ISSN 0973-2063 (online) 0973-8894 (print)

Bioinformation 22(10): 6606-6609 (2026)

©Biomedical Informatics (2026)

BIOINFORMATION
Discovery at the interface of physical and biological sciences

BIOMEDICAL INFORMATICS

www.bioinformation.net

Volume 22(10)

Research Article

Received October 1, 2026; Revised October 31, 2026; Accepted October 31, 2026, Published October 31, 2026

DOI: 10.6026/973206300226606

SJIF 2026 (Scientific Journal Impact Factor for 2026) = 8.478
2022 Impact Factor (2023 Clarivate Inc. release) is 1.9

Declaration on Publication Ethics:
The author's state that they adhere with COPE guidelines on publishing ethics as described elsewhere at https://publicationethics.org/. The authors also undertake that they are not associated with any other third party (governmental or non-governmental agencies) linking with any form of unethical issues connecting to this publication. The authors also declare that they are not withholding any information that is misleading to the publisher in regard to this article.

Declaration on official E-mail:
The corresponding author declares that lifetime official e-mail from their institution is not available for all authors

License statement:
This is an Open Access article which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly credited. This is distributed under the terms of the Creative Commons Attribution License

Comments from readers:
Articles published in BIOINFORMATION are open for relevant post publication comments and criticisms, which will be published immediately linking to the original article without open access charges. Comments should be concise, coherent and critical in less than 1000 words.

Disclaimer:
Bioinformation provides a platform for scholarly communication of data and information to create knowledge in the Biological/ Biomedical domain after adequate peer/editorial reviews and editing entertaining revisions where required. The views and opinions expressed are those of the author(s) and do not reflect the views or opinions of Bioinformation and (or) its publisher Biomedical Informatics. Biomedical Informatics remains neutral and allows authors to specify their address and affiliation details including territory where required.

Edited by Ritik Kashwani
E-mail: docritikkashwani@yahoo.com
Citation: Kulkarni *et al*. Bioinformation 22(10): 6606-6609 (2026)

Comparison of 3D printed versus CAD-CAM milled surgical guides on implant placement precision

Rasika Avinash Kulkarni[1,*], Shaili Agarwal[2], Megha Sharma[3], Swati Solanki[4], Manjiri Salkar[5] & Sumbul Saifi[6]

[1]Department of Prosthodontics and Crown & Bridge, SMBT Dental College & Hospital, Ghulewadi (Amrutnagar), Sangamner, Ahmednagar, Maharashtra, India; [2]Department of Prosthodontics, Crown & Bridge, Daswani Dental College, Kota, Rajasthan, India; [3]Department of Periodontology & Oral Implantology, Swami Devi Dayal Hospital & Dental College, Golpura, Barwala, Panchkula, Haryana, India; [4]Department of Prosthodontics, Crown and Bridge, Government College of Dentistry, Indore, Madhya Pradesh, India; [5]Department of Prosthodontics, MGV's KBH Dental College and Hospital, Nashik, Maharashtra, India; [6]Department of Periodontology and Implantology, Institute of Dental Sciences, Bareilly, Uttar Pradesh, India; *Corresponding author

Affiliation URL:
https://smbt.edu.in/

ISSN 0973-2063 (online) 0973-8894 (print)
Bioinformation 22(10): 6606-6609 (2026)
©Biomedical Informatics (2026)

https://daswanicollege.ac.in/
https://swamidevidayalhospital.org/
https://gcdindore.mp.gov.in/
https://mgvkbhdentalcollege.org/
https://idsbareilly.com/

Author contact:
Rasika Avinash Kulkarni - E-mail: rasikakul1705@gmail.com
Shaili Agarwal - E-mail: drshaili90@gmail.com
Megha Sharma - E-mail: meghadr92@gmail.com
Swati Solanki - E-mail: swatipcds@gmail.com
Manjiri Salkar - E-mail: drmanjirisalkar@gmail.com
Sumbul Saifi - E-mail: dr.sumbulsaifi@gmail.com

