Accuracy of Guided Implant Surgery Using an Intraoral Scanner and Desktop 3D-Printed Tooth-Supported Guides

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Purpose: The increasing popularity of desktop 3D printers makes guided surgery more accessible. The aim of this in vitro study was to evaluate the accuracy of single-tooth guided implant surgery by means of a 3D-printed tooth-supported guide. Materials and Methods: Fifteen implants were virtually planned to replace a missing first mandibular molar, using planning software for guided implant surgery (Exoplan, Exocad). A tooth-supported guide was designed and manufactured using a desktop 3D printer (Asiga MAX UV). The implants were placed fully guided in resin casts, and a digital impression was taken to register their position. This scan was compared with the virtual implant position in the planning software, and the internal fit of the guides was evaluated using metrology software. One planning was executed six times for measuring precision. Results: For trueness, the mean angular deviation was 2.63 degrees (SD: 1.69 degrees; range: 0.38 to 5.99 degrees), the mean coronal deviation was 0.52 mm (SD: 0.25; range: 0.09 mm to 1.07 mm), and the mean apical deviation was 0.90 mm (SD: 0.47; range: 0.14 to 1.74 mm). The absolute apical mean deviation in the buccolingual direction (x-axis) was 0.70 mm (SD: 0.42, 0.12 to 1.65 mm; P < .001); in the mesiodistal direction (y-axis), it was 0.34 mm (SD: 0.26; range: 0.01 to 0.80 mm; P = .650); and in the vertical direction (z-axis), it was 0.32 mm (SD: 0.27; range: 0.02 to 1.00 mm; P = .010). The mean internal fit of the guides was 79.5 µm (SD: 19.6 µm; range: 51 to 118 µm). Conclusion: Desktop 3D-printed tooth-supported guides demonstrate an acceptable fit and acceptable level of accuracy for single implant placement. Int J Oral Maxillofac Implants 2023;37:479–484. doi: 10.11607/jomi.9432

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Guided implant surgery has become a common treatment modality, and its clinical outcome and accuracy have been evaluated in numerous studies and systematic reviews.1–6 Implant preparation and placement are directed by the surgical guide, which allows flapless surgery. The latter reduces treatment time, eases patient discomfort, and simplifies implant placement.7

Numerous implant planning software is available, some of which allows designing and exporting the guide for chairside fabrication. Surgical guides can be fabricated using a subtractive (milling) or additive technique (3D printing), although the accuracy of implant positioning was not affected by the fabrication method.8 When it comes to 3D printing, there are different technologies available, which might affect the final precision of the guide. Gjelvold et al9 evaluated the accuracy of surgical guides produced by desktop 3D printers and reported smaller deviations at the entry point and vertical implant position for the digital light processing (DLP) printer compared with a stereolithography printer. On the other hand, Chen et al10 found a similar outcome when examining the accuracy and dimensional stability of surgical guides manufactured by desktop Stereolitography Apparatus (SLA) 3D printers or a lab-based PolyJet printer.

Differences between the virtual implant plan and actual implant position are inevitable due to possible errors during CBCT imaging and segmentation, deviations in guide positioning, and a certain freedom during drilling and implant placement.1,4,11 This will affect the angulation and coronal and apical position of the implant.2,8 The final implant position corresponds best with the virtual plan at the coronal aspect, but the deviation increases further away from the point of entry.2 Because of these inevitable deviations, numerous studies advised respecting a 2-mm safety zone surrounding the implant when creating the virtual plan.3,12

Overall, the use of surgical guides demonstrates a predictable and acceptable level of accuracy.6 Depending on the indication, these guides can be tooth-, bone-, or mucosa-supported. Tooth-supported guides

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are more stable and accurate compared with mucosa- or bone-supported guides, although the latter are mainly used in edentulous arches.\textsuperscript{13}

Most studies use a second postoperative CBCT to compare the actual implant position with the virtual planned implant.\textsuperscript{14–16} This method has some disadvantages, such as the additional radiation exposure for the patient and the occurrence of beam hardening, which is caused by the implant and interferes with the outline of the implant.\textsuperscript{17}

To overcome these drawbacks, Son et al\textsuperscript{18} compared a postoperative intraoral optical scan of the implant position with the virtual planned implant.\textsuperscript{14–16} This method has some disadvantages, such as the additional radiation exposure for the patient and the occurrence of beam hardening, which is caused by the implant and interferes with the outline of the implant.\textsuperscript{17}

To overcome these drawbacks, Son et al\textsuperscript{18} compared a postoperative intraoral optical scan of the implant position with the virtual planned implant. Skjerven et al\textsuperscript{19} compared this method with the CBCT-based approach and concluded that both techniques generate similar results.

