A COMPARATIVE STUDY ON IMPLANT PLACEMENT ACCURACY BETWEEN VACUUM-FORMED THERMOPLASTIC GUIDES AND CAD-CAM 3D PRINTED GUIDES

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ABSTRACT

Background: Surgical guides play an important role in transferring virtual implant planning to the clinical setting. The accuracy of implant placement may vary depending on the guide fabrication technique.

Aim: To compare the implant placement accuracy of vacuum-formed thermoplastic guides and CAD-CAM fabricated 3D printed surgical guides.

Materials and Methods: This comparative clinical study included 48 implant sites in 15 partially edentulous patients. Implant sites were allocated to either thermoplastic surgical guides (n=24) or CAD-CAM 3D printed surgical guides (n=24). Preoperative and postoperative CBCT scans were used to assess coronal, apical, angular, and depth deviations between planned and actual implant positions. Statistical analysis was performed using an independent sample t-test.

Results: The 3D printed guide group showed significantly lower coronal deviation (0.80 ± 0.21 mm vs. 1.45 ± 0.31 mm), apical deviation (1.12 ± 0.28 mm vs. 1.68 ± 0.42 mm), angular deviation (2.93 ± 0.92° vs. 5.84 ± 1.28°), and depth deviation (0.64 ± 0.14 mm vs. 1.18 ± 0.30 mm) compared with the thermoplastic guide group ($p < 0.05$).

Conclusion: CAD-CAM fabricated 3D printed surgical guides demonstrated significantly greater implant placement accuracy than conventional thermoplastic guides and may provide a more predictable approach for guided implant surgery.

Keywords: Dental implants, guided implant surgery, CAD-CAM, 3D printing, surgical guide accuracy.

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INTRODUCTION

Dental implants have proved to be one of the most dependable approaches for the replacement of missing teeth because of their effectiveness, aesthetic value, and overall success rate. Successful implementation of an implant prosthesis largely depends on correct positioning of the implant in all three dimensions. Incorrect positioning may adversely affect the restoration process, its aesthetics, the maintenance of oral hygiene, and even cause damage to surrounding anatomical structures such as the inferior alveolar nerve, mental foramen, and the maxillary sinus. (1)

Freehand implant surgery is widely practised, but it is highly dependent on the surgeon's skill and can result in deviations in the angulation, depth and mesiodistal positioning of the implant. Such inaccuracies can have an adverse effect on prosthetic rehabilitation and the biomechanical loading of implants. To minimise such errors and improve surgical precision, guided implant surgery has been introduced in modern implant dentistry. (2)

Guided implant surgery involves virtual implant planning with cone-beam computed tomography (CBCT) and digital imaging technologies, followed by the fabrication of a surgical guide to aid in the precise transfer of the planned implant position during surgery. (1) Static surgical guides are generally fabricated using either conventional thermoplastic vacuum forming techniques or computer-aided design and computer-aided manufacturing (CAD-CAM) based three-dimensional (3D) printing technologies. [3]

Thermoplastic surgical guides are fabricated using transparent, vacuum-formed sheets that are moulded over diagnostic casts. These guides are relatively economical and easy to fabricate, requiring minimal laboratory equipment. [4] Recent advances in digital dentistry have led to the development of CAD/CAM-fabricated, 3D-printed surgical guides. These guides are digitally designed using implant planning software and manufactured using additive manufacturing techniques, such as stereolithography (SLA) or digital light processing (DLP).[5]

Despite the advantages of guided implant surgery, discrepancies between the planned and actual positions of implants continue to be reported in the literature. Factors such as the fabrication technique used for the guide, guide support, sleeve tolerance, imaging accuracy and operator experience may influence the accuracy of implant placement. [6]

The present study therefore aims to evaluate and compare the accuracy of implant placement using thermoplastic and 3D-printed surgical guides, by assessing the deviation in coronal, apical, angular and depth positions between the planned and actual implant locations. The findings may help to identify a guide system that is more accurate and clinically reliable for implant surgery.

