Annals of Orthodontics and Periodontics Specialty
Volume 1, Page No: 72-83
Available Online at: aopsj.com

ISSN: 3062-3405

Original Article

Accuracy Assessment of Implants Inserted Using Thermoplastic Versus 3D-Printed Surgical Guides: A Randomized Clinical Trial

Sarwar Beg[1], Penchalaneni Josthna[1], Sneha Rai[1*]

1. Department of Periodontics, Dr. Harvansh Singh Judge Institute of Dental Sciences and Hospital, Panjab University, Chandigarh, India.

***E-mail** ✉ sneharai@gmail.com

Abstract

This investigation aimed to compare the precision of dental implant placement using two categories of surgical guides: thermoplastic and three-dimensional (3D) printed. A total of 32 implants were inserted in 20 healthy individuals, each presenting a single missing tooth. The implant sites were randomly divided into two groups: Group A (thermoplastic guide, $n = 16$ implants) and Group B (3D-printed guide, $n = 16$ implants). All implant placements were digitally planned through a uniform protocol, and discrepancies between the planned and actual implant positions were analyzed using medical imaging software. The evaluated parameters included angular deviation (AD), three-dimensional error at the coronal entry point, three-dimensional error at the apex (3D EA), vertical deviation (VD), and overall composite deviation. Although all outcome measures showed improvement, statistically significant differences were noted for AD ($P = 0.005$), 3D EA ($P = 0.01$), and VD ($P = 0.007$). For Group A, the mean ± SD for AD, 3D EA, and VD were 5.58° ± 1.93°, 0.96 ± 0.32 mm, and 0.58 ± 0.36 mm, respectively. In Group B, these values were 3.94° ± 0.64°, 0.64 ± 0.35 mm, and 0.29 ± 0.13 mm ($P < 0.05$). Within the limits of this study, implants guided by 3D-printed templates achieved higher placement accuracy and exhibited smaller deviations from their preoperative positions compared to those placed with thermoplastic guides.

Key words: Dental implant precision, Vertical deviation, Angular deviation, Guided implant surgery, Thermoplastic guide, 3D printed surgical guide, Three-dimensional error

How to cite this article: Beg S, Josthna P, Rai S. Accuracy Assessment of Implants Inserted Using Thermoplastic Versus 3D-Printed Surgical Guides: A Randomized Clinical Trial. Ann Orthod Periodontics Spec. 2021;1:72-83. https://doi.org/10.51847/Hz0nzNQZou

Introduction

Dental implants have become the treatment of choice for both fully and partially edentulous patients. Properly placed implants restore oral function, esthetics, comfort, and speech, while avoiding harm to critical anatomical regions such as the mandibular canal or maxillary sinus [1, 2]. Over time, surgical methods for implant placement have evolved from manual freehand approaches to the use of patient models, panoramic imaging, and surgical templates, culminating in advanced computer-assisted navigation systems [3-5].

A surgical guide serves as a clinical aid for accurately directing implant angulation and insertion depth [6]. These devices minimize placement errors that are often encountered during unguided, freehand procedures.

Traditional guides are usually vacuum-formed templates incorporating 2-mm guide holes and metallic sleeves. Such guides are fabricated through diagnostic wax-ups, denture teeth arrangements, or by duplicating existing restorations [7-9].

The evolution of dental imaging—especially the emergence of cone-beam computed tomography (CBCT)—has allowed clinicians to achieve detailed three-dimensional (3D) visualization with minimal radiation exposure [10, 11]. CBCT provides enhanced accuracy for assessing buccolingual dimensions that are typically overlooked in standard two-dimensional radiography [12,13].

The fifth ITI Consensus Conference strongly recommended the adoption of 3D imaging for prosthetically driven implant planning, particularly in cases involving complex anatomy, grafting, or guided placement procedures [13, 14].

Static-guided surgery enables simultaneous evaluation of bone morphology and surrounding anatomical landmarks [15]. Among its advantages are reduced risk of nerve or sinus injury, prevention of fenestrations or root damage, higher precision of implant placement, shorter surgical duration, and greater patient satisfaction [15, 16].

However, the fabrication of stereolithographic surgical templates involves several sequential steps, each with a possibility of technical error. These individual inaccuracies, though minor, can accumulate and be expressed as overall linear or angular deviations [17-20].

Accuracy, in this context, refers to the degree of conformity between the digitally planned implant position and the actual placement achieved intraorally. This alignment can be verified by comparing pre- and postoperative CBCT scans or matching corresponding jaw models [19-21].

Despite guided systems, discrepancies between planned and actual implant positions can still occur—especially in areas with limited inter-implant space or minimal papilla height in esthetic zones. Understanding these variations is essential to select the most reliable guide for precise implant positioning.

The current research was therefore conducted to assess and compare the positional accuracy of dental implants placed using thermoplastic versus 3D-printed surgical guides.

Materials and Methods

This investigation followed a randomized, controlled, parallel-group interventional design. Prior approval was obtained from the institutional ethics board of the dental institute, and the project was also listed in the Clinical Trial Registry of India (CTRI/2019/). The trial process adhered strictly to the CONSORT reporting standards for randomized clinical studies.

The required sample size was computed using an alpha value of 0.05 and a statistical power of 80%, applying software from the mentioned manufacturer and country. The standard formula $(n = [Z\alpha/2 + Z\beta]^2 \times 2 \times \sigma^2 / d^2)$ yielded a sample of 32 implants**.**

Participants were assigned at random, using a random number sequence, to one of the two intervention arms based on the guide system utilized:

Group A (n = 16): Implants placed using thermoplastic surgical guides

Group B (n = 16): Implants inserted using three-dimensional printed guides

Altogether, 32 implants were positioned in 20 systemically healthy adults who met the inclusion standards. Each volunteer signed a written consent form confirming their willingness to take part.

