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Original Article

# Comparative Evaluation of Accuracy of Implants Placed with Thermoplastic and Three-Dimensional-Printed Surgical Guides: A Randomized Controlled Trial

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**Abstract**

The current study was planned to evaluate the accuracy of dental implant placement with two different types of surgical guides: Thermoplastic and three-dimensional (3D) printed. A total of 32 implants were placed in 20 healthy, partially dentate individuals with an isolated single missing tooth. The implant sites were randomly allocated into two treatment groups: Group A (thermoplastic implant surgical guide, $n$ = 16 implants) and Group B (3D printed implant surgical guide, $n$ = 16 implants). All the cases in both groups were digitally planned according to a defined protocol, and a comparison of the planned and actual implant positions was performed using the medical image analysis software. The differences in the outcome variables, i.e., angular deviation (AD), 3D error at the entry, 3D error at the apex (3D EA), vertical deviation (VD), and composite deviation, were statistically analyzed. All the outcome variables showed improvements, but statistically significant improvement was shown by AD ($P$ = 0.005), 3D EA ($P$ = 0.01), and VD ($P$ = 0.007). The mean and standard deviation (SD) for AD, (3D EA), and VD were 5.58° ±1.93°, 0.96 ± 0.32 mm, and 0.58 ± 0.36 mm, respectively, for group A. The mean and SD for AD, (3D EA), and VD were 3.94° ± 0.64°, 0.64 ± 0.35 mm, and 0.29 ± 0.13 mm, respectively, for group B ($P$ < 0.05). Within the limits of the study, dental implants placed using 3D-printed surgical guides were positioned clinically with greater accuracy, and fewer deviations were observed from their presurgical planned positions as compared to the thermoplastic surgical guides.

**Key words:** Accuracy of dental implant positioning, Vertical deviation, Angular deviation, Guided surgery, Thermoplastic dental implant surgical guides, Three-dimensional error

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## Introduction

Dental implants and implant-supported restorations have evolved into the standard of care for individuals who are either fully or partially edentulous. Following rehabilitation, a properly positioned dental implant offers the best chance of restoring speech, function, comfort, and appearance. A properly placed dental implant in all three dimensions serves as the basis for an optimal prosthesis and ensures that there is no damage to vital anatomic structures such as maxillary sinus or mandibular canal.[1, 2] Various operative techniques have been developed over a period of time, to insert the dental implants into the desired sites. These techniques evolved from free handed implant placement to designing a surgical template by employing patient models and a panoramic radiograph to construct a surgical template and finally to computer navigation system-based implant procedures.[3-5]

An implant surgical guide can be described as a tool that helps in the precise angulations and surgical placement of dental implants.[6] They tend to minimize the positional inaccuracy and uncertainty that may be caused by free-hand implant surgery.

Conventional implant surgical guides to aid in implant placement can be vacuum formed with 2-mm drill holes and metal tubes. These are fabricated with a diagnostic tooth arrangement through a diagnostic wax-up, a denture tooth set-up, or duplication of preexisting teeth or restoration [7-9].

With the advancement in dental imaging techniques, particularly with the incorporation of cross-sectional imaging, cone-beam computed tomography (CBCT) has emerged as a relatively low-dose 3D dental imaging technique that enhances the diagnostic accuracy for implant planning.[10, 11] It provides us with a more precise and credible measurement of facio-lingual dimensions, which is often missed out in 2D panoramic imaging.[12, 13]

The fifth ITI consensus conference has recommended 3D imaging for accurate prosthetically driven implant planning, especially in critical anatomic situations, grafting procedures, and guided implant placement surgeries.[13, 14]

Static-guided implant surgery facilitates the simultaneous analysis of the surrounding anatomy and the 3D topography of the bone.[15] The avoidance of potential complications such as damage to the mandible nerve, sinus perforation, fenestration, dehiscence, and adjacent tooth root damage is one of the benefits of guided surgery. Other benefits include high precision in implant placement and positioning, shorter operating times in complicated cases, and improved patient acceptance outcomes.[15, 16]

The protocol for stereolithographic guide fabrication has an ordered sequence of steps; each step of the procedure may be associated with certain inherent errors during execution. These deviations may reflect the sum of all the errors occurring during various steps.[17, 18] Thus, all errors, although seldom occurring, can be cumulative, and can be expressed by linear and angular measurements. The final inaccuracy is the sum of all the deviations.[19, 20]

Accuracy is defined as matching the position of the digitally planned implant with the real position of the same in the patient's mouth. Matching of the two implant positions (planned and actual) can be based on a second CBCT scan (allowing matching between preoperative planning and postoperative implant positions) or via "model matching" (by comparing pre- and postoperative models of the treated jaw).[19-21]

It is, therefore, important to note that when placing an implant with a fabricated surgical guide, the actual location of the implant can vary from the planned location. This becomes especially important in complex clinical situations, for example, when the distance of bone required between implants-to-teeth as well as implants-to-implants in regards to papilla height is minimal, especially for the aesthetic zone. Therefore, it is imperative to understand the variability associated with different implant surgical guides to optimize their use for implant positioning in terms of accuracy.

The present study was designed to evaluate the accuracy of implants placed with two different surgical guides; thermoplastic versus 3D printed.