MATERIAL AND METHODS

Study Design

The present study was designed as a comparative clinical study to evaluate and compare the transfer accuracy of implant placement using thermoplastic surgical guides and CAD-CAM fabricated 3D printed surgical guides in partially edentulous patients requiring dental implant rehabilitation.

Study Setting

The study was conducted in the Department of Oral and Maxillofacial Surgery after obtaining informed consent from patient.

Study Population

Patients reporting to the outpatient department for replacement of missing teeth with dental implants were screened.

A total of 48 implant site (15 patients) requiring implant rehabilitation were included in the study and randomly divided into two groups by computerised randomization:

- **Group A:** Thermoplastic surgical guide group (n = 24) (5 patients)
- **Group B:** CAD-CAM fabricated 3D printed surgical guide group (n = 24) (10 patients)

Inclusion Criteria

Patients fulfilling the following criteria were included in the study:

1. Patients aged between 20 and 70 years.
2. Adequate bone height and width for implant placement without the need for bone augmentation.
3. Patients with good oral hygiene and satisfactory periodontal health.

Exclusion Criteria

The following patients were excluded from the study:

1. Patients with uncontrolled systemic diseases.
2. Smokers and tobacco users.
3. Pregnant or lactating females.
4. Patients with parafunctional habits such as bruxism.
5. Patients with limited mouth opening.
6. Patients requiring bone grafts for augmentation
7. Patients with history of radiation therapy

Preoperative Evaluation

A detailed history, clinical examination and radiographic assessment were carried out for all patients. Diagnostic impressions were made, and study casts were prepared.

Cone-beam computed tomography (CBCT) scans were obtained using standardized exposure parameters. The Digital Imaging and Communications in Medicine (DICOM) files were imported into implant planning software for virtual implant planning.

Virtual implant placement was planned prosthetically according to the available bone dimensions and restorative requirements while maintaining adequate clearance from adjacent anatomical structures.

Fabrication of Surgical Guides

Group A – Thermoplastic Surgical Guide

For patients in Group A, a conventional thermoplastic surgical guide (Figure 1) was fabricated on the diagnostic cast using a vacuum-forming machine and transparent thermoplastic sheet (Figure 3). The metal guide sleeves were placed in planned implant position onto the guide, and osteotomy access holes were prepared corresponding to the implant site (Figure 2). Metal sleeves were incorporated into guide for drilling procedure.

Figure 1: (a) Thermoplastic Surgical Guide and (b)Guide in situ

Figure 2: Postop CBCT of implant placed with Thermoplastic Surgical Guide

Figure 3: Thermoforming Unit

Group B – CAD-CAM 3D Printed Surgical Guide`

For Group B, surgical guides were digitally designed using implant planning software based on CBCT data and virtual implant planning (Figure 4-8). The guide design was exported as a stereolithography (STL) file and fabricated using a 3D printer with biocompatible resin material. (Figure 9)

