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Efficacy of Guided Versus Freehand Dental Implant Placement: A Comparative Clinical Study

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Abstract **Original Research Article**

***Background*:** Computer-guided implant surgery integrates CBCT-based planning with digital impressions and 3D-printed surgical guides to control implant position compared with conventional freehand placement. ***Objective*:** To compare guided implant placement with freehand implant placement by quantifying the deviation between planned and final implant positions. ***Materials and Methods*:** This comparative clinical study included implant cases treated between February 2024 and May 2024 in private clinics in Baghdad and Hilla. Guided cases were planned by matching CBCT (DICOM) and intraoral scans (STL) in implant-planning software and fabricated using 3D-printed surgical guides with compatible sleeves. Freehand cases were placed conventionally without a guide. Deviation ("misplacement", mm) between planned and final implant position was measured in coronal and sagittal views in the buccolingual direction. Deviation values were analyzed per implant. ***Results*:** A total of 55 implants were evaluated (freehand: n = 28; guided: n = 27). Mean deviation was 1.221 ±0.546 mm in the freehand group and 0.170 ±0.230 mm in the guided group. The maximum deviation was 2.44 mm (freehand) versus 1.00 mm (guided). The between-group difference was statistically significant (Welch's t-test, $p < 0.0001$). ***Conclusions*:** Guided implant surgery demonstrated significantly lower deviation from the planned position compared with freehand implant placement, supporting the value of digitally planned, prosthetically driven implant positioning.

Keywords: Guided Implant Surgery, Freehand Implant Placement, CBCT, Surgical Guide, Implant Deviation, Digital Dentistry.

1. INTRODUCTION

Dental implants are widely used to replace missing teeth and restore oral function and aesthetics. Optimal outcomes depend on accurate, prosthetically driven implant positioning while maintaining safe distances from critical anatomical structures and achieving predictable long-term success (Albrektsson *et al.,* 1986; Misch, n.d.). Conventional freehand placement relies on clinical experience and interpretation of radiographic and intraoperative landmarks, which can contribute to positional deviation, particularly in complex cases or full-arch rehabilitation.

Computer-guided implant surgery integrates CBCT imaging with digital impressions and planning software to virtually position implants and fabricate surgical guides that help control angulation, depth, and location. Image-based planning and customized drill guides have been described to support implant placement in challenging anatomy (Vrielinck *et al*., 2003). Therefore, comparing guided and freehand methods using measurable deviation outcomes is clinically relevant.

This study aimed to compare guided implant placement versus freehand implant placement by quantifying the deviation (mm) between planned and final implant positions.

2. MATERIALS AND METHODS

2.1 Study Design and Setting

This comparative clinical study included implant cases treated in private clinics (Al-massa, Al-swak, and Noble clinics) in Baghdad and Hilla, Iraq, between February 2024 and May 2024 for dental implant treatment due to tooth loss. Procedures were performed by experienced dentists.

2.2 Participants

Patients were clinically evaluated before treatment. Patients with temporomandibular disorders (TMD) or joint diseases were excluded to minimize factors that could affect procedural accuracy and reduce the need for intraoperative modifications.

2.3 Study Groups

- **Freehand Group (Control):** conventional implant placement without a surgical guide.
- **Guided Group:** CBCT- and software-planned implant placement using a 3D-printed surgical guide and compatible sleeves.

2.4 Guided Workflow (Data Acquisition, Planning, and Guide Fabrication)

For guided cases, CBCT was acquired and saved as DICOM files. Intraoral scans were performed using an intraoral scanner (3Shape TRIOS®) and saved as STL files. DICOM and STL datasets were imported and matched in implant-planning software (Blue Sky Bio Plan 4 on macOS; additional software used depending on cases included EXOPLAN, Real Guide and 3Shape). The implant plan was reviewed and approved by the treating clinicians. The surgical guide design was exported as an STL file for printing. Manufacturer-compatible sleeves were used; in selected cases, resin sleeves were utilized.

2.5 Outcome Measure (Deviation / Misplacement)

Deviation ("misplacement", mm) was measured between the planned implant position and the final implant position. Measurements were recorded in coronal and sagittal views in the buccolingual direction within the planning/analysis software.

2.6 Statistical Analysis

Data were analyzed per implant. Continuous variables were summarized as mean ±standard deviation (SD) and median (interquartile range, IQR). Between-group comparisons of mean deviation were performed using Welch's independent samples t-test. Statistical significance was set at $p < 0.05$.

3. RESULTS

A total of 55 implants were evaluated (freehand: n = 28; guided: n = 27). The guided group demonstrated substantially lower deviation from the planned position compared with the freehand group. Mean deviation was 0.170 ±0.230 mm in the guided group versus 1.221 ±0.546 mm in the freehand group. Median (IQR) deviation was 0.10 (0.00–0.20) mm for guided surgery and 1.025 (0.785–1.480) mm for freehand placement. The maximum deviation observed was 1.00 mm in guided surgery and 2.44 mm in freehand placement. The between-group difference in mean deviation was statistically significant (Welch's t-test, $p < 0.0001$).