## Materials and Methods

The study design is a parallel-group randomized controlled interventional trial. This trial had been approved by the institutional ethics committee of the dental institute and has also been registered in the Clinical Trial Registry, India (CTRI) (CTRI/2019/). The work protocol has been reported according to the CONSORT guidelines as recommended for randomized clinical trials. The sample size was calculated by taking $\alpha = 0.05$ with a power of 80% using mention software's parent company and country. By using the formula ($n = [Z\alpha/2 + Z\beta]\ 2 \times 2 \times \sigma 2/d2$), the sample size comes out to be 32. Based on the types of implant surgical guides used, the patients were randomly allocated to one of the following study groups using a random number table for the allocation of the patients into two different groups.

- Group A ($n = 16$): Implants placed using thermoplastic surgical guides
- Group B ($n = 16$): Implants placed using a 3D-printed surgical guide.

Thirty-two implants were placed in 20 selected patients fulfilling the predefined inclusion/exclusion criteria. The subject's willingness to participate in the study was sought and recorded as written informed consent duly signed by the patient.
The following inclusion criteria were applied:

1. Partially edentulous patients
2. The presence of an isolated single missing tooth
3. Patient's demonstrating good general health with no local or systemic contraindication for implant placement
4. Patient's having an adequate mouth opening for implant placement.

The following exclusion criteria were applied:

1. Patients with poor oral hygiene
2. Any general contraindication to implant placement
3. Any active periodontal infections
4. Any uncontrolled systemic disease or condition
5. Presence of smoking habits (>10 cigarettes per day)
6. Anatomical situation requiring a regenerative procedure before or contemporaneous with the implant surgery
7. Any signs, whether clinical or radiographic, for bone pathologies.

The following parameters were evaluated and compared in the planned and placed positions of dental implants in both groups.[17]

1. Angular deviation (AD) between the planned and actual placement of the implant using the two proposed techniques (in degrees)
2. 3D error at the entry (3D EE) point of the implant measured at the center of the implant between the planned and actual positions in both the proposed techniques (in mm)
3. 3D error at the apex (3D EA) measured at the center of the implant apex between the planned and actual positions in both the proposed techniques (in mm)
4. The vertical deviation (VD) at the entry point measured at the center of the implant between the planned and actual positions in both of the proposed techniques (in mm)
5. The composite deviation (CD) between planned and placed implants (in mm) was evaluated as a novice dimension in this study.