Figure 4: CAD-CAM Printed Maxillary Surgical Guide

Figure 5: CAD-CAM Printed Mandibular Surgical Guide

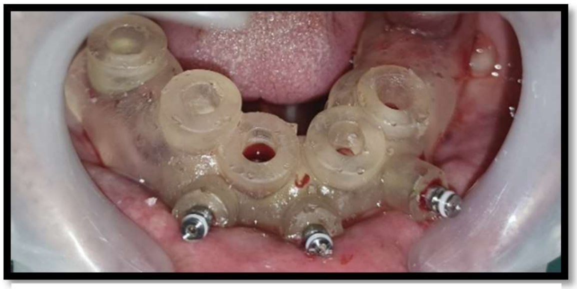

Figure 6: Mandibular Surgical Guide in-situ

Figure 7: Maxillary Surgical Guide in-situ

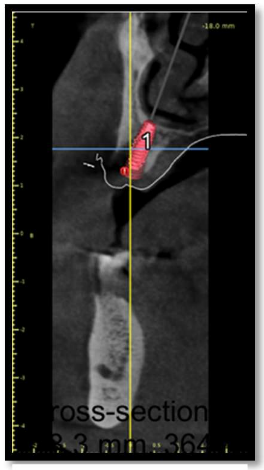

Figure 8: Planned Implant Position

Figure 9: Actual Implant Position

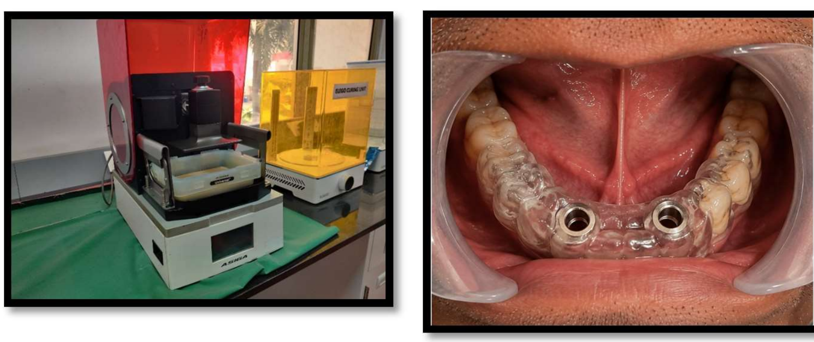

Figure 10: 3D Printer

Surgical Procedure
All implant surgeries were performed by a single surgeon under local anesthesia following standard aseptic protocol.
The surgical guide was positioned intraorally and checked for stability before osteotomy preparation (Figure 6,7). Sequential drilling was carried out according to the implant manufacturer's protocol under copious saline irrigation.
Implants of standardized dimensions were placed in all patients. Following implant placement, cover screws/healing abutments were placed, and postoperative instructions were given.

Postoperative Evaluation
Postoperative CBCT scans were obtained immediately after implant placement using the same scanning parameters as the preoperative scans. The postoperative implant position was superimposed on the preoperative virtual implant planning using implant planning software. The deviations between planned and actual implant positions were assessed. (Figure 8,9)

Parameters Evaluated

1. **Coronal deviation (mm):**
   Linear deviation at the implant platform between planned and actual implant positions.
2. **Apical deviation (mm):**
   Linear deviation at the implant apex between planned and actual implant positions.
3. **Angular deviation (degrees):**
   Angular discrepancy between the long axes of planned and placed implants.
4. **Depth deviation (mm):**
   Vertical discrepancy between planned and actual implant placement depth.
   All measurements were recorded by an independent blinded evaluator.

Statistical Analysis
The collected data were entered into Microsoft Excel and analysed using Statistical Package for Social Sciences (SPSS) software version 32.0 (IBM Corp., Armonk, NY, USA).

Descriptive statistics including mean, standard deviation (SD), minimum value, and maximum value were calculated for all study variables. Quantitative variables such as coronal deviation, apical deviation, angular deviation, and depth deviation were expressed as mean ± standard deviation.

The normality of data distribution was assessed using the Shapiro–Wilk test. Since the data showed normal distribution, parametric tests were used for intergroup comparison.

An independent sample t-test was applied to compare the mean deviations between the thermoplastic surgical guide group and the CAD-CAM fabricated 3D printed surgical guide group.

A p-value of less than 0.05 was considered statistically significant, while a p-value less than 0.001 was considered highly statistically significant.

RESULTS

Among the 15 patients included in the study, 10 were males and 5 were females. Total of 48 implants, 24 implant in each group. The mean age of patients in Group A (thermoplastic guide group) was 38.6 ± 7.2 years, whereas the mean age in Group B (3D printed guide group) was 36.9 ± 6.8 years.

Coronal Deviation
The mean coronal deviation in the thermoplastic surgical guide group was 1.45 ± 0.31 mm, whereas in the 3D printed surgical guide group it was 0.80 ± 0.21 mm. The difference between the two groups was statistically significant (Independent t-test, $p = 0.003$).

Apical Deviation
The mean apical deviation observed in the thermoplastic guide group was 1.68 ± 0.42 mm compared to 1.12 ± 0.28 mm in the 3D printed guide group. Statistical analysis revealed a significant difference between the groups (Independent t-test, $p = 0.002$).

Angular Deviation
The mean angular deviation in the thermoplastic guide group was 5.84 ± 1.28 degrees, while the 3D printed guide group demonstrated a mean angular deviation of 2.93 ± 0.92 degrees. The reduction in angular deviation with CAD-CAM guides was highly statistically significant (Independent t-test, $p < 0.001$).