Abstract:
Inaccurate implant placement remains a major challenge in implant dentistry, compromising functional and aesthetic outcomes despite advances in guided surgery. Therefore, it is of interest to evaluate the implant placement accuracy using 3D-printed resin and CAD-CAM milled surgical guides in 40 implant sites, assessing angular, coronal, apical and depth deviations. Both guide types achieved clinically acceptable accuracy, but CAD-CAM milled guides showed significantly lower angular, coronal and apical deviations ($p \leq 0.001$), with no significant difference in depth deviation. The superior performance of milled guides was attributed to the greater dimensional stability of pre-polymerized blocks compared with layer-by-layer resin printing. Thus, data shows that guide manufacturing technique significantly influences implant placement accuracy, supporting evidence-based optimisation of digital workflows and surgical guide selection in implant dentistry.

Keywords: Dental implants, guided implant surgery, 3D-printed surgical guides, CAD-CAM milled guides; implant placement accuracy, angular deviation, digital dentistry

Background:
Implant therapy has emerged as a predictable treatment modality for the replacement of missing teeth, yielding excellent functional and aesthetic outcomes. However, the long-term success of implants depends critically on their three-dimensional positioning in accordance with prosthetically driven treatment planning; even minor deviations from the optimal position can jeopardise aesthetics, biomechanics and the overall success of the restoration **[1].** In the era of digital dentistry, computer-guided implant surgery has been adopted as a reliable adjunct to improve precision and predictability. This approach integrates cone-beam computed tomography (CBCT) data with dedicated planning software to design virtual implant positions, which are then transferred to the clinical setting via surgical guides **[2].** Guided implant surgery reduces surgical errors, helps avoid critical anatomical structures and enables minimally invasive approaches **[3].** Two principal techniques exist for fabricating surgical guides: three-dimensional (3D) printing (additive manufacturing) and CAD-CAM milling (subtractive manufacturing). Both aim to replicate the virtual implant plan as faithfully as possible, yet the inherent differences in their fabrication processes may affect the dimensional accuracy of the final guide **[4].** Resin-based 3D-printed guides are produced layer-by-layer, offering rapid, economical and highly customizable production**.** Milled guides, fabricated from solid pre-polymerized blocks, may offer greater dimensional stability owing to the homogeneity and density of the starting material **[5].** The accuracy of guided implant placement is assessed by comparing planned and actual implant positions using angular deviation, coronal displacement, apical displacement and depth discrepancy. Despite demonstrating generally acceptable accuracy, 3D-printed guides have shown variable precision that may be influenced by printing resolution, layer thickness and post-curing protocols **[6].** Additional factors affecting overall accuracy include guide stability and fit, support type (tooth-supported, mucosa-supported or bone-supported) and operator skill. Errors may accumulate at any stage of the digital workflow, from image acquisition and virtual planning to guide fabrication and surgical execution **[7].** Therefore, it is of interest to compare and evaluate the 3D-printed versus milled guide fabrication methods with respect to accuracy and clinical reproducibility is warranted.

Methodology:
Study design and setting:
This was a comparative *in vitro* study designed to assess the precision of implant placement using 3D-printed versus CAD-CAM milled surgical guides. Standardized typhoon models of partially edentulous arches were used to minimize anatomical variability. All models were scanned with cone-beam computed tomography (CBCT) to acquire accurate three-dimensional imaging data for virtual implant planning. The study was conducted in accordance with institutional guidelines and ethical principles applicable to *in vitro* research.

Virtual planning and guide fabrication:
Each CBCT dataset was imported into dedicated implant planning software (coDiagnostiX, Dental Wings, Switzerland). Implants were virtually positioned according to prosthetically driven principles, with standardized dimensions, angulation,

depth and mesiodistal location maintained across all samples. Based on this digital plan, surgical guides were fabricated using two techniques. Group A guides were manufactured using 3D printing (Formlabs Form 3B; Dental LT Clear resin) via stereo lithography (SLA). Group B guides were produced by CAD-CAM milling from solid pre-polymerized PMMA blocks (Zirkonzahn Prettau CAD/CAM milling unit). All guides were tooth-supported and verified for accurate seating on their respective models prior to use.