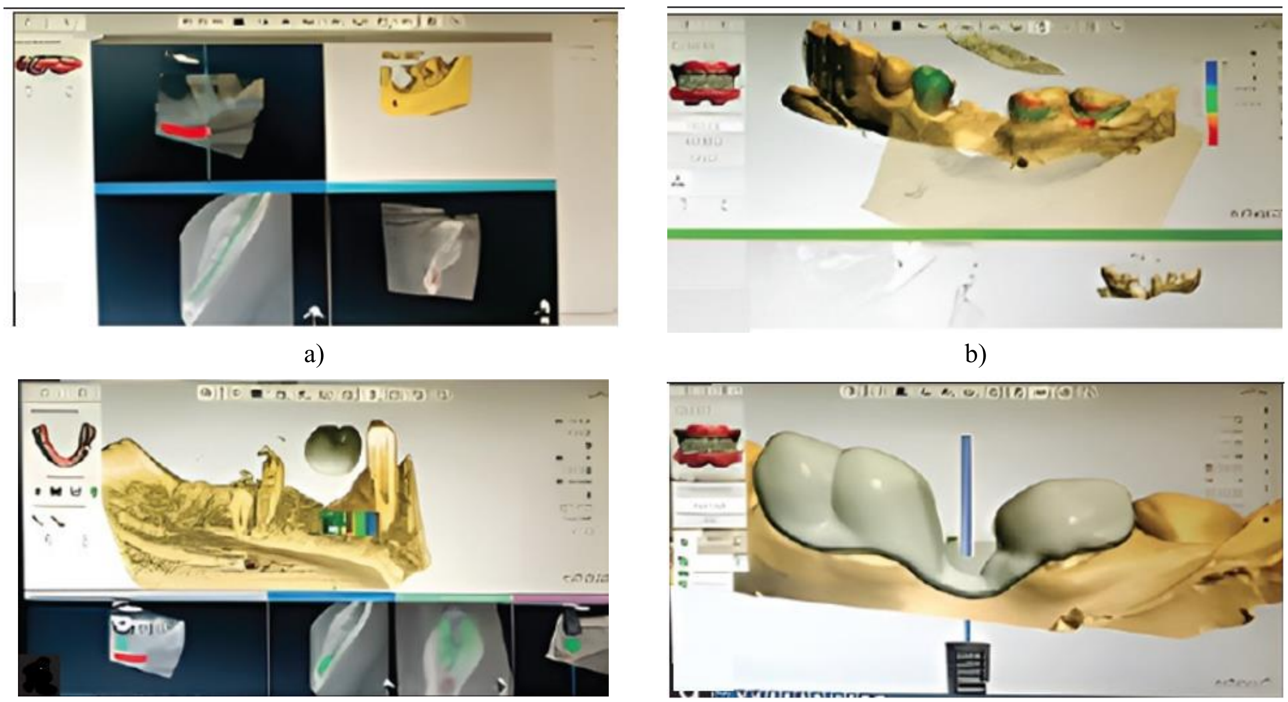
*Implant planning protocol*

*Thermoplastic group*

An overextended impression was taken to capture the maximum area of the edentulous ridge, and a diagnostic model was made. The diagnostic model was duplicated, and a prosthetic wax-up was done on the duplicated cast at the desired location of implant placement.[9, 22] Bone sounding was done under topical anesthesia using a 27G short anesthetic needle with an endodontic rubber stopper. Parallelism and height of the contour were assessed with the help of a dental surveyor, and undercuts and embrasures on the cast were blocked out with a type 1 gypsum product. After assessing the bone width on the CBCT and measuring the distance from the adjacent tooth, the same was transferred to the model. The cast was drilled at the proposed implant position with a 2-mm drill bur mounted in a bench top drill press to a depth of approximately 5–10 mm. Guide pins were inserted in the cast and the parallelism and angulations were assessed with respect to the adjacent tooth. A 2-mm guide sleeve was secured in place, with the center of the sleeve in line with the drilled hole.[9, 23, 24] There was 0.1 mm of inherent gap according to the guide manufacturing protocol to avoid any static or dynamic interference in the drill and sleeve dimensions. After finalizing the position of the guide sleeve, a transparent Biocryl C sheet (2.0 mm × 125 mm) was adapted to the cast using a Biostar® (scheudental) vacuum forming machine. The sheet was trimmed to the desired size, and the fit was evaluated on the cast and in the patient's mouth before surgery.

*Virtual implant planning for a three-dimensional-printed implant guide*

After an initial screening of the patient and obtaining the CBCT of the patient, a full mouth intra-oral scan of the patient was recorded using an intraoral scanner and saved as a standard tessellation language (STL) file format. For virtual planning of the implant placement and designing of the surgical guide, the preoperative CBCT in the digital imaging and communications in medicine (DICOM) format and the saved scan in the STL format were uploaded to the implant planning software. The scan data and CBCT data were overlapped, and implant planning was done accordingly. A rapid prototyping 3D printer printed the final guide design **(Figure 1)**.



a) b) c) d)

**Figure 1.** Depicting the stages in designing of the three-dimensional-printed surgical guide. (a) Nerve tracing, (b) Overlap of scan data and cone-beam computed tomography, (c) Implant planning, (d) Guide designing undertaken

*Presurgical procedure*

All the patients underwent complete ultrasonic scaling and root planning 1 week before the planned surgical procedure. Patients were informed about the importance of maintaining good oral hygiene, and individualized advice was given to each patient.

*Surgical procedure*

The risks and benefits of implant surgery specific to the patient's situation were thoroughly explained before surgery. A written, informed consent was obtained for the procedure. All implant surgery was performed under local anesthesia (lignocaine 2% with 0.005 mg adrenaline, 1:200,000 dilutions). The perfect fit of the template was assessed before surgery on the cast and inside the oral cavity of the patient.

A full-thickness flap (buccal and lingual) was raised to expose the full dimensions of the alveolar ridge of the planned implant site. The surgical site was thoroughly debrided of all the granulation tissue, and all sharp edges and irregularities of bone were removed. For the thermoplastic group, a surgical guide was secured over the operative area, and a 2-mm twist drill was used as a pilot drill through the sleeve at 800 rpm and 35 N/cm with copious irrigation up to the planned implant length for both groups. A set of incremental drills with increasing diameter was used to sequentially increase the width of the osteotomy site up to the planned implant diameter, using the initial osteotomy as a guide. The implant (Osstem TSIII SA Fixture) was inserted using a hand ratchet up to the crestal level, and the cover screw provided with the implant was secured over the implant **(Figure 2)**.