Table 1: Deviation between planned and final implant position (per-implant)

Group	n (implants)	Mean ± SD (mm)	Median (IQR) (mm)	Min–Max (mm)
Freehand	28	1.221 ± 0.546	1.025 (0.785–1.480)	0.40–2.44
Guided	27	0.170 ± 0.230	0.10 (0.00–0.20)	0.00–1.00

Table 2: Between-group comparison (per-implant deviation)

Outcome	Deviation (mm)
Mean difference (Freehand − Guided)	1.051 mm
95% CI	0.823 to 1.279 mm
Test	Welch's independent samples t-test
P value	< 0.0001

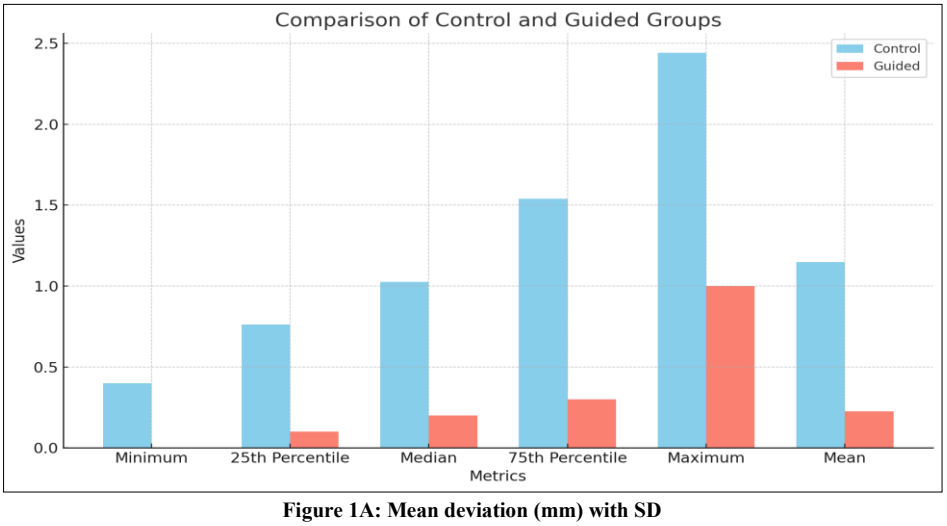

Figure 1A: Mean deviation (mm) with SD

Freehand: median 1.025 (IQR 0.785–1.480) mm; Guided: median 0.10 (IQR 0.00–0.20) mm.

Figure 1. Comparison of deviation (mm) between guided and freehand implant placement. Figure 1A shows mean ±SD; Figure 1B shows median and IQR.

4. DISCUSSION

This study compared guided and freehand implant placement by measuring deviation between planned and final implant positions. Guided implant placement demonstrated markedly lower deviation than freehand placement, and the difference was statistically significant. These results support the clinical value of CBCT-based digital planning and guided workflows for improving implant positioning accuracy, particularly when a prosthetically driven implant position is required (Misch, n.d.). Image-based planning and the use of customized drill guides have previously been reported as supportive approaches in complex anatomical situations (Vrielinck *et al*., 2003).

A limitation of the present analysis is that deviation was analyzed per implant; multiple implants may originate from the same patient, which can introduce clustering. Future studies should consider patient-level analyses and additional deviation dimensions (e.g., mesiodistal and apical deviations), as well as standardized post-operative imaging protocols.

5. CONCLUSIONS

Within the limitations of this comparative clinical study, guided implant placement demonstrated substantially higher accuracy than conventional freehand placement, as reflected by lower deviation between planned and final implant positions. In our sample, the guided group showed a much smaller mean deviation (0.170 ±0.230 mm) compared with the freehand group (1.221 ±0.546 mm), and the difference was statistically significant (Welch's t-test, $p < 0.0001$). These results support the clinical value of CBCT-based planning combined with intraoral scanning and 3D-printed surgical guides to improve the predictability of implant positioning in the buccolingual dimension.

From a clinical perspective, improved positioning accuracy may contribute to more prosthetically driven implant placement, better restoration emergence profiles, and potentially fewer intraoperative adjustments. However, guided workflows require careful attention to each step of the digital chain—from image acquisition and DICOM–STL matching, to guide design, printing, and sleeve/drill compatibility—because errors or inaccuracies at any stage may affect the final implant position.

Several practical considerations should be acknowledged. Guided surgery can be more demanding in terms of preoperative planning time and coordination between software, printing, and clinical components, and it may be less flexible than freehand placement when unexpected intraoperative findings occur. [In some cases, factors such as guide stability/fit, limited mouth opening, sleeve access, or workflow compatibility between sleeves and drilling systems required additional attention.] Therefore, the guided approach should be implemented with strict verification protocols (fit-check of the guide, sleeve verification, and planned implant position review) to maximize accuracy.

Overall, guided implant placement is recommended when high positional precision is required, especially for prosthetically driven cases. Future studies with larger samples, standardized postoperative imaging, and patient-level analyses are encouraged to further validate these findings and to evaluate additional deviation dimensions (e.g., mesiodistal, vertical/apical, and angular deviations), as well as clinical outcomes such as prosthetic complications and long-term success.

Abbreviations: CBCT, Cone Beam Computed Tomography, DICOM, Digital Imaging and Communications in Medicine; STL, Standard Tessellation Language, CAD/CAM, Computer-Aided Design/Computer-Aided Manufacturing.

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