Inclusion criteria

1. Individuals presenting with partial edentulism
2. Single-tooth absence in an otherwise intact arch
3. Good systemic and oral health, with no contraindications to surgery
4. Sufficient mouth opening for implant instrumentation

Exclusion criteria

1. Inadequate oral hygiene
2. General medical contraindications to dental implant placement

3. Active periodontal disease or infection
4. Poorly controlled systemic illnesses
5. Smoking exceeding 10 cigarettes per day
6. Insufficient bone volume requiring grafting before or during implant insertion
7. Bone pathologies detected radiographically or clinically

Parameters for evaluation

Comparison between planned and actual implant positions in both groups was performed using the following indices:[17]

1. Angular deviation (AD): Difference in implant angulation between planned and final placement (°)
2. 3D error at entry (3D EE): Linear offset at the coronal center between planned and inserted implant (mm)
3. 3D error at apex (3D EA): Linear discrepancy at the apical center between both positions (mm)
4. Vertical deviation (VD): Height variation at the implant entry point (mm)
5. Composite deviation (CD): Combined three-dimensional variance (mm), introduced as a new variable in this study

Implant planning protocol

Thermoplastic group

A maximally extended impression of the edentulous ridge was recorded, from which a diagnostic cast was fabricated. The model was replicated, followed by a wax-up of the desired prosthetic contour at the target implant site [9, 22].

Under topical anesthesia, bone sounding was carried out using a 27-gauge short needle with a rubber stopper to determine ridge height. Parallelism and contour height were verified on a surveying unit, while undercuts and embrasures were blocked out using Type I gypsum material.

After CBCT examination of ridge width and distance from neighboring teeth, measurements were transferred to the model. A 2-mm pilot hole was drilled on the cast at the preselected location to a depth of 5–10 mm using a bench-mounted drill press. Guide pins were inserted to assess angulation relative to adjacent structures.

A 2-mm metal sleeve was then positioned concentrically over the prepared site [9, 23, 24]. A 0.1-mm tolerance was incorporated to prevent mechanical resistance between drill and sleeve during use.

After confirming proper alignment, a clear Biocryl C sheet (2.0 mm × 125 mm) was vacuum-formed over the cast with a Biostar® (Scheu-Dental) device. The guide was trimmed, adjusted to the desired dimensions, and its fit validated both on the model and intraorally before surgical use.

Virtual implant planning for the 3D-printed surgical guide

Following the initial patient screening and acquisition of cone-beam computed tomography (CBCT) scans, a full-arch intraoral digital impression was recorded with an intraoral scanner and exported as an STL file (Standard Tessellation Language). For virtual implant planning and guide fabrication, both the preoperative CBCT (in DICOM format) and the STL scan were uploaded into a dedicated implant planning software. The datasets were superimposed and aligned, allowing for accurate virtual positioning of the implant within the anatomical framework. The final surgical guide design was then fabricated through additive manufacturing using a rapid-prototyping 3D printer **(Figure 1)**.

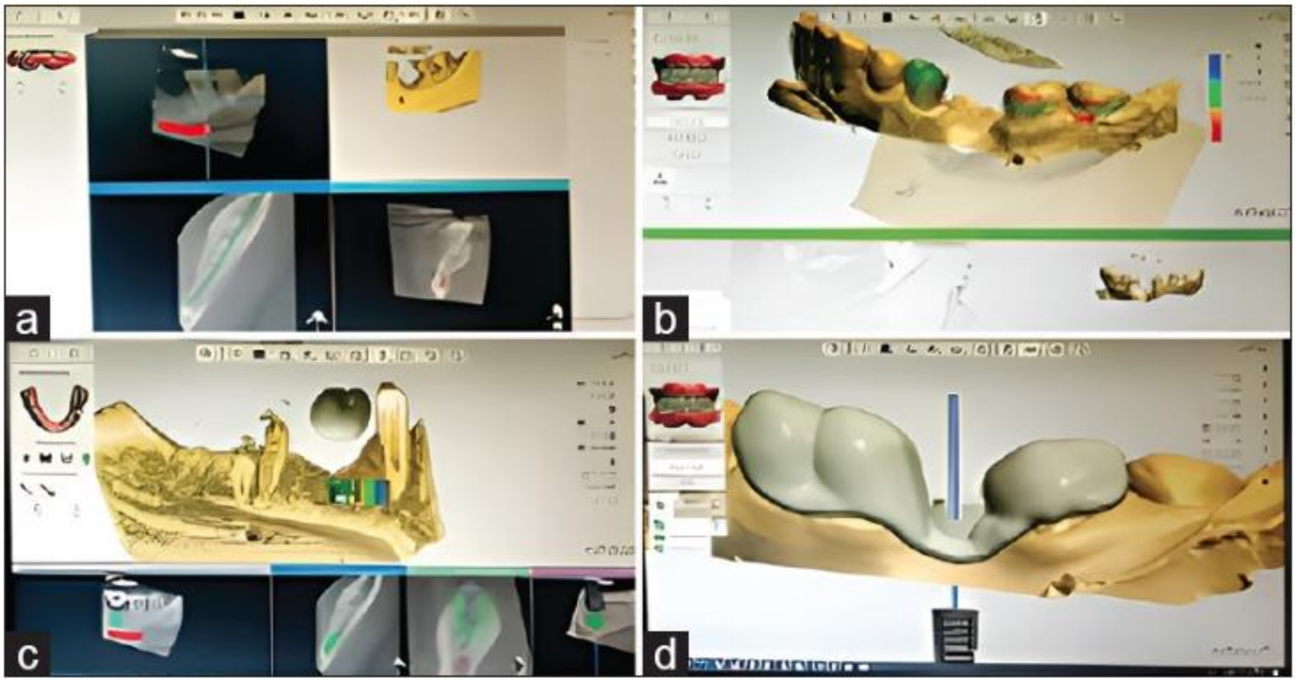


Figure 1. Sequential illustration of the design process for a 3D-printed surgical guide: (a) tracing of the mandibular nerve, (b) merging of intraoral scan and CBCT data, (c) virtual implant positioning, and (d) digital guide design

Presurgical protocol

One week prior to surgery, all participants underwent ultrasonic scaling and root planing. Each patient received individualized oral hygiene instructions and was advised on maintaining optimal plaque control before the surgical phase.