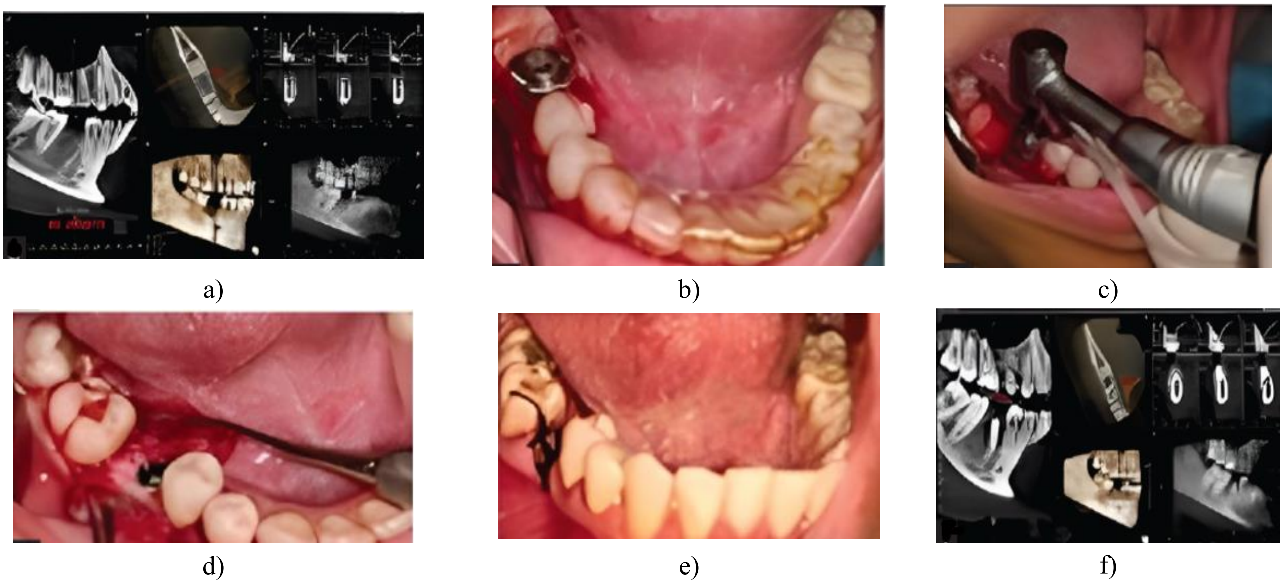



**Figure 2:** Treatment protocol for thermoplastic surgical guide. (a) Preoperative cone-beam computed tomography (CBCT), (b) Thermoplastic guide in place, (c) Osteotomy being done by pilot drill, (d) Implants placed, (e) Sutures placed, (f) Postoperative CBCT

For the 3D-printed surgical guide group, implant site preparation was done in accordance with the predefined, fully guided implant surgical protocol using the customized 3D printed surgical guide **(Figure 3)**.

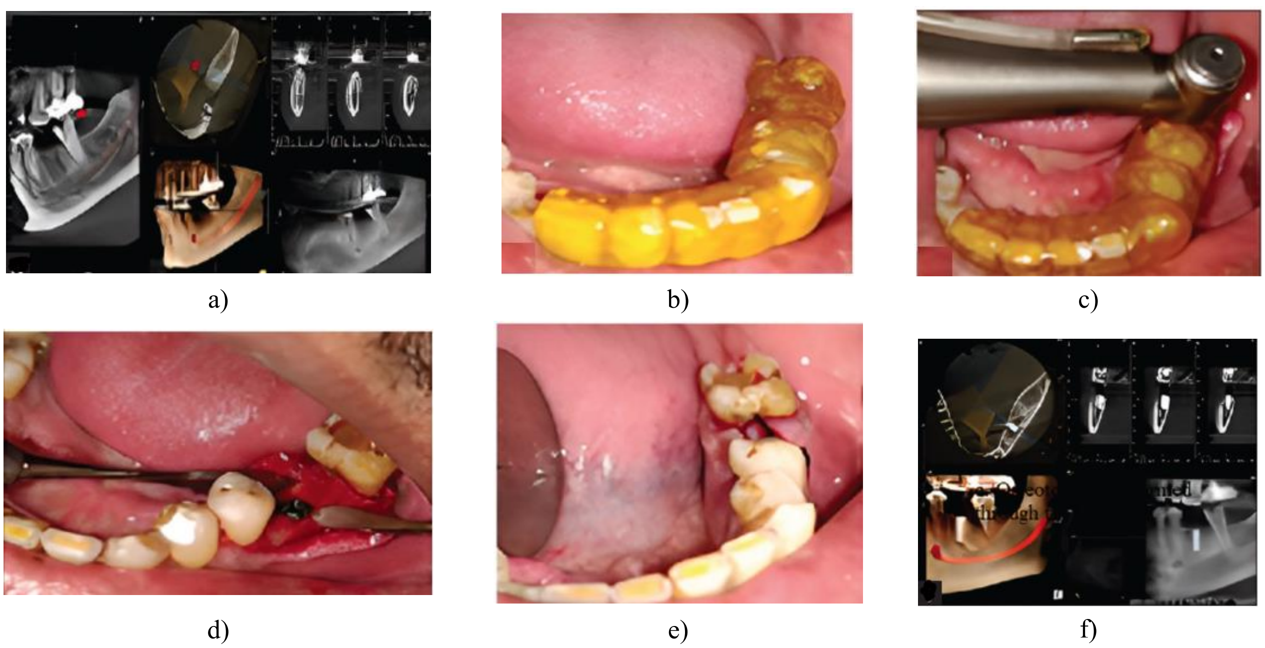
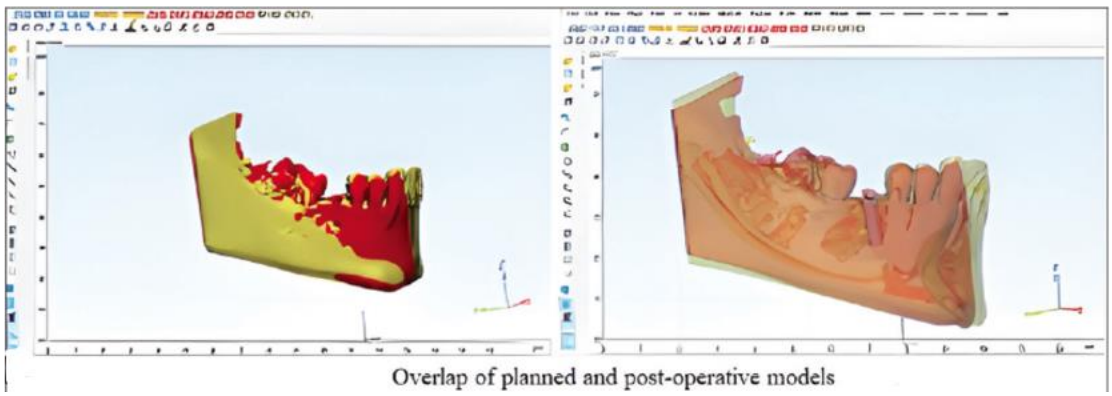