In the case of tooth-supported templates, different configurations can be distinguished: a single-tooth gap, an interrupted dental arch with multiple missing teeth, or a shortened dental arch, where the last tooth or teeth are missing. The lowest deviations are observed for single-tooth gaps, where the guide is supported at both ends by neighboring teeth.\textsuperscript{1,20} Studies on guided placement of single implants, using an intraoral scan as reference, reported mean angular, coronal, and apical deviations varying from 1.6 to 3.7 degrees, 0.47 to 1.0 mm, and 0.32 to 1.5 mm, respectively.\textsuperscript{8,12,19–23} One study by Tan et al\textsuperscript{23} used median and interquartile range instead of mean and SD. They reported 3.91 degrees, 0.42 mm, and 0.87 mm, respectively.

Accuracy is defined as trueness and precision, where trueness is the ability to match the actual value and precision is the ability to reproduce the measurements consistently.\textsuperscript{24}

The purpose of this study was to evaluate the accuracy of single implant placement and fit of the guide, using in-office 3D-printed tooth-supported surgical guides.

**MATERIALS AND METHODS**

**Cast**

CBCT data (ProMax 3D, Planmeca) and an optical scan (D700, 3Shape) of a mandibular cast were collected from a patient with a missing molar in the mandibular left first molar position. The data were anonymized, and the optical scan was used to produce 20 identical resin casts by means of a 3D printer (Asiga MAX UV) and printing liquid resin (Model Oker, NextDent SG, 3D Systems, Vertex-Dental B.V.; Fig 1). Each cast was scanned individually with an intraoral scanner (Primescan, Dentsply Sirona) to exclude deviations from the printing process for the further analyses.

**Implant Planning**

The CBCT and intraoral scans were imported into the implant planning software (Exoplan, Exocad), and a single implant (Bone Level Roxolid, 4.1 mm × 10 mm, Straumann) was planned in the mandibular left first molar position. A tooth-supported guide was virtually designed covering the mandibular left canine to the third molar and saved as a Surface Tessellation Language (STL) file. This process was repeated for 15 of the casts. One implant planning was randomly chosen to be carried out five more times in the remaining casts.

**Guide Fabrication**

The surgical guides were fabricated by means of the same DLP printer (Asiga MAX UV) and a printing liquid, intended for surgical guides (NextDent SG, 3D Systems, Vertex-Dental B.V.), with a layer thickness of 100 µm. Each guide was printed twice, all horizontally (0-degree angle), and support structures were added without interfering with the internal structures. After printing, all guides were ultrasonically cleaned for 10 minutes in 90% alcohol. For half of the guides, the guide sleeves were manually fixated into the guide, prior to final
curing in a UV light box for 30 minutes (LC-3DPrint Box, 3D Systems). The other 15 guides were cleaned and cured without the sleeves for further 3D mapping.

**Implant Placement**

All 15 surgical guides were positioned on the teeth of their corresponding resin cast, and the drilling protocol (hard bone) was performed according to the instructions of the implant company. The implants were placed through the guide sleeve to verify the correct vertical position. Once the implant was in the correct position, a digital impression was performed (Primescan, Dentsply Sirona) using an intraoral scan body (Elos Accurate, Elos Medtech). One guide was reused for the additional placement of five implants in the remaining casts, which were subsequently scanned using the intraoral scanner to determine the precision.

**Evaluation**

**Trueness.** The reference model was created by importing the virtual plan into CAD software (Exocad Plovdiv 2.4, Exocad) and exporting the virtual cast with an implant dummy as an STL file.

The test model was generated by matching an STL file of the scanbody and implant dummy on the digital impression. Both models were imported into metrology software (Geomagic Qualify X), and the reference and test were aligned using a best-fit algorithm, with the neighboring teeth serving as a reference.

**Precision.** All six scans from the same surgical plan were superimposed and compared with one another, which resulted in 15 alignments and measurements.

