epoxy cast with scan body attached to the implant.

scanned via inEos X5 bench scanner and exported STL files of the scans were saved. The STL files were exported and superimposed onto the STL 3D reference model using GeoMagic Control X software. In order to enhance the accuracy of the alignment, any extraneous areas beyond the field of interest were excluded. Deviation values post-alignment were visualized through a color-coded heat map. The assessment and evaluation process of these deviation measurements was conducted using Blender software 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)**.

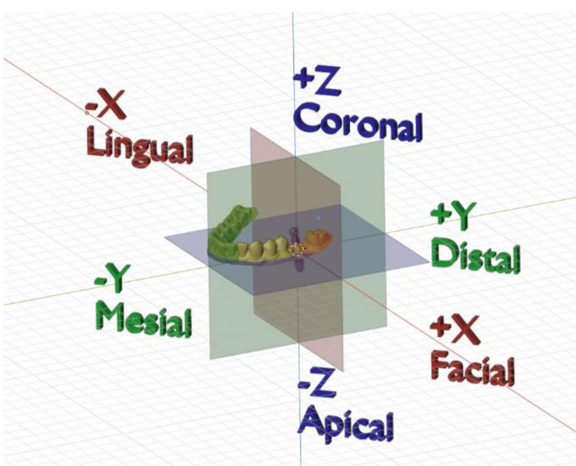

Figure (4): X, Y, and Z planes.

The deviations were measured in micrometers (µm) and presented as a 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 the bucco-lingual and mesio-distal regions of the planned and placed implant positions **(Figure 5)**.

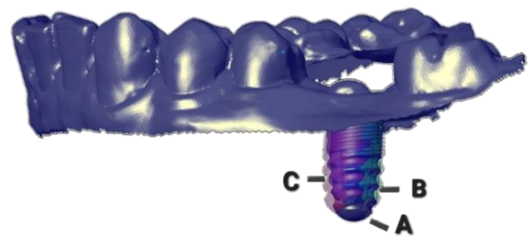

Figure (5): Diagram showing deviation.
(A): Planned implant position;
(B): SLA implant group;
(C): Milled implant group.

Statistical analysis

Numerical data were presented as mean with 95% confidence intervals, standard deviation, median, minimum, and maximum values. They were explored for normality by checking the data distribution and using Shapiro-Wilk test. RMS values were assessed using this formula: RMS=$\sqrt{(\mathbf{\Delta X + \Delta Y + \Delta Z})}$ and their values were normally distributed and were analyzed using independent t-test.Other data were non-parametric and were analyzed using Mann-Whitney U test.The significance level was set at $p \leq 0.05$.Statistical analysis was performed with R statistical analysis software version 4.3.0 for Windows.

RESULTS (Table 1 and Figure 6)

Results of this study have shown RMS deviation of (1077.23±186.26μm) for SLA fabricated surgical guides and (1103.67±374.48μm) value of deviation for milled surgical guides at the entry point with no significant difference (p=0.689). RMS deviation of (1347.57±60.23μm) for SLA

Table (1): Deviation difference between SLA 3D printed and Milled surgical guides (Mann-Whitney U test).

Variable	SLA		Milled		*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)	1207.78	1103.67±374.48 (583.74-1526.62)	0.689
RMS Deviation at apical point (μm)	1335.18	1347.57±60.23 (1275.40-1449.19)	1557.13	1565.65±531.12 (1021.54-2424.32)	0.471
Angular deviation (degrees)	0.9	0.89±0.12 (0.69-1)	3.3	3.89±1.90 (3.29-2.12)	<0.001*