**Figure 2:** Treatment protocol for thermoplastic surgical guide. (a) Preoperative cone-beam computed tomography (CBCT), (b) Thermoplastic guide in place, (c) Osteotomy being done by pilot drill, (d) Implants placed, (e) Sutures placed, (f) Postoperative CBCT

*Postoperative care*

All the study participants were instructed with postoperative instructions and a preventive measure. Postoperative medications include a systematic antibiotic (amoxicillin, 500 mg, three times a day for 5 days) and an analgesic (diclofenac/aceclofenac, twice a day for the day of surgery, then as an analgesic when required). A follow-up appointment was scheduled after 1 week for suture removal, and a postoperative CBCT was taken under the same standardized protocols as the preoperative CBCT.
Both preoperative and postoperative CBCT scans data were overlapped using the image analysis software mimics 17 (registration feature) for the measurement of the study parameters. The analysis for assessing the possible differences between the planned and the final implant position was done by importing both the planned and the actual data into mimics innovation suite version 17, for the ease of identification color coding was generated. Both the datasets were overlapped manually in the software using anatomical landmarks and a 3D model was generated. The deviations were measured for the specific parameters as mentioned, by the tools provided in the software itself **(Figures 4 and 5)**.[25-27] A diagrammatic presentation of the measured deviations for the specified parameters is provided in **Figure 6**.

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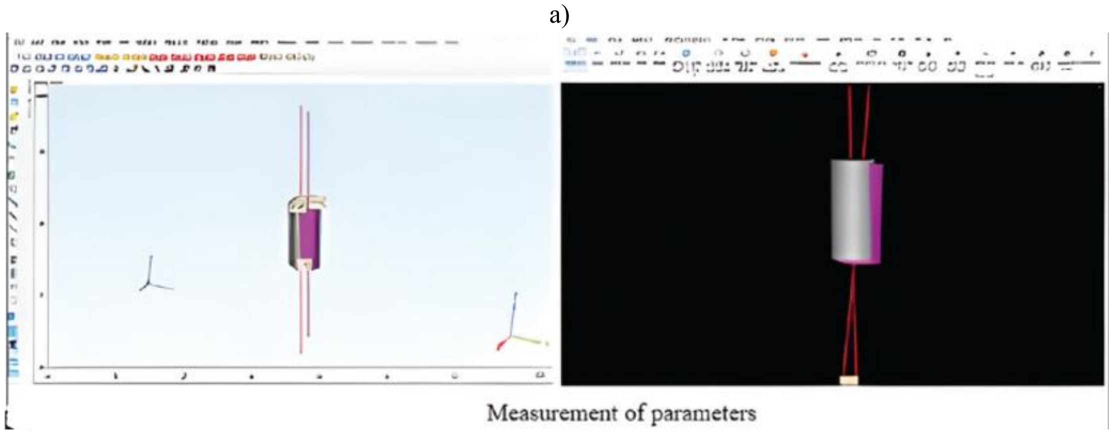
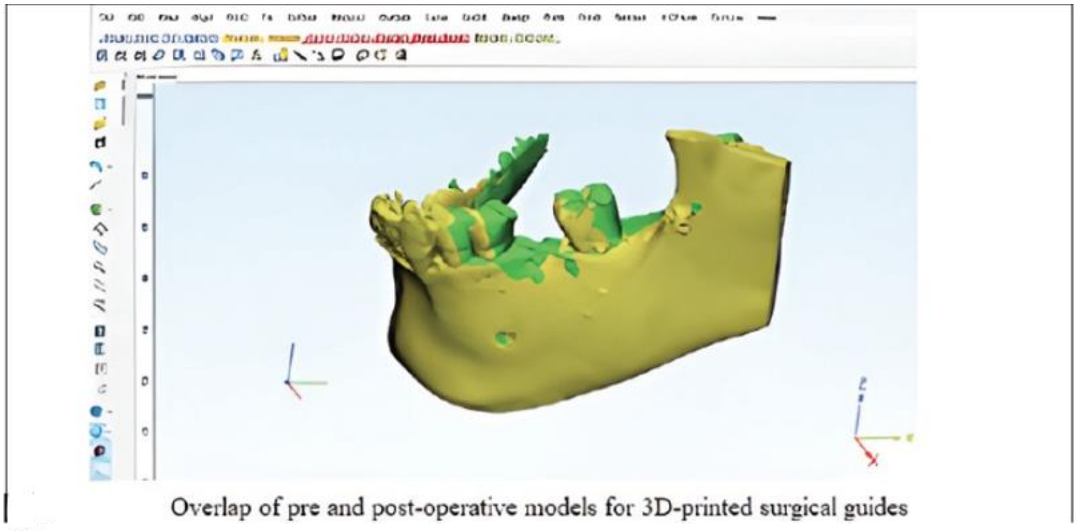
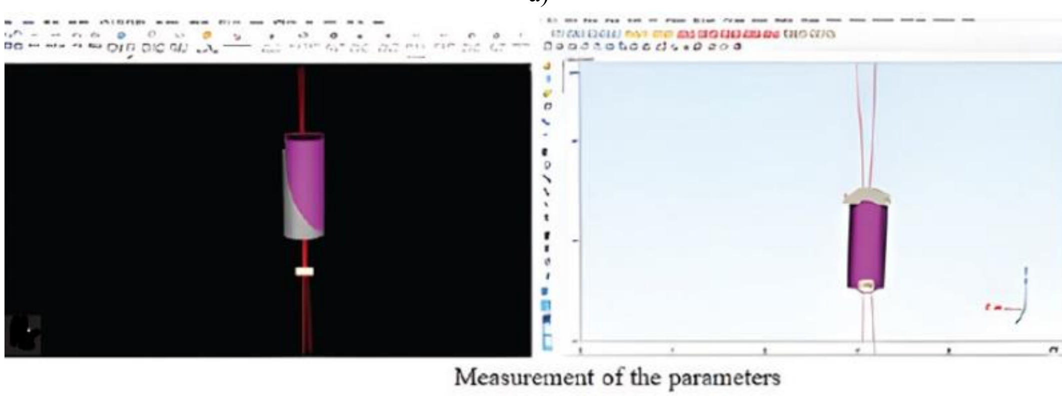