Surgical procedure

Before surgery, the risks, benefits, and treatment plan were thoroughly explained to each patient, and written informed consent was obtained. All implant placements were carried out under local anesthesia (2% lignocaine with 0.005 mg epinephrine, 1:200,000 dilution). The fit and stability of the surgical guide were verified both on the diagnostic cast and intraorally prior to drilling.

A full-thickness mucoperiosteal flap was raised on both buccal and lingual aspects to expose the alveolar crest at the implant site. The exposed bone was cleansed of granulation tissue, and any sharp or irregular bone margins were contoured.

For the thermoplastic guide group, the guide was secured over the surgical site, and a 2-mm pilot drill was used through the guide sleeve at 800 rpm and 35 N/cm torque under abundant saline irrigation. Osteotomy enlargement was achieved with sequential drills of increasing diameter, following the pilot path to reach the planned implant diameter. The Osstem TSIII SA Fixture implant was placed up to the crestal level using a hand ratchet, and the cover screw was positioned afterward **(Figure 2)**.

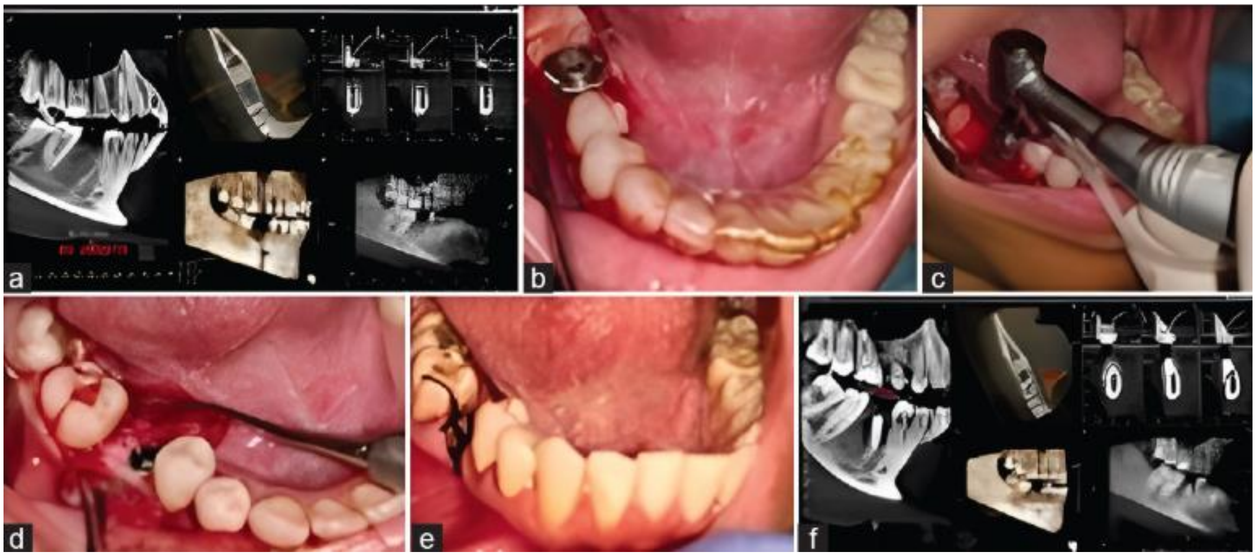


Figure 2. Clinical workflow for thermoplastic surgical guides: (a) Pre-surgical CBCT, (b) Thermoplastic guide placement, (c) Pilot drilling, (d) Implant insertion, (e) Suturing, (f) Post-surgical CBCT evaluation

For the 3D-printed guide group, implant osteotomy was completed according to the fully guided surgical protocol, using the custom-fabricated 3D-printed guide to ensure optimal angulation and depth control **(Figure 3)**.