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

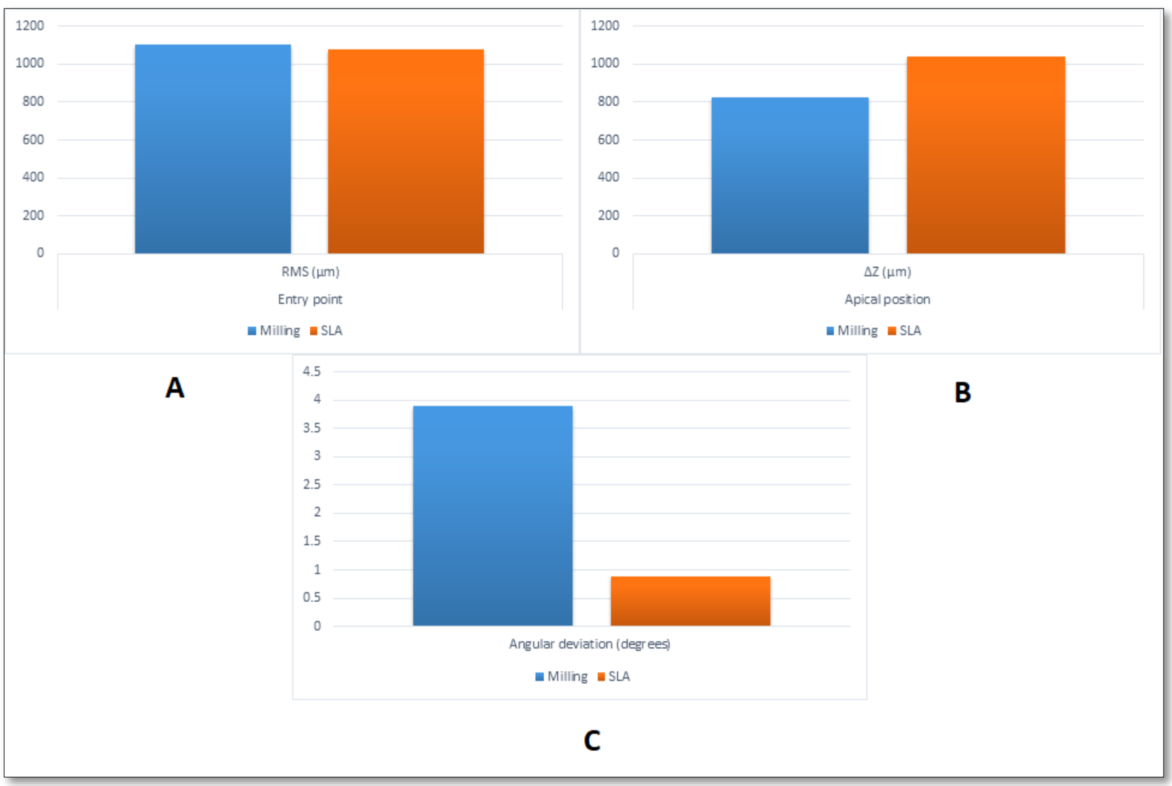

Figure (6): Bar charts showing average deviation of **(A):** entry point; **(B):** apical point; **(C):** angular deviation.

fabricated surgical guides and (1565.65±531.12μm) value of deviation for milled surgical guides at the apical point with no significant difference ($p=0.471$). An angular deviation of (0.89±0.12°) for SLA fabricated surgical guides and (3.89±1.90°) value of deviation for milled surgical guides was found to show a significant difference ($p<0.001$). The statistical analysis conducted on the deviations observed in dental implant position between SLA 3D printing and Milled groups is summarized in **Table (1)** and **Figure (6)**.

DISCUSSION

The null hypothesis was rejected, as the findings of this study revealed statistically significant differences in the accuracy of the final implant placement, with SLA 3D printed surgical guides demonstrating a notable advantage over CAD/CAM milled surgical guides.

In the dynamic field of dentistry, especially in the specialized area of fixed prosthodontics, notable progress has been achieved, particularly in dental implantology. Accurate implant placement is crucial, as it directly impacts both the functional and aesthetic aspects of dental prosthetics and the long-term oral health of patients. Surgical guides play a pivotal role in ensuring precise implant positioning, acting as a bridge between virtual implant planning and real-world surgery. The accuracy of implant placement driven by prosthetic considerations relies on the guides' ability to translate virtual plans into precise surgical actions. Traditionally, surgical guides were made using computer-aided design and manufacturing (CAD/CAM) milling. However, the rise of 3D printing as an alternative method has sparked a debate within the dental community about the accuracy of guides produced by these two different approaches.[16-20] Notably, these procedures were conducted by a skilled operator. Despite adherence to standardized protocols, deviations between the planned and actual implant positions were observed. Point of entry and apical positions showed some deviation from the planned positions, SLA 3D printed guides showed higher accuracy than milled guides. However this deviation was not statistically significant. On the other hand, angular deviation showed significantly higher accuracy for SLA 3D printed guides than the milled guides. Many studies showed comparable findings; A systematic review by Van Assche et al.[21] found deviation of 990 μm at the top part, 1240 μm at the bottom part, and a misalignment of 3.81°. In another study by Turbush et al.[22]

An in-laboratory assessment of various surgical guides was conducted, revealing mean deviations of 1000 µm at the upper portion and 1150 µm at the lower portion, along with a misalignment of 2.26°.