b)

**Figure 4:** Superimposition of presurgical and postsurgical data and the positional accuracy measurements for thermoplastic group. (a) Overlap of planned and postoperative models, (b) Measurement of parameters




a)




b)

**Figure 5:** Superimposition of presurgical and postsurgical data and the positional accuracy measurements for three-dimensional (3D) printed group. (a) Overlap of pre- and postoperative models for 3D-printed surgical guides, (b) Measurement of the parameters

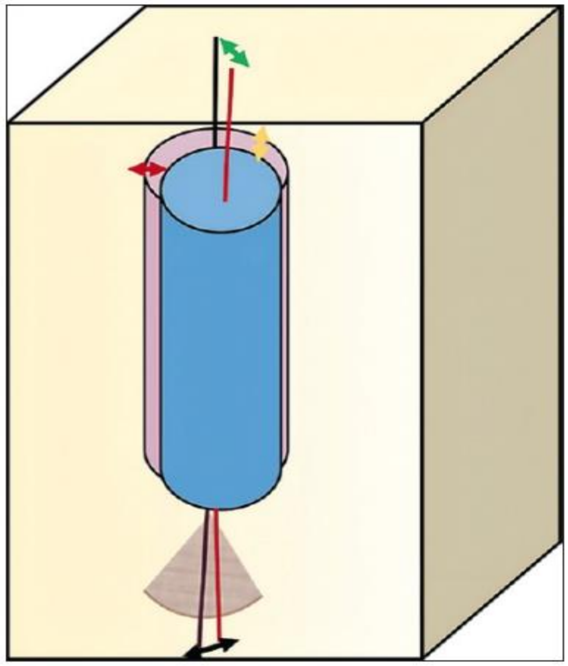


**Figure 6:** Diagrammatic presentation of the measured deviations for the specified study parameters. Violet cylinder represents planned position. Blue cylinder represents actual position. Green arrow represents three-dimensional (3D) error at the entry (in mm). Red arrow represents composite deviation (in mm). Yellow arrow represents vertical deviation at entry point (in mm). Black arrow represents (3D) error at the apex (in mm). Brown represents angular deviation in degrees

*Statistical analysis*

The Kolmogorov-Smirnov test was applied for checking the distribution of data and the results indicated that the data was normally distributed. Therefore, the intergroup comparisons for the means of clinical parameters and deviations between the planned and placed implants were analyzed using the independent *t*-test. All the quantitative data were expressed as mean ± standard deviation (SD) all the above-mentioned analyses were conducted using IBM SPSS 22.0 (IBMCorp., Armonk, NY, USA) statistical software was utilized for data analysis. $P$ <0.05 was considered statistically significant, and the value < 0.001 was considered highly significant statistically.

## Results and Discussion

A total of 32 implants were placed in 20 patients included in the study. The distribution of implant sites and types of implants placed are tabulated in **Table 1**. The diameter of the study implants varied from 3.00 mm, 3.5 mm, 3.6 mm, and 4.00 mm, respectively, and the length of the placed implants varied from 7.00 mm, 8.00 mm, 8.5 mm, 10.00 mm, and 11.00 mm, respectively.

**Table 1:** Distribution and characteristics of the dental implants placed in Groups A and B

| Variables | Group A | Group B |
|---|---|---|
| Type of arch | | |
| Maxilla | 6 | 1 |
| Mandible | 10 | 15 |
| Side of arch | | |
| Right | 8 | 10 |
| Left | 8 | 6 |
| Implant location | | |
| Anterior | 1 | 1 |

| | | |
|---|---|---|
| Premolar | 2 | 2 |
| Molar | 13 | 13 |
| Implant diameter (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 | - |

mm – Millimeter

The mean score of AD, (3D EE), (3D EA), VD, and CD between the planned and actual placement of the implant for group A was 5.58° ± 1.93°, 0.55 ± 0.18 mm, 0.96 ± 0.32 mm, 0.58 ± 0.36 mm, and 0.63 ± 0.26 mm, respectively.

