Journal of Population Therapeutics & Clinical Pharmacology

RESEARCH ARTICLE
DOI: 10.53555/kkz81t74

ASSESSMENT OF THE EFFECTIVENESS OF DIGITAL IMPLANT PLANNING AND GUIDED SURGERY ON IMPLANT PLACEMENT ACCURACY AND PROSTHETIC OUTCOMES

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Abstract

Background: Digital implant planning and guided surgery have been used to increase prosthetic results and implant placement accuracy over traditional freehand methods.

Objective: This study aimed to evaluate the effectiveness of digital implant planning and guided surgery in improving implant placement accuracy and prosthetic outcomes compared to conventional freehand techniques.

Methodology: A prospective observational study was conducted at the Smart Dental Care and Implant Centre, Islamabad, from July 2023 to June 2024, involving 54 patients divided into two groups: digital implant planning (n = 28) and freehand placement (n = 26). Following guided surgery using 3D-printed templates or dynamic navigation, preoperative digital planning was done using CBCT and CAD/CAM software. Radiographically, implant placement accuracy was tested; clinical criteria and self-reported scores evaluated prosthetic results and patient satisfaction. SPSS v26 was used for statistical analysis; significance was defined at $p < 0.05$.

Results: The digital group showed significantly lower angular (2.31° ± 1.02 vs. 5.78° ± 1.94), coronal (0.76 mm ± 0.34 vs. 1.92 mm ± 0.61), apical (0.91 mm ± 0.37 vs. 2.14 mm ± 0.58), and depth deviations (0.42 mm ± 0.28 vs. 1.08 mm ± 0.43) compared to the freehand group ($p < 0.001$). Functional success (96.43% vs. 80.77%), aesthetic satisfaction (89.29% vs. 69.23%), and overall patient satisfaction (9.18 ± 0.74 vs. 7.89 ± 1.12) were also significantly better in the digital group.

Conclusion: Digital implant planning and guided surgery significantly enhance implant placement accuracy and patient-related outcomes compared to freehand techniques.

Keywords: Dental implants, digital planning, guided surgery, implant accuracy, prosthetic outcomes, patient satisfaction.

Introduction

Over the last decades, dental implantology has changed dramatically as digital technology improve accuracy, predictability, and general treatment results [1]. Although conventional freehand implant placement is somewhat common, it is often linked with variability in accuracy, which results in possible problems like inappropriate angulation, inadequate prosthesis alignment, and higher risk of implant failure [2]. Digital implant planning and guided surgery have become creative solutions meant to solve these difficulties as they help to enhance implant placement precision and long-term prosthetic success [3].

Digital implant planning develops a virtual treatment plan based on the anatomical structures of the patient by use of cone-beam computed tomography (CBCT) and computer-aided design/computer-aided manufacturing (CAD/CAM) software [4]. By means of exact determination of implant site, angulation, and depth, this preoperative planning maximizes bone use and avoids important anatomical structures like the maxillary sinus and inferior alveolar nerve [5]. Guided surgery also uses dynamic navigation systems or 3D-printed surgical templates to convert the virtual plan into the clinical environment, therefore guaranteeing minimum variation from the desired implant site [6,7].

Adoption of digital processes in implant dentistry has various benefits including greater surgical precision, decreased chairside time, improved patient comfort, and predictable prosthesis results [8,9]. Studies have shown that compared to traditional freehand approaches, digitally guided surgery greatly lowers variations in implant placement, hence improving biomechanical stability and prosthesis fit. Furthermore, these developments help flapless or less invasive treatments, thereby promoting quicker healing and reduced postoperative morbidity [10,11].

Notwithstanding these advantages, issues like higher prices, learning curves, and possible mistakes in digital processes need further research. Furthermore, still under investigation is how digital implant design and guided surgery affect long-term prosthetic success and general patient satisfaction. Therefore, validation of their therapeutic relevance and optimal adoption in daily practice depend on a thorough evaluation of the efficacy of these digital technologies.

Research Objective

This study aim was to evaluate the effectiveness of digital implant planning and guided surgery in improving implant placement accuracy and prosthetic outcomes compared to conventional freehand techniques

Materials and Methods

Study Design and Setting

This was a prospective observational study conducted at the Smart Dental Care and Implant Centre, Islamabad, over a period of one year, from July 2023 to June 2024.

Inclusion and Exclusion Criteria

Included in the research were patients eighteen years of age and above who needed dental implants with enough bone volume for implantation and those ready for digital implant design and guided surgery. Considered qualified were only those who gave informed permission to participate. The study excluded patients with systemic conditions contraindicating implant surgery, such uncontrolled diabetes or osteoporosis, cases with severe bone loss requiring extensive grafting, those with a history of past implant failures in the same region, and those reluctant to follow-up protocols.