The deviations in the milled guides may be because of the PMMA milling process, which can be sensitive due to the material's hardness. This hardness increases the pressure during cutting, possibly causing heat-related stresses and material changes. The cutting conditions, like excessive vibrations, can add to these stresses, especially in areas with thin material. These factors were mentioned in a study by Ahmed et al.[23] The deviations could be because PMMA is naturally brittle and might create tiny cracks when it's machined, impacting the surgical guide's accuracy. Furthermore, the milling tools can wear out quickly, which shortens their lifespan. These reasons were found in a study conducted by Maha et al.[24] the outcomes of the deviation measurements in our study align with the results reported in prior research.

In this study, the observed deviation in implant angle may be due to the surgical guide's instability.[25] This instability could result from intentional blocking undercuts in the epoxy cast, designed to help it fit properly. The challenge heightened during drilling, as it was tough to stabilize the guide on the cast, especially when holding it in place.[26] The use of a two-drill system with high torque for drilling through the epoxy cast may have caused slight movements in the guide, leading to the observed deviation. These findings emphasize the crucial need for careful guide design and secure fixation during surgery to improve the accuracy of implant placement.

While SLA printed guides were more accurate than milled guides, deviations still occurred during implant placement. These discrepancies could result from previously mentioned factors like guide instability. Other contributors include using metal sleeve, 3D printer resolution, material surface polish, machine reproducibility, offset settings, post-processing, and 3D printer calibration.[16,27]

However, a recent 2023 study by Russo-et al.[19] offered different results than our study. They examined the precision of CAD/CAM milled surgical guides versus SLA 3D printed surgical guides, focusing on the alignment where teeth and mucosa met, and the alignment of sleeves' housings between the virtual and physical guides on casts. In contrast to our findings, they concluded that milled surgical guides demonstrated higher accuracy than 3D printed guides.

They also highlighted that achieving a surgical guide with absolute zero deviation from the reference CAD design might be unattainable due to inherent manufacturing tolerances.

A major drawback in our study was the implant placement drilling in epoxy casts. Using a two-drill implant system with hard epoxy resin required high torque, which caused slight movements in the surgical guides. This instability may have contributed to the angular deviations seen in both groups.

The study had several limitations. Firstly, it used artificial models and materials, lacking the biological variability observed in clinical situations. Additionally, these models were simplified, possibly not fully capturing the complexity of real clinical scenarios. The investigation did not account for variables like saliva, soft tissue, humidity, and patient movement within the oral environment.

CONCLUSION

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 CAD/CAM milling technique for the fabrication of surgical guides.

2. Lower deviation was expected for single implant tooth-supported surgical guide but variation in deviation occurred.

3. Angular positions demonstrated higher deviation than the horizontal and vertical positions.

FUNDING: No external funding was received for this research.

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

REFERENCES

1. Da Silva Salomão GV, Santos FT, Allegrini Junior S. The importance of prosthetic planning for implant-supported dentures in esthetic zones - A case report. Int J Surg. 2019;54:15-9.
2. Kuzekanani M. Nickel-Titanium Rotary Instruments: Development of the Single-File Systems. J Int Soc Prev Community Dent. 2018;8(5):386-90.
3. Forna N, Agop-Forna D. Esthetic aspects in implant-prosthetic rehabilitation. Med Pharm Reports. 2019;92(3):6-13.
4. Gupta H, Singh A, Panghal VS. Prosthetically Driven Implants: How much a Reality? Int J Oral Implantol Clin Res. 2013;4(1):44-6.
5. Widmann G, Fischer B, Berggren J, Dennhardt A, Schullian P, Reto B. Cone Beam Computed Tomography vs Multislice Computed Tomography in Computer-Aided Design/Computer-Ass - isted Manufacture Guided Implant Surgery Based on Three-Dimensional Optical

Scanning and Stereolithographic Guides: Does Image Modality Matter? Int J Oral Maxillofac Implants. 2016;527-33.