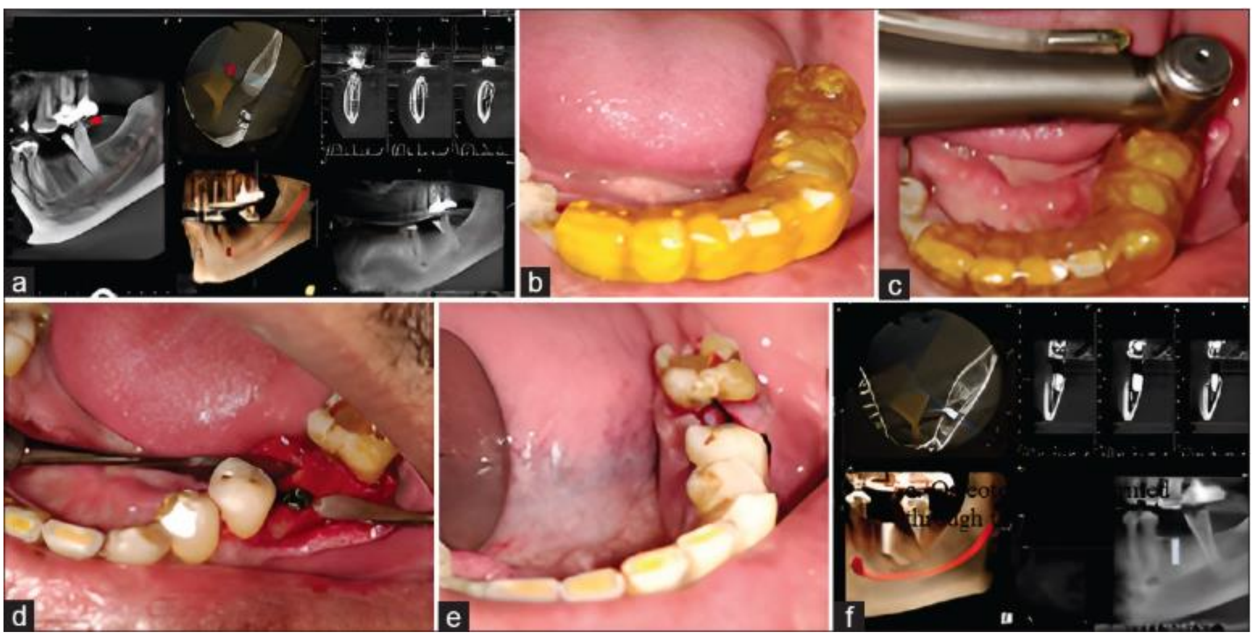


Figure 3. Stepwise procedure for 3D-printed surgical guides: (a) Pre-operative CBCT, (b) Guide positioning, (c) Drilling through guide sleeves, (d) Implant placement, (e) Suturing, (f) Post-operative CBCT verification

Postoperative management

All participants were given standard postoperative instructions and prescribed medications, including an antibiotic (amoxicillin 500 mg, three times daily for 5 days) and an analgesic (diclofenac or aceclofenac twice daily on the day of surgery, then as needed). A follow-up appointment was scheduled one week post-surgery for suture removal and acquisition of a postoperative CBCT, following the same imaging parameters as the baseline scan.

The preoperative and postoperative CBCT data were then aligned using Mimics Innovation Suite (version 17) with its registration tool for measurement of positional deviations. Both datasets (planned and actual implant positions) were imported into the software, color-coded for distinction, and manually aligned using key anatomical landmarks. A three-dimensional comparative model was generated, and deviations in all measured parameters were calculated using the in-built measurement tools **(Figures 4–6)** [25-27].

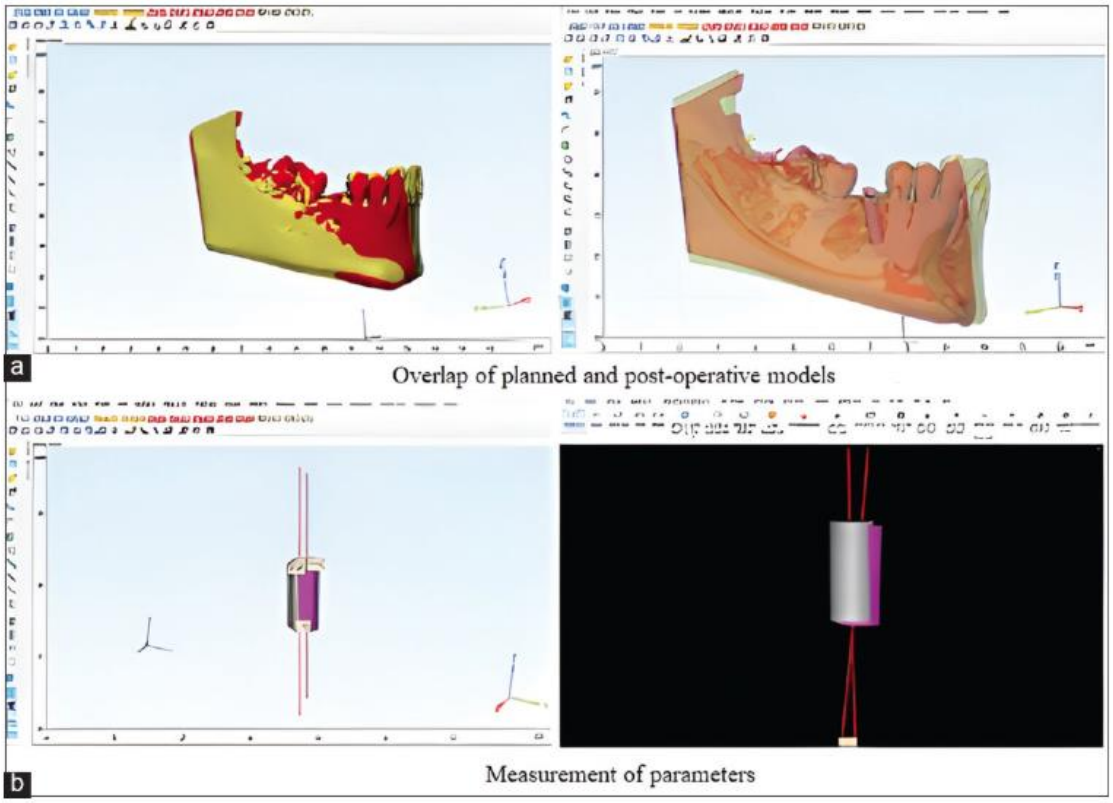
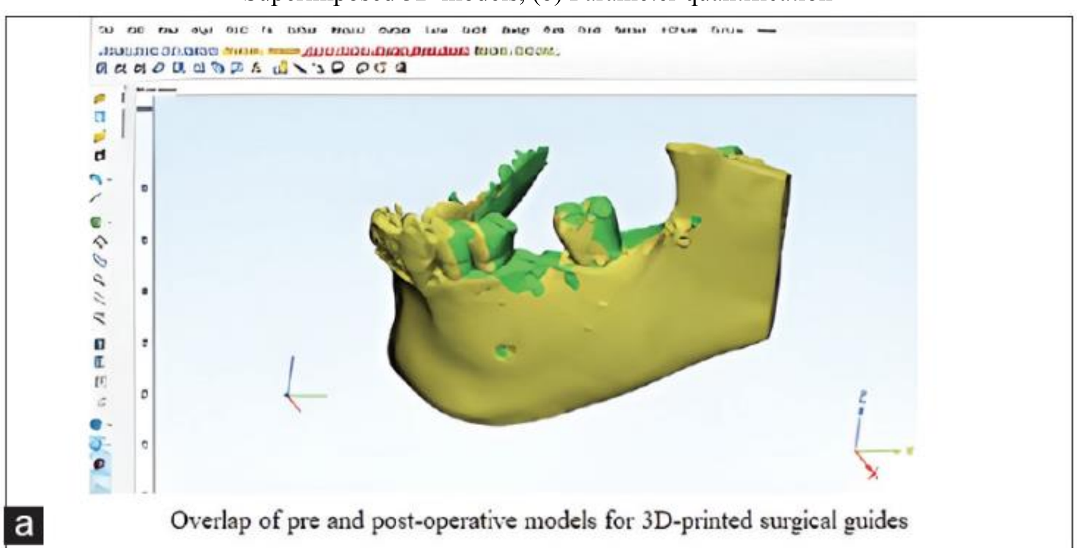