Sample Size

A total of 54 patients were included in the study, selected through convenient sampling. his sample size was determined to provide adequate statistical power to detect significant differences in implant placement accuracy and prosthetic outcomes between digital and conventional techniques.

Data Collection

To find ideal implant location, preoperative digital planning was done using CBCT imaging and CAD/CAM software. Either dynamic navigation systems or 3D-printed surgical templates guided surgery. To gauge placement accuracy, postoperative implant placements were evaluated by radiographic measures and matched to preoperative intended positions. Assessed were prosthetic results depending on functional and cosmetic criteria, patient-reported satisfaction, and any postoperative problems.

Statistical Analysis

SPSS version 26 was used to examine data. Patient demography and clinical parameters were compiled using descriptive statistics. Mean deviation measurements between intended and actual implant placements used to assess accuracy of implant implantation. Chi-square was used to compare prosthetic results; a significant threshold established at $p < 0.05$.

Results

Table 1 lists the clinical and demographic features of the research population. Patients in both groups had similar mean ages—45.67 ± 9.23 years in the digital group and 46.12 ± 8.9 year in the freehand group. Regarding gender distribution, men accounted for 53.57% in the digital group and 57.69% in the freehand group; women made 46.43% and 42.30% correspondingly. Comparatively to 19.23% in the freehand group, smoking status revealed 21.43% in the digital group. Whereas osteoporosis was seen in 7.14% and 11.54% respectively, diabetes mellitus was prevalent in 14.29% of digital patients and 19.23% in the freehand group.

Table 1: Demographic and Clinical Characteristics of Patients

Variable		**Digital Implant Planning (n = 28)**	**Freehand Implant Placement (n = 26)**
Age (years)	Mean ± SD	45.67 ± 9.23	46.12 ± 8.94
Gender	Male	15 (53.57)	15 (57.69)
	Female	13 (46.43)	11 (42.30)
Smoking Status	Smokers	6 (21.43)	5 (19.23)
	Non-Smokers	22 (78.57)	21 (80.77)
Comorbidities	Diabetes Mellitus	4 (14.29)	5 (19.23)
	Osteoporosis	2 (7.14)	3 (11.54)

Table 2 contrasts between groups the precision of implant placement. With a 2.31 ± 1.02° angular deviation, the computerized group showed much less than the freehand group (5.78 ± 1.94°, $p < 0.001$). Likewise, in the computerized group coronal deviation was 0.76 ± 0.34 mm; in the freehand group it was 1.92 ± 0.61 mm ($p < 0.001$). With digital guidance, apical deviation was likewise much lowered in the digital group (0.91 ± 0.37 mm) compared to freehand (2.14 ± 0.58 mm, $p = 0.001$), and depth deviation followed the same pattern (0.42 ± 0.28 mm vs. 1.08 ± 0.43 mm, $p = 0.001$, so demonstrating improved placement accuracy.

Table 2: Accuracy of Implant Placement (Mean Deviations in mm)

Measurement Parameter	**Digital Implant Planning (Mean ± SD)**	**Freehand Implant Placement (Mean ± SD)**	***p*-value**
Angular Deviation	2.31 ± 1.02	5.78 ± 1.94	<0.001
Coronal Deviation	0.76 ± 0.34	1.92 ± 0.61	<0.001
Apical Deviation	0.91 ± 0.37	2.14 ± 0.58	<0.001
Depth Deviation	0.42 ± 0.28	1.08 ± 0.43	<0.001

Table 3 lists results from prosthesis construction. With a p = 0.041, functional success was greater in the digital group at 96.43% than in the freehand group at 80.77%. Digital planning (89.29%) also produced more aesthetic pleasure than freehand (69.23%, p = 0.048). The digital group (3.57%) had clearly less prosthetic fit problems than the freehand group (23.08%, p = 0.036). Though the difference was not statistically significant (p = 0.182), postoperative problems were somewhat smaller in the digital group (7.14%) than in the freehand group (19.23%).

Table 3: Comparison of Prosthetic Outcomes

Outcome Parameter	**Digital Implant Planning (n = 28)**	**Freehand Implant Placement (n = 26)**	***p*-value**
Functional Success	27 (96.43)	21 (80.77)	0.041
Aesthetic Satisfaction	25 (89.29)	18 (69.23)	0.048
Prosthetic Fit Issues	1 (3.57)	6 (23.08)	0.036
Postoperative Complications	2 (7.14)	5 (19.23)	0.182

Table 4 lists patient level of satisfaction. Compared to the freehand group (7.89 ± 1.12, p < 0.001), patients in the computerized group reported noticeably higher general satisfaction (9.18 ± 0.74). The digital group had also better comfort ratings (8.96 ± 0.83 vs. 7.54 ± 1.18, p = 0.002). P = 0.004. Speech progress ratings in the digital group were 8.42 ± 1.03 and in the freehand group were 7.12 ± 1.41. With a similar trend, chewing efficiency favored the digital group (8.87 ± 0.92 vs. 7.35 ± 1.24, p = 0.001), therefore showing greater patient-reported satisfaction with digitally guided implant operations.