For Group B, the mean score of AD, (3D EE), (3D EA), VD, and CD between the planned and actual placement of the implant was 3.94° ±0.64°, 0.57 ± 0.32 mm, 0.64 ± 0.35 mm, 0.29 ± 0.13 mm, and 0.49 ± 0.18 mm, respectively.

The mean, SD, standard error, minimum, and maximum values for all the parameters for both study groups are shown in **Tables 2 and 3**, respectively. A statistically significant difference between the two techniques was found in three of the five parameters.

**Table 2:** Mean, standard deviation, and standard error of the study parameters for Group A

| | **AD (°)** | **3D (EE) (mm)** | **3D (EA) (mm)** | **VD (mm)** | **CD (mm)** |
|---|---|---|---|---|---|
| *n* | 16 | 16 | 16 | 16 | 16 |
| Mean | 5.58 | 0.55 | 0.96 | 0.58 | 0.63 |
| SD | 1.93 | 0.18 | 0.32 | 0.36 | 0.26 |
| SE | 0.48 | 0.14 | 0.08 | 0.09 | 0.06 |
| Minimum | 1.2 | 0.27 | 0.52 | 0.21 | 0.22 |
| Maximum | 8.03 | 2.54 | 1.54 | 1.53 | 1.08 |

*n* – Total number; SD – Standard deviation; SE – Standard error; AD – Angular deviations; 3D (EE) – Three-dimensional error at the entry point; 3D (EA) – Three-dimensional error at the apex; VD – Vertical deviation; CD – Composite deviation; mm – millimeter

**Table 3:** Mean, standard deviation, and standard error of the study parameters for Group B

| | **AD (°)** | **3D (EE) (mm)** | **3D (EA) (mm)** | **VD (mm)** | **CD (mm)** |
|---|---|---|---|---|---|
| *n* | 16 | 16 | 16 | 16 | 16 |
| Mean | 3.94 | 0.57 | 0.64 | 0.29 | 0.49 |
| SD | 0.64 | 0.32 | 0.35 | 0.13 | 0.18 |
| SE | 0.16 | 0.08 | 0.09 | 0.03 | 0.04 |
| Minimum | 2.84 | 0.22 | 0.17 | 0.12 | 0.23 |
| Maximum | 4.85 | 1.23 | 1.43 | 0.59 | 0.98 |

*n* – Total number; SD – Standard deviation; SE – Standard error; AD – Angular deviations; 3D (EE) – Three-dimensional error at the entry point; 3D (EA) – Three-dimensional error at the apex; VD – Vertical deviation; CD – Composite deviation; mm – millimeter

AD ($P = 0.005$), 3D EA measured at the center of the implant ($P = 0.01$), and VD at the entry point measured at the center of the implant ($P = 0.007$). **Table 4** compiles the comparative result of the *t*-test between Group A and Group B.

**Table 4:** Comparative analysis of the mean values of all the study parameters in Groups A and B

| Group | *n* | Mean±SD | *P* |
|---|---|---|---|
| AD (°) | | | |
| Group A | 16 | 5.58±1.93 | 0.005 |
| Group B | 16 | 3.94±0.64 | |
| 3D (EE) (mm) | | | |
| Group A | 16 | 0.81±0.55 | 0.136 |
| Group B | 16 | 0.57±0.32 | |
| 3D (EA) (mm) | | | |
| Group A | 16 | 0.96±0.32 | 0.01 |
| Group B | 16 | 0.64±0.35 | |
| VD (mm) | | | |
| Group A | 16 | 0.58±0.36 | 0.007 |
| Group B | 16 | 0.29±0.13 | |
| CD (mm) | | | |
| Group A | 16 | 0.63±0.26 | 0.086 |
| Group B | 16 | 0.49±0.18 | |

*P* value is significant at $P<0.05$. *n* – Total number; SD – Standard deviation; AD – Angular deviations; 3D (EE) – Three-dimensional error at the entry point; 3D (EA) – Three-dimensional error at the apex; VD – Vertical deviation; CD – Composite deviation; P – Probability value; mm – millimeter

Overall, the implants placed with a 3D-printed surgical guide display fewer deviations than the planned positions in all the parameters measured as compared to the thermoplastic surgical guide.

*Discussion*

A correct 3D positioning of dental implants is of paramount importance, which leads to good esthetic and prosthetic outcomes and further decreases the biological and technical outcomes, which are associated with any malalignment.[28] A recent study done by Canullo *et al*. for risk assessment of peri-implantitis states that nearly half of the cases of peri-implantitis were due to implant malpositioning.[29]

In the present study, the mean AD between the planned and placed implant positions in the thermoplastic-guided implant surgical guide was 5.58° ± 1.93°. Our study results are in accordance with the data published by Younes *et al*. (2018), in which they reported a mean AD of 5.95° ± 0.87°.[30] Varga *et al*. reported a mean AD of 5.71° ± 3.68°.[31] The data obtained by Vercruyssen *et al*. are different from those obtained in the present study; they reported a mean AD of 8.43°.[21] The plausible explanation for this is that these authors used a pilot drill-guided option in the completely edentulous patient, due to which some sense of direction was lost because there were no adjacent teeth to provide any anatomical markers.