Figure 4. Overlay of planned and postoperative datasets with deviation analysis for thermoplastic guide cases: (a) Superimposed 3D models, (b) Parameter quantification



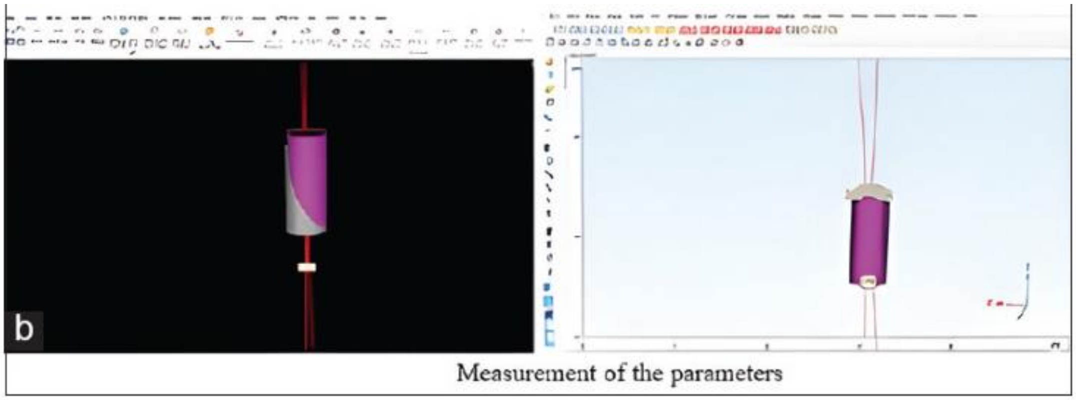


Figure 5. Overlay and deviation assessment for 3D-printed guide cases: (a) Superimposition of pre- and postoperative models, (b) Measurement of deviations

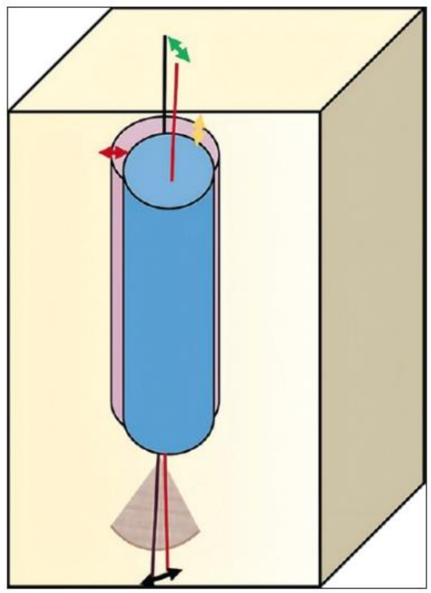


Figure 6. Schematic illustration of deviation parameters: violet cylinder—planned implant, blue cylinder—actual implant, green arrow—3D error at entry (mm), red arrow—composite deviation (mm), yellow arrow—vertical deviation (mm), black arrow—3D error at apex (mm), brown arc—angular deviation (°)

Statistical analysis

Data distribution was evaluated using the Kolmogorov–Smirnov test, confirming normality. Therefore, independent t-tests were applied for intergroup comparisons of mean deviation values and clinical outcomes between planned and actual implant positions. Quantitative results were expressed as mean ± standard deviation (SD). All analyses were carried out using IBM SPSS Statistics 22.0 (IBM Corp., Armonk, NY, USA). A P-value < 0.05 denoted statistical significance, while $P < 0.001$ indicated highly significant differences.

Results

A total of 32 implants were surgically inserted in 20 individuals who met the inclusion standards of this investigation. Details regarding the distribution of sites and the types of implants employed are displayed in **Table 1**. The implant diameters ranged from 3.00 mm to 4.00 mm (3.00, 3.5, 3.6, and 4.00 mm), while their lengths varied between 7.00 mm and 11.00 mm (7.00, 8.00, 8.5, 10.00, and 11.00 mm).

Table 1. Arrangement and characteristics of implants used in Groups A and B (mm – millimeter)

Characteristic	Cohort A	Cohort B
Arch Type		
Upper Jaw	6	1
Lower Jaw	10	15
Arch Side		
Right Side	8	10
Left Side	8	6
Implant Position		
Front	1	1
Premolar Region	2	2
Molar Region	13	13
Implant Width (mm)		
3.0	1	-
3.5	-	4
3.6	1	-
4.0	14	12
Implant Length (mm)		
7.0	1	2
8.0	3	-
8.5	2	9
10.0	9	5
11.0	1	-

For Group A, the mean differences between the planned and actual implant positions were as follows: AD = 5.58° ± 1.93°, 3D EE = 0.55 ± 0.18 mm, 3D EA = 0.96 ± 0.32 mm, VD = 0.58 ± 0.36 mm, and CD = 0.63 ± 0.26 mm.