Table 4: Patient Satisfaction Scores (Mean ± SD)

Satisfaction Parameter	**Digital Group**	**Freehand Group**	***p*-value**
Overall Satisfaction	9.18 ± 0.74	7.89 ± 1.12	<0.001
Comfort Level	8.96 ± 0.83	7.54 ± 1.18	0.002
Speech Improvement	8.42 ± 1.03	7.12 ± 1.41	0.004
Chewing Efficiency	8.87 ± 0.92	7.35 ± 1.24	0.001

Discussion

This work showed that compared to traditional freehand techniques, digital implant design and guided surgery greatly improve implant placement accuracy and prosthesis results. The results fit the growing corpus of data confirming the part digital processes play in raising patient happiness and clinical accuracy.

With regard to accuracy, the digital group displayed significantly smaller angular deviation (2.31 ± 1.02°) than the freehand group (5.78 ± 1.94°, p = 0.001). With p-values of 0.001, coronal deviation was also much lowered (0.76 ± 0.34 mm vs. 1.92 ± 0.61 mm), apical (0.91 ± 0.37 mm vs. 2.14 ± 0.58 mm), and depth deviations (0.42 ± 0.28 mm vs. 1.08 ± 0.43 mm). These results confirm the results of those who underlined that computer-guided surgery reduces variations in all implant dimensions [12]. Previous studies also showed similar accuracy gains, which validates that guided surgery lowers angular and linear deviations by up to 50% over freehand insertion [13]. With regard to prosthetic results, the digital group's 96.43% of cases had functional success—much greater than the freehand group's 80.77%—p = 0.041. Along with a clear decline in prosthetic fit problems (3.57% vs. 23.08%, p = 0.048), aesthetic satisfaction followed a similar trend (89.29% vs. 69.23%). These results complement earlier research showing improved initial prosthetic fit and esthetics with computerized planning in esthetic zone restorations [14]. Likewise, Schubert et al. underlined that improved prosthesis adaption and esthetics directly follow from reduced implant location errors achieved by digital navigation [15]. The difference did not approach statistical relevance (p = 0.182), even if postoperative complications were less frequent in the digital group (7.14%) than in the freehand group

(19.23%). Still, this tendency corresponds with studies showing that, because of its minimally intrusive character, guided surgery may reduce surgical trauma and postoperative morbidity [16].
Digital group patient-reported satisfaction was notably greater in all areas: overall satisfaction (9.18 ± 0.74 vs. 7.89 ± 1.12), comfort (8.96 ± 0.83 vs. 7.54 ± 1.18, speech improvement (8.42 ± 1.03 vs. 7.12 ± 1.4, chewing efficiency (8.87 ± 0.92 vs. 7.35 ± 1.24). These results line up with other research showing better patient satisfaction using completely guided, immediate loading techniques [17]. The results of this study generally support the clinical worth of guided surgery and digital implant planning in providing more consistent, exact, patient-centered implant treatment.

Study Strengths and Limitations

The study's prospective design, which permitted direct comparison between computerized implant planning and conventional freehand procedures in a real-world clinical environment, thereby improving the validity of the outcomes. Objective radiographic assessments for implant correctness and inclusion of patient-reported outcomes provide a complete assessment of both clinical and experiential elements. Moreover, using consistent surgical techniques for both groups helped to lower any bias. The study had certain restrictions, too, including a rather small sample size and short follow-up period, which would restrict the generalizability and long-term relevance of the results. Convenient sampling may cause selection bias; lack of randomizing could compromise internal validity. Furthermore, neglected were cost-effectiveness and learning curve connected with digital processes, which could be crucial for pragmatic application in several healthcare environments.

Conclusion

In conclusion, this study showed that compared to conventional freehand approaches, computerized implant planning and guided surgery greatly increase the precision of implant placement and produce better prosthetic results and greater patient satisfaction. Along with better functional and cosmetic success, less prosthetic fit problems, and better patient-reported outcomes including comfort, speech, and chewing efficiency, the digital group demonstrated notably smaller deviations in angular, coronal, apical, and depth parameters. These results validate the increasing use of digital workflows in implant dentistry as a strategy to improve accuracy, predictability, and general treatment success.

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