The mean AD between the planned and actual implant positions in the 3D printed implant surgical guide was 3.94° ±0.64°. The results of the present study are in line with those reported by Arisan *et al*.,[32] Kühl *et al*.,[33] Arisan *et al*.,[34] Smitkarn *et al*.,[35] and Varga *et al*.[31] In a meta-analysis done by Van Assche *et al*., the authors reported a mean AD of 3.8°.[19] In another systematic review done by Tahmaseb *et al*., they reported a mean AD of 3.89°.[36] Both of these results are comparable to the findings of the present study. The results of the study reported by Younes *et al*. (2018)[30] are also comparable to the present study.

The mean 3D EE point and the apex for the thermoplastic-guided implant surgical guide were 0.55 ± 0.32 and 0.96 ± 0.32 mm, respectively, while for the 3D printed implant guide group, the mean 3D EE point and apex were 0.57 ± 0.32 and 0.64 ± 0.35 mm, respectively. The result for the 3D-printed surgical guide is consistent with other published data by Arisan *et al*.,[32] who reported a mean error of 0.78 mm at the entry and 0.81 mm at the exit and Vasak *et al*.,[37] who reported a mean error of 0.82 mm at the entry and 1.05 mm at the exit. Smitkarn *et al*. (2019)[35] reported a mean error of 1.0 ± 0.6 mm at entry and 1.3 ± 0.6 mm at exit. The results of the present study are in contrast to those of Kühl *et al*.,[33] who reported a mean error of 1.52 mm at entry and 1.55 mm at exit and Cassetta *et al*.,[38] who reported a mean error at entry of 1.52 mm and 1.97 mm at exit. The reason for these differences could be explained by the fact that the Kühl *et al*.'s[33] study was done on human cadavers using two different fully guided surgical guides, and the result reflects the average of the guides used. Cassetta *et al*.[38] included both edentulous and partially edentulous patients in their study with mucosa, bone, and tooth-supported surgical guides with or without pins.

In a systematic review and meta-analysis by Schneider *et al*., a mean deviation at entry and apex was reported to be 1.1 and 1.6 mm, respectively.[39] In a meta-analysis done by Van Assche *et al*.,[19] a mean deviation of 1.0 mm at implant shoulder and a mean deviation of 1.2 mm at implant apex were reported. Tahmaseb *et al*.[36] in their systematic review reported an accuracy of 1.12 mm at the entry point and 1.39 mm at the apex. These three systematic reviews consisted of both *in vitro*, cadaveric, and clinical human studies with different variants (mucosa-supported, bone-supported, and tooth-supported) of 3D-printed fully guided implant surgical guides.

The VD between the planned and real implant positions (in mm) was 0.58 ± 0.36 mm in the thermoplastic group and 0.29 ± 0.13 mm in the 3D-printed surgical guide group. Similar results were reported by Younes *et al*. (2018) who reported a mean VD of 0.68 ± 0.09 mm for the pilot-guided group and 0.43 ± 0.09 mm for the fully guided group.[30]

The composite implant deviation was a novel dimensional measurement incorporated in this study. It focuses on encompassing both the radial and horizontal components between the center of the planned and placed implant and the implant shoulder. The reported deviation for the composite implant for the thermoplastic group in the present study was 0.63 ± 0.26 mm and 0.49 ± 0.18 mm for the 3D printed surgical guide group.

In the present study, statistically, significant differences were found for ADs (95% CI, $P = 0.005$), 3D EE (95% CI, $P = 0.01$), VD (95% CI, $P = 0.007$) between the planned and placed positions. These findings are similar to those of Smitkarn *et al*. (2019).[35]

Overall, in the present study, implants placed with 3D-printed implant surgical guides were closer to planned positions in all the studied dimensions and showed greater accuracy and precision than thermoplastic surgical guides. The clinical relevance of a computer-assisted virtually planned and 3D-printed dental implant guide is that it is meticulously planned before the surgery by incorporating the inputs of dental disciplines associated with it, like a maxillofacial radiologist, a restorative dentist, and an operating surgeon. This will ensure a predictable outcome in terms of soft-tissue profile, the best possible utilization of the available bone dimensions, and superior esthetics and function. Thereby, minimizing any chances of future complications whatsoever that may arise due to the malpositioning of the dental implant.

The current study had a few limitations in terms of the inclusion of only partially edentulous patients, which limits the external validity of the study as the results may not be immediately extrapolated to completely edentulous patients. Future research can be designed for more cost-effective options for surgical guide construction since cost appears to be a significant factor in decision-making for guided surgery from the patient's perspective. Certain modifications, which will help the clinician use guided surgery in cases of reduced jaw opening, can also be explored as a next step.

## Conclusion

Within the limitations of the study, the findings from the current study suggest implants inserted using 3D-printed surgical guides' demonstrated closer alignment with planned positions across all dimensions compared to those guided by thermoplastic guides and provided better accuracy for implant placements with superior accuracy and precision. The significance of employing computer-assisted virtual planning and 3D-printed dental implant guides lies in the thorough presurgical planning process, thus ensuring predictable outcomes concerning soft-tissue contours, optimal utilization of available bone structure, and enhanced esthetics and functionality. Future well-designed prospective comparative randomly controlled trials should be conducted to ascertain the findings and obtain better insights into the use of 3D-printed implant surgical guides in diverse clinical situations.

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**Conflict of interest:** None

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**Ethics statement:** None

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