6. Van Assche N, Quirynen M. Tolerance within a surgical guide. Clin Oral Implants Res. 2010;21(4):455-8.
7. D'haese J, Ackhurst J, Wismeijer D, De Bruyn H, Tahmaseb A. Current state of the art of computer-guided implant surgery. Periodontol 2000. 2017;73(1): 121-33.
8. Mascarenhas VI, de Molon RS, Tavares LJ, Mendes LMF, Tonetto MR, Bandeca MC. The use of computer guided implant surgery in oral rehabilitation: A literature review. World J Dent. 2014;5(1):60-3.
9. D'Souza KM, Aras MA. Types of implant surgical guides in dentistry: A review. J Oral Implantol. 2012;38(5):643 -52.
10. Jeong YG, Lee WS, Lee KB. Accuracy e-valuation of dental models manufactured by CAD/CAM milling method and 3D printing method. J Adv Prosthodont. 2018;10(3):245-51.
11. Almog DM, Torrado E, Meitner SW. F-abrication of imaging and surgical guides for dental implants. J Prosthet Dent. 2001;85(5):504-8.
12. Masood SH. Introduction to Advances in Additive Manufacturing and Tooling. Compr Mater Process. 2014;10:1–2.
13. Van Noort R. The future of dental devices is digital. Dent Mater. 2012;28(1):3-12
14. Yau HT, Yang TJ, Lin YK. Comparison of 3D printing and 5-axis milling for the production of electronic dental models fromintraoral scanning. Comput. Des. Appl. 2016;13(1):32-8.
15. Kasparova M, Grafova L, Dvorak P, Dostalova T, Prochazka A, Eliasova H. Possibility of reconstruction of dental plaster cast from 3D digital study models. Biomed Eng Online. 2013; 12:49:1-11.
16. Gjelvold B, Mahmood DJH, Wennerberg A. Accuracy of surgical guides from 2 different desktop 3D printers for computed tomography-guided surgery. J Prosthet Dent. 2019;121(3):498-503
17. Maló P, De Araújo Nobre M, Lopes A, Francischone C, Rigolizzo M. 'All-on-4' Immediate-Function Concept for Compl-etely Edentulous Maxillae: A Clinical Report on the Medium (3 Years) and Long-Term (5 Years) Outcomes. Clin Implant Dent Relat Res. 2012;14(1):139-50.
18. Kola M, Rabah A, Raghav D, Sabra S, Harby NM, Khalil H, et al. Surgical templates for dental implant positioning; current knowledge and clinical perspec-tives. Niger J Surg. 2015;21(1):1-5.

19. Lo Russo L, Guida L, Mariani P, Ronsivalle V, Gallo C, Cicciù M, et al. Effect of Fabrication Technology on the Accuracy of Surgical Guides for Dental-Implant Surgery. Bioengineering. 2023; 10(7):1-10.
20. Setzer FC, Kim S. Comparison of long-term survival of implants and endodontically treated teeth. J Dent Res. 2014;93(1):19-26.
21. Van Assche N, Vercruyssen M, Coucke W, Teughels W, Jacobs R, Quirynen M. Accuracy of computer-aided implant placement. Clin Oral Implants Res. 2012; 23(6):112-23.
22. Turbush SK, Turkyilmaz I. Accuracy of three different types of stereolithographic surgical guide in implant placement: An in vitro study. J Prosthet Dent. 2012;108 (3):181-8.
23. Ahmed MF, AbdelHamid AM, AlAbbasy FH. Accuracy of Implant Placement Using Two Different Types of Cad/Cam Surgical Guides (an Invitro Study). Alexandria Dent J. 2019;44(3):28-33.
24. Nagi M. Accuracy of implant placement using three different surgical guides. Egypt Dent J. 2018;64(4):3713-21.
25. Vasak C, Watzak G, Gahleitner A, Strbac G, Schemper M, Zechner W. Computed tomography-based evaluation of template (NobelGuide™)-guided implant positions: A prospective radiological study. Clin Oral Implants Res. 2011;22(10):1157-63.
26. Henprasert P, Dawson DV, El-Kerdani T, Song X, Couso-Queiruga E, Holloway JA. Comparison of the Accuracy of Implant Position Using Surgical Guides Fabricated by Additive and Subtractive Techniques. J Prosthodont. 2020;29(6): 534-41.
27. Bell C, Sahl E, Kim Y, Rice D. Accuracy of Implants Placed with Surgical Guides: Thermoplastic Versus 3D Printed. Int J Periodontics Restorative Dent. 2018;38 (1):113–9.