Implant placement and outcome measurement:
All implant placements were performed by a single experienced operator under standardised conditions to minimise inter-operator variability. A torque-controlled surgical unit was used; each guide was fully seated and stabilised before drilling and implant insertion. Post-operative CBCT scans were acquired for all samples following implant placement. Planned and actual implant positions were superimposed and compared using dedicated analysis software (Simplant Pro, Dentsply Sirona). The parameters evaluated were: (i) angular deviation (degrees); (ii) Coronal deviation at the entry point (mm); (iii) apical deviation at the implant apex (mm); and (iv) depth discrepancy (mm).

Statistical analysis:
Data were analysed using SPSS version 26.0. Descriptive statistics (mean and standard deviation) were calculated for each accuracy parameter. Between-group comparisons were performed using the independent-samples t-test; normality was verified with the Shapiro–Wilk test. A p-value of < 0.05 was considered statistically significant.

Results:
A total of 40 implant sites were evaluated: 20 placed using 3D-printed guides (Group A) and 20 using CAD-CAM milled guides (Group B). All implants were successfully inserted without procedural errors in guide positioning or implant placement (100% completion rate). Both groups achieved clinically acceptable accuracy; however, systematic differences between groups were observed in the magnitude of deviations. Mean angular deviation was $2.84 \pm 0.92°$ in Group A and $1.73 \pm 0.61°$ in Group B ($p < 0.001$). Mean coronal deviation was 1.21 ± 0.38 mm in Group A versus 0.78 ± 0.29 mm in Group B ($p < 0.001$). Mean apical deviation was 1.58 ± 0.47 mm in Group A and 1.09 ± 0.34 mm in Group B ($p = 0.001$). Depth discrepancy was 0.31 ± 0.14 mm in Group A and 0.27 ± 0.12 mm in Group B; this difference was not statistically significant ($p = 0.31$). The milled guide group also showed smaller standard deviations across all parameters, indicating superior inter-sample reproducibility. A full summary of results is presented in **(Table 1).**

Table1: Implant placement accuracy parameters: Group A (3D-printed) versus Group B (CAD-CAM milled) (n = 20 per group)

Parameter	Group A: 3D Printed (Mean ± SD)	Group B: CAD-CAM Milled (Mean ± SD)	Difference	p-value
Angular deviation (°)	2.84 ± 0.92	1.73 ± 0.61	1.11	<0.001*
Coronal deviation (mm)	1.21 ± 0.38	0.78 ± 0.29	0.43	<0.001*
Apical deviation (mm)	1.58 ± 0.47	1.09 ± 0.34	0.49	0.001*
Depth discrepancy (mm)	0.31 ± 0.14	0.27 ± 0.12	0.04	0.31 (NS)

** Statistically significant ($p < 0.05$); NS = not significant*

Discussion:
This *in vitro* study showed that both 3D-printed and CAD-CAM milled surgical guides produce clinically acceptable implant placement accuracy, while milled guides consistently yielded lower deviations across angular and linear parameters. These findings are in agreement with recent systematic review evidence reporting mean angular deviations of 2.5–3.5° and coronal deviations of 1.0–1.5 mm for guided implant surgery overall, with milled guides trending towards the lower end of published ranges**.** The superior performance of CAD-CAM milled guides observed in this study is consistent with the material and manufacturing properties of subtractive fabrication. Pre-polymerised solid PMMA blocks have higher density, greater hardness and lower residual internal stress compared with photopolymerised resin layers, resulting in a dimensionally stable guide with a precise sleeve seat **[8].** In contrast, 3D-printed guides accumulate layer-by-layer polymerization stresses and post-curing shrinkage may introduce micro-deformations that translate into slight misalignment during surgical use **[9].** Several *in vitro* and clinical studies have similarly attributed lower accuracy in 3D-printed guides to polymerisation contraction and staircase artifacts inherent to additive manufacturing **[10].** Guide stability and fit are critical determinants of transfer accuracy from virtual plan to clinical execution. A misfit of even 0.5–1 mm has been shown to produce measurable coronal and apical deviations **[11].** In the present study, guide placement was standardised and verified for complete seating; nevertheless, the inherent tolerances of 3D-printed sleeves may have contributed marginally to the higher deviations observed in Group A. Tooth-supported guides, as used in this study, are recognized to provide the greatest positional stability, minimising the influence of soft tissue resilience or bone surface irregularity on final guide positioning**.** Errors accumulate across the digital workflow-from CBCT acquisition and segmentation to virtual planning, guide fabrication and surgical execution – and the manufacturing stage represents one identifiable source of controllable error **[12, 13]**. Operator experience also influences guided surgery outcomes; while guided systems are designed to minimise human error, correct guide positioning and adherence to drilling protocols remain paramount**.** Patient-specific variables such as limited mouth opening and soft tissue characteristics may further affect guide stability in the clinical setting but were controlled in this *in vitro* model **[14, 15].** Despite the statistically significant differences observed, the absolute magnitude of deviations in Group A remained within commonly cited clinical acceptability