In Group B, these mean values were recorded as AD = 3.94° ± 0.64°, 3D EE = 0.57 ± 0.32 mm, 3D EA = 0.64 ± 0.35 mm, VD = 0.29 ± 0.13 mm, and CD = 0.49 ± 0.18 mm.

Comprehensive descriptive data — including mean, SD, SE, minimum, and maximum values — for both groups are presented in **Tables 2 and 3**. Statistical testing revealed significant differences in three out of five assessed parameters.

Table 2. Mean, SD, and SE of evaluated parameters for Group A

Measurement	Angular Deviation (°)	Three-dimensional error at the entry point (mm)	Three-dimensional error at the apex (mm)	Vertical deviation (mm)	Crestal Deviation (mm)
Sample Size	16	16	16	16	16
Average	5.58	0.55	0.96	0.58	0.63
Standard Deviation	1.93	0.18	0.32	0.36	0.26
Standard Error	0.48	0.14	0.08	0.09	0.06
Minimum Value	1.2	0.27	0.52	0.21	0.22
Maximum Value	8.03	2.54	1.54	1.53	1.08

(n – number; SD – standard deviation; SE – standard error; AD – angular deviation; 3D EE – 3D error at entry; 3D EA – 3D error at apex; VD – vertical deviation; CD – composite deviation; mm – millimeter)

Table 3. Mean, SD, and SE of evaluated parameters for Group B

Parameter	Angular deviations (°)	Three-dimensional error at the entry point (mm)	Three-dimensional error at the apex (mm)	Vertical deviation (mm)	Composite deviation (mm)
Sample Count	16	16	16	16	16
Average Value	3.94	0.57	0.64	0.29	0.49
Standard Deviation	0.64	0.32	0.35	0.13	0.18

Standard Error	0.16	0.08	0.09	0.03	0.04
Lowest Value	2.84	0.22	0.17	0.12	0.23
Highest Value	4.85	1.23	1.43	0.59	0.98

(n – number; SD – standard deviation; SE – standard error; AD – angular deviation; 3D EE – 3D error at entry; 3D EA – 3D error at apex; VD – vertical deviation; CD – composite deviation; mm – millimeter)

A statistically significant difference was observed in AD (P = 0.005), 3D EA (P = 0.01), and VD (P = 0.007). These outcomes, determined at the implant center, are summarized through a comparative t-test in **Table 4**.

Table 4. Comparative evaluation of mean scores for Groups A and B

Measurement	Cohort	Sample Size	Average ± Standard Deviation	P-Value
Angular Deviation (°)				
	Cohort A	16	5.58±1.93	0.005
	Cohort B	16	3.94±0.64	
Entry Point Displacement (mm)				
	Cohort A	16	0.81±0.55	0.136
	Cohort B	16	0.57±0.32	
Apex Displacement (mm)				
	Cohort A	16	0.96±0.32	0.01
	Cohort B	16	0.64±0.35	
Vertical Shift (mm)				
	Cohort A	16	0.58±0.36	0.007
	Cohort B	16	0.29±0.13	
Crestal Offset (mm)				
	Cohort A	16	0.63±0.26	0.086
	Cohort B	16	0.49±0.18	

(Significance at P < 0.05; n – number; SD – standard deviation; AD – angular deviation; 3D EE – 3D error at entry; 3D EA – 3D error at apex; VD – vertical deviation; CD – composite deviation; mm – millimeter)

In summary, 3D-printed surgical guides yielded smaller positional discrepancies across all parameters than thermoplastic guides, demonstrating superior precision.

Discussion

Maintaining precise three-dimensional implant alignment is essential for achieving functional and esthetic success, while minimizing biological or mechanical complications related to misplacement [28]. According to Canullo *et al.*, nearly 50% of peri-implantitis cases arise from improper implant angulation or location [29].

Within this study, the mean angular variation (AD) between the intended and achieved implant sites for the thermoplastic guide was 5.58° ± 1.93°. This finding closely matches those reported by Younes *et al.* (2018) (5.95° ± 0.87°) [30] and Varga *et al.* (5.71° ± 3.68°) [31]. However, Vercruyssen *et al.* observed a higher deviation (8.43°) [21]. Their elevated results likely stemmed from performing pilot-drill–based implantations in fully edentulous patients, where the absence of adjacent teeth eliminated key reference points for spatial orientation.

Conversely, for the 3D-printed guide, the mean AD was found to be 3.94° ± 0.64°, consistent with research by Arisan *et al.* [32] Kühl *et al.* [33] Arisan *et al.* (subsequent study) [34] Smitkarn *et al.* [35] and Varga *et al.* [31] A meta-analysis by Van Assche *et al.* documented an average AD of 3.8° [19] while Tahmaseb *et al.* reported 3.89° in a systematic review [36] both nearly identical to the present outcomes. Similarly, Younes *et al.* [30] reported comparable values.

For thermoplastic-guided placement, the 3D EE and 3D EA were measured at 0.55 ± 0.32 mm and 0.96 ± 0.32 mm, respectively. In the 3D-printed guide cohort, these values were 0.57 ± 0.32 mm (entry) and 0.64 ± 0.35 mm (apex). These results align with Arisan *et al.* [32] (0.78 mm entry, 0.81 mm exit) and Vasak *et al.* [37] (0.82 mm entry, 1.05 mm exit). Smitkarn *et al.* [35] noted slightly higher deviations (1.0 ± 0.6 mm entry; 1.3 ± 0.6 mm exit).