Depth Deviation
The mean depth deviation in the thermoplastic surgical guide group was 1.18 ± 0.30 mm, whereas the 3D printed guide group showed a mean depth deviation of 0.64 ± 0.14 mm. The observed difference was statistically significant (Independent t-test, $p = 0.005$)

Table 1: Results

Parameter	**Thermoplastic Guide (Mean ± SD)**	**3D Printed Guide (Mean ± SD)**	**p-value**	**Significance**
Coronal deviation (mm)	1.45 ± 0.31	0.80 ± 0.21	0.003	Significant
Apical deviation (mm)	1.68 ± 0.42	1.12 ± 0.28	0.002	Significant
Angular deviati	5.84 ± 1.28	2.93 ± 0.92	<0.001	Highly significant

on (degrees)				
Depth deviation (mm)	1.18 ± 0.30	0.64 ± 0.14	0.0048	Significant

Overall Accuracy Assessment

The CAD-CAM fabricated 3D printed surgical guides demonstrated superior transfer accuracy in all evaluated parameters when compared with thermoplastic surgical guides. The deviations observed in the 3D printed guide group were consistently lower than those observed in the thermoplastic guide group.

Among all evaluated parameters, angular deviation showed the greatest reduction with the use of 3D printed guides. Improved guide stability, accurate sleeve positioning, and enhanced adaptation of digitally fabricated guides may have contributed to the increased accuracy observed in the 3D printed guide group.

The findings of the present study suggest that CAD-CAM fabricated 3D printed surgical guides provide more precise transfer of virtual implant planning to the clinical scenario compared with conventional thermoplastic surgical guides.

DISCUSSION

Surgical guides have been introduced to improve the precision of implant placement and minimize complications associated with freehand implant surgery. [7] The present study compared the transfer accuracy of thermoplastic surgical guides (Figure 1) and CAD-CAM fabricated 3D printed surgical guides (Figure 4, 5) in terms of coronal deviation, apical deviation, angular deviation, and depth deviation.

In this study, the mean coronal and apical deviations were significantly lower in the 3D-printed guide group. The findings of Schneider et al. are comparable, as they determined that computer-assisted implant surgery enhances the accuracy of implant placement and minimises positional inaccuracies.[5] Additionally, Vercruyssen et al. noted enhanced precision with CAD-CAM surgical guides, attributing this to enhanced guide stability and precise drill guidance.[8]

Angular deviation was found to be considerably lower in the CAD-CAM guide group. It was higher in the thermoplastic guide group. This observation is in accordance with the study conducted by Cassetta et al., who reported that stereolithographic surgical guides demonstrated superior angular accuracy compared to conventional guide systems[4] and the increased deviations observed in the thermoplastic guide group may be attributed to manual errors during guide fabrication, inadequate rigidity of thermoplastic material, and reduced accuracy in sleeve positioning. Conventional vacuum-formed guides are more operator-dependent and may undergo dimensional changes during both fabrication and usage. Similar limitations of conventional surgical guides have been described by D'haese et al. in their review on guided implant surgery.[3]

The improved accuracy observed with CAD-CAM fabricated 3D printed guides may be due to digital planning, accurate transfer, of virtual implant position, better adaptation to supporting structures and reduced human error during guide fabrication. The metal sleeves additionally stabilizes the the drill during osteotomy preparation.

Although the present study demonstrated superior accuracy with 3D printed guides, certain deviations were still observed in both groups. Even when guided surgery protocols are followed, implant placement accuracy may be influenced by factors such as patient movement during CBCT acquisition, guide seating errors, tolerance between drill and sleeve, and operator handling.[2]

CONCLUSION

Within the limitations of the present study, CAD-CAM fabricated 3D printed surgical guides were found to provide more accurate transfer of implant position compared to thermoplastic surgical guides. Further studies with larger sample sizes and long-term clinical evaluation are recommended to validate these findings.

3D printed surgical guides may provide a more reliable and precise method for transfer of virtual implant planning during implant surgery.

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