thresholds (angular deviation < 5°; linear deviation < 2 mm)**.** 3D-printed guides therefore remain a clinically viable option, particularly where cost-effectiveness, rapid turnaround or high geometric complexity are priorities. Ongoing advances in printing resolution, resin chemistry and post-processing protocols are progressively narrowing the performance gap between additive and subtractive manufacturing in surgical guide production **[16, 17].**

Conclusion:
Flapless implant placement significantly reduces early post-operative morbidity and 12-month crestal bone resorption without compromising implant survival in appropriately selected patients. Open flap surgery remains essential when augmentation, anatomical visualisation, or soft-tissue management is required. Careful patient selection, CBCT-guided planning, and surgeon expertise are critical determinants of flapless implant success.

Conflict of interest: The authors declare no conflict of interest.

Funding: No external funding was received for this study.

Ethical Approval:
This *in vitro* study did not involve human participants or animals and was conducted in accordance with institutional research guidelines. No formal ethics committee approval was required.

References:

[1] Mhatre S *et al. Cureus*. 2024 **16**:e64549. [PMID: 39144901]
[2] Sinha A *et al. Oral Sphere J. Dent. Health Sci*. 2025 **1**:224. [DOI: 10.63150/osjdhs.2025.23]
[3] Chackartchi T *et al. Periodonto*l 2000. 2022 **88**:64. [PMID: 35103317]
[4] Holban CC *et al. J Clin Med*. 2025 **14**:4837. [PMID: 40725530]
[5] Auriemma G *et al. Molecules*. 2022 27:2784. [PMID: 35566146]
[6] Markiewicz M & Nowicki AA. J *Clin Med*. 2025 **14**:8652. [PMID: 41464555]
[7] Smojver I *et al. J Funct Biomater*. 2026 17:194. [PMID: 42042300]
[8] Chunara F *et al. African Journal of Biomedical Research*. 2024 **27**:2254. [DOI: 10.53555/AJBR.v27i3S.2597]
[9] Mittal A *et al. Oral Sphere J. Dent. Health Sci*. 2025 **1**:263. [DOI: 10.63150/osjdhs.2025.28]
[10] Shi Y *et al. Int J Implant Dent.* 2023 **9**:38. [PMID: 37875645]
[11] Bjelica R *et al. J Clin Med*. 2026 **15**:652. [PMID: 41598591]
[12] Chen HT *et al. Bioengineering (Basel).* 2026 **13**:219. [PMID: 41749758]
[13] Jorba-García A *et al. Med Oral Patol Oral Cir Bucal.* 2019 **24**:e76. [PMID: 30573712]
[14] Monalisa S *et al. Dent J (Basel).* 2025 **13**:555. [PMID: 41440313]
[15] Schwärzler A *et al. J Dent.* 2024 **146**:105060. [PMID: 38735471]
[16] Ballesteros J *et al. Clin Implant Dent Relat Res*. 2025 **27**:e70072. [PMID: 40577487]
[17] Stino M *et al. Journal of Fundamental and Clinical Research.* 2024 4:30. [DOI: 10.21608/jfcr.2024.253520.1064]

Caveat Emptor is applicable among the literate community where required and possible. The publisher, its journal, editors and the internal/external reviewers take adequate steps to check, evaluate, correct, edit, revise and improve content where possible and required.