By contrast, Kühl *et al.* [33] identified larger discrepancies (1.52 mm entry; 1.55 mm exit) and Cassetta *et al.* [38] observed 1.52 mm at the start and 1.97 mm at the end. Such variations likely arise from methodological differences—Kühl *et al.* conducted their tests on cadaveric jaws with multiple guide systems, while Cassetta *et al.* evaluated partially and completely edentulous individuals using diverse support designs (mucosa-, bone-, or tooth-supported).

In a systematic review and meta-analysis by Schneider *et al.* [39] the average positional variation was reported as 1.1 mm at the entry site and 1.6 mm at the apex. Similarly, Van Assche *et al.* [19] observed mean discrepancies of 1.0 mm at the implant shoulder and 1.2 mm at the apex. Meanwhile, Tahmaseb *et al.* [36] documented mean deviations of 1.12 mm at the entry and 1.39 mm at the apex in their review. Collectively, these three meta-analyses included a range of in vitro, cadaveric, and clinical human trials, utilizing diverse forms of 3D-printed fully guided surgical templates—namely mucosa-, bone-, and tooth-supported designs.

In the current research, the vertical deviation (VD) between the designed and actual implant positions measured 0.58 ± 0.36 mm for the thermoplastic template and 0.29 ± 0.13 mm for the 3D-printed guide. Comparable outcomes were reported by Younes *et al.* who identified a VD of 0.68 ± 0.09 mm in pilot-guided procedures and 0.43 ± 0.09 mm in fully guided placements [30],

A new evaluative measure termed the composite implant deviation (CD) was introduced in this study to represent a combined assessment of the horizontal and radial deviations between the centers of the planned and actual implant shoulders. For this parameter, the thermoplastic group showed a deviation of 0.63 ± 0.26 mm, whereas the 3D-printed guide group recorded 0.49 ± 0.18 mm.

Statistically, significant variations were detected in AD (95% CI, P = 0.005), 3D EE (95% CI, P = 0.01), and VD (95% CI, P = 0.007) when comparing the predicted versus actual implant sites. These outcomes parallel those reported by Smitkarn *et al.* [35].

Overall, the findings confirm that 3D-printed implant guides enabled implant positioning closer to the intended plan across all evaluated dimensions, outperforming thermoplastic guides in precision and consistency. The clinical implication of using computer-aided virtual planning combined with 3D printing lies in its multidisciplinary integration, involving experts such as maxillofacial radiologists, restorative dentists, and oral surgeons. This collaborative design ensures predictable surgical outcomes, promotes optimal bone utilization, enhances soft-tissue contours, and leads to superior functional and esthetic results, while minimizing potential postoperative complications stemming from implant misplacement.

Despite these promising findings, the present study had certain limitations, most notably the inclusion of only partially edentulous subjects, which restricts generalization to fully edentulous populations. Future investigations should aim to explore more economical fabrication approaches for surgical guides, given that cost remains a major determinant in patient decision-making. Moreover, further innovations could focus on design modifications enabling guided surgeries for patients with limited mouth opening.

Conclusion

Considering the scope and constraints of the current work, it can be inferred that implants placed using 3D-printed surgical guides exhibited closer alignment with the intended positions in all measured axes, outperforming those guided by thermoplastic templates. These systems achieved greater placement precision and enhanced overall accuracy. The main advantage of a digitally planned, computer-assisted 3D-printed surgical guide is the thorough preoperative design process, which ensures predictable outcomes regarding soft-tissue architecture, maximized bone support, and improved esthetic and functional rehabilitation.

For broader validation, future randomized controlled clinical trials with larger and more diverse samples are strongly recommended to provide further insight into the clinical reliability and applicability of 3D-printed implant surgical guides.

Acknowledgments: None

Conflict of interest: None

Financial support: None

Ethics statement: None

References

1. Nikzad S, Azari A. A novel stereolithographic surgical guide template for planning treatment involving a mandibular dental implant. J Oral Maxillofac Surg. 2008;66(7):1446-54.
2. Tatakis DN, Chien HH, Parashis AO. Guided implant surgery risks and their prevention. Periodontol 2000. 2019;81(1):194-208.
3. Le B, Nielsen B. Esthetic implant site development. Oral Maxillofac Surg Clin North Am. 2015;27(2):283-311.
4. Marchack CB, Chew LK. The 10-year evolution of guided surgery. J Calif Dent Assoc. 2015;43(3):131-4.
5. Kasten B, Arastu A, Panchal N. Dental implant surgery: From conventional to guided to navigated approach. Curr Oral Health Rep. 2018;5(3):140-6.
6. The glossary of prosthodontic terms: Ninth edition. J Prosthet Dent. 2017;117(5 Suppl):e1-e105.
7. ten Bruggenkate CM, de Rijcke TB, Kraaijenhagen HA, Oosterbeek HS. Ridge mapping. Implant Dent. 1994;3(3):179-82.
8. Allen F, Smith DG. An assessment of the accuracy of ridge-mapping in planning implant therapy for the anterior maxilla. Clin Oral Implants Res. 2000;11(1):34-8.
9. Stumpel LJ 3rd. Cast-based guided implant placement: A novel technique. J Prosthet Dent. 2008;100(1):61-9.
10. Guerrero ME, Jacobs R, Loubele M, Schutyser F, Suetens P, van Steenberghe D. State-of-the-art on cone beam CT imaging for preoperative planning of implant placement. Clin Oral Investig. 2006;10(1):1-7.
11. McGuigan MB, Duncan HF, Horner K. An analysis of effective dose optimization and its impact on image quality and diagnostic efficacy relating to dental cone beam computed tomography (CBCT). Swiss Dent J. 2018;128(4):297-316.
12. Abdinian M, Baninajarian H. The accuracy of linear and angular measurements in the different regions of the jaw in cone-beam computed tomography views. Dent Hypotheses. 2017;8(4):100-4.
13. Ganz SD. Three-dimensional imaging and guided surgery for dental implants. Dent Clin North Am. 2015;59(2):265-90.
14. Lee CY, Ganz SD, Wong N, Suzuki JB. Use of cone beam computed tomography and a laser intraoral scanner in virtual dental implant surgery: Part 1. Implant Dent. 2012;21(4):265-71.
15. Ersoy AE, Turkyilmaz I, Ozan O, McGlumphy EA. Reliability of implant placement with stereolithographic surgical guides generated from computed tomography: Clinical data from 94 implants. J Periodontol. 2008;79(8):1339-45.
16. Jung RE, Schneider D, Ganeles J, Wismeijer D, Zwahlen M, Hämmerle CH, et al. Computer technology applications in surgical implant dentistry: A systematic review. Int J Oral Maxillofac Implants. 2009;24 Suppl:92-109.
17. Cristache CM, Gurbanescu S. Accuracy evaluation of a stereolithographic surgical template for dental implant insertion using 3D superimposition protocol. Int J Dent. 2017;2017:4292081.
18. Beretta M, Poli PP, Maiorana C. Accuracy of computer-aided template-guided oral implant placement: A prospective clinical study. J Periodontal Implant Sci. 2014;44(4):184-93.
19. 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(Suppl 6):112-23.
20. Vercruyssen M, Hultin M, Van Assche N, Svensson K, Naert I, Quirynen M. Guided surgery: Accuracy and efficacy. Periodontol 2000. 2014;66(1):228-46.
21. Vercruyssen M, Cox C, Coucke W, Naert I, Jacobs R, Quirynen M. A randomized clinical trial comparing guided implant surgery (bone- or mucosa-supported) with mental navigation or the use of a pilot-drill template. J Clin Periodontol. 2014;41(7):717-23.
22. George FM, Chan HL, Razzoog ME, Oh TJ. Fabrication of a cast-based implant surgical guide using guide sleeves. J Prosthet Dent. 2011;106(6):409-12.
23. Becker CM, Kaiser DA. Surgical guide for dental implant placement. J Prosthet Dent. 2000;83(2):248-51.

24. Arfai NK, Kiat-Amnuay S. Radiographic and surgical guide for placement of multiple implants. J Prosthet Dent. 2007;97(5):310-2.
25. Cevidanes LH, Bailey LJ, Tucker GR Jr, Styner MA, Mol A, Phillips CL, et al. Superimposition of 3D cone-beam CT models of orthognathic surgery patients. Dentomaxillofac Radiol. 2005;34(6):369-75.
26. Cevidanes LH, Styner MA, Proffit WR. Image analysis and superimposition of 3-dimensional cone-beam computed tomography models. Am J Orthod Dentofacial Orthop. 2006;129(5):611-8.
27. Nada RM, Maal TJ, Breuning KH, Bergé SJ, Mostafa YA, Kuijpers-Jagtman AM. Accuracy and reproducibility of voxel-based superimposition of cone beam computed tomography models on the anterior cranial base and the zygomatic arches. PLoS One. 2011;6(2):e16520.
28. Buser D, Martin W, Belser UC. Optimizing esthetics for implant restorations in the anterior maxilla: Anatomic and surgical considerations. Int J Oral Maxillofac Implants. 2004;19 Suppl:43-61.
29. Canullo L, Tallarico M, Radovanovic S, Delibasic B, Covani U, Rakic M. Distinguishing predictive profiles for patient-based risk assessment and diagnostics of plaque-induced, surgically and prosthetically triggered peri-implantitis. Clin Oral Implants Res. 2016;27(10):1243-50.
30. Younes F, Cosyn J, De Bruyckere T, Cleymaet R, Bouckaert E, Eghbali A. A randomized controlled study on the accuracy of free-handed, pilot-drill guided and fully guided implant surgery in partially edentulous patients. J Clin Periodontol. 2018;45(6):721-32.
31. Varga E Jr, Antal M, Major L, Kiscsatári R, Braunitzer G, Piffkó J. Guidance means accuracy: A randomized clinical trial on freehand versus guided dental implantation. Clin Oral Implants Res. 2020;31(5):417-30.
32. Arisan V, Karabuda CZ, Ozdemir T. Implant surgery using bone- and mucosa-supported stereolithographic guides in totally edentulous jaws: Surgical and postoperative outcomes of computer-aided versus standard techniques. Clin Oral Implants Res. 2010;21(9):980-8.
33. Kühl S, Zürcher S, Mahid T, Müller-Gerbl M, Filippi A, Cattin P. Accuracy of full guided versus half-guided implant surgery. Clin Oral Implants Res. 2013;24(7):763-9.
34. Arisan V, Karabuda ZC, Pişkin B, Özdemir T. Conventional multi-slice computed tomography (CT) and cone-beam CT (CBCT) for computer-aided implant placement. Part II: Reliability of mucosa-supported stereolithographic guides. Clin Implant Dent Relat Res. 2013;15(6):907-17.
35. Smitkarn P, Subbalekha K, Mattheos N, Pimkhaokham A. The accuracy of single-tooth implants placed using fully digital-guided surgery and freehand implant surgery. J Clin Periodontol. 2019;46(9):949-57.
36. Tahmaseb A, Wismeijer D, Coucke W, Derksen W. Computer technology applications in surgical implant dentistry: A systematic review. Int J Oral Maxillofac Implants. 2014;29 Suppl:25-42.
37. 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.
38. Cassetta M, Giansanti M, Di Mambro A, Calasso S, Barbato E. Accuracy of two stereolithographic surgical templates: A retrospective study. Clin Implant Dent Relat Res. 2013;15(3):448-59.
39. Schneider D, Marquardt P, Zwahlen M, Jung RE. A systematic review on the accuracy and the clinical outcome of computer-guided template-based implant dentistry. Clin Oral Implants Res. 2009;20(Suppl 4):73-86.