**Measurements**

All models were aligned according to the same coordinate system, with the occlusal plane defined by the x, y-axis. The outcome variables were as shown in Fig 2:

- Angular deviation: Angle between the axis of the planned implant and the placed implant
- Coronal deviation: Distance between the center of the neck of the planned implant and the center of neck of the placed implant
- Apical deviation: Distance between the center of the apex of the planned implant and the center of apex of the placed implant
- Buccolingual (x-axis), mesiodistal (y-axis), and coronal-apical (z-axis) displacement of the implant apex, based on changes of the coordinates.

**Fit of the Guide**

All 15 guides without sleeves were sprayed with a thin layer of anti-glare spray (Helling 3D Scan Spray, CyberOptics) and positioned in a lab scanner (AutoScan-DS-MIX, Shining 3D) with an accuracy of ≤ 7 µm. Only the internal surface of the guide was scanned. After scanning, the respective guides were matched with their virtual design. A best-fit algorithm was used to superimpose the scan of the printed guide with the guide design (Geomagic Qualify X), and the absolute deviation was calculated out of mean positive and negative values.

**Statistical Analyses**

Descriptive statistics were used to evaluate the differences between the virtually planned and placed implants for angular, coronal, and apical measurements.

For the coordinates, the mean and standard deviation are reported for the positive and negative values as well as the mean for the absolute values.

One sample t test was executed on the mean with the positive and negative values. The level of significance was defined as $P < .05$. 

**Fig 2** The (a) coronal deviation, (b) angular deviation, (c) apical deviation, and (d) horizontal/vertical displacement at the implant apex between the virtual and actual implant position were measured.
RESULTS

Trueness
The mean angular deviation was 2.63 degrees (SD: 1.69 degrees; range: 0.38 to 5.99 degrees), the mean coronal deviation was 0.52 mm (SD: 0.25; range: 0.09 to 1.07 mm), and the mean apical deviation was 0.90 mm (SD: 0.47; range: 0.14 to 1.74 mm; Fig 3). The safety zone of 2 mm was not exceeded.

The absolute apical mean deviation in the buccolingual direction (x-axis) was 0.70 mm (SD: 0.42, range: 0.12 to 1.65 mm; P < .001); in the mesiodistal direction (y-axis), it was 0.34 mm (SD: 0.26; range: 0.01 to 0.80 mm; P = .650); and in the vertical direction (z-axis), it was 0.32 mm (SD: 0.27; range: 0.02 to 1.00 mm; P = .010; Fig 4).

The positive and negative values are depicted in Fig 5. Overall, there was a mean buccal displacement at the implant apex of 0.7 mm (SD: 0.42, range: 0.12 to 1.65 mm), a mean mesial displacement of 0.05 mm (SD: 0.44, range: –0.80 mm to 0.80 mm), and a mean coronal displacement of 0.26 mm (SD: 0.33, range: –0.19 mm to 1.00 mm). Eleven implants (73%) were placed less deep than virtually planned.

Precision
The mean angular, coronal, and apical deviations were 1.22 degrees (SD: 0.76 degrees, range: 0.22 to 2.29 degrees), 0.33 mm (SD: 0.15 mm, range: 0.14 to 0.63 mm), and 0.42 mm (SD: 0.17 mm, range: 0.13 to 0.74 mm), respectively.

The absolute apical mean deviation in the buccolingual direction (x-axis) was 0.30 mm (SD: 0.17, 0.05 to 0.63 mm; P = .046); in the mesiodistal direction (y-axis), it was 0.20 mm (SD: 0.11; range: 0.05 to 0.40 mm; P = .828); and in the vertical direction (z-axis), it was 0.15 mm (SD: 0.27; range: 0.01 to 0.45 mm; P = .084; Fig 4).

Fit of the Guide
The mean deviation of the guide was 79.5 µm (SD: 19.6 µm; range: 51.0 to 118.0 µm). Overall, the highest discrepancies were located at the edges of the guide and where the metal sleeve should be positioned (Fig 6).

DISCUSSION

This study evaluated the accuracy of guided implant placement using a software package that allows implant planning, design, and chairsde printing of the surgical guide by means of a desktop 3D printer. For trueness, the mean deviations were 0.52 mm at the coronal aspect, 0.90 mm at the apical aspect, and 2.63 degrees in angulation. These results are comparable with other studies using an optical scan as reference, with mean deviations varying from 1.6 to 3.7 degrees in angulation, 0.47 to 1.0 mm at the coronal aspect, and 0.32 to 1.5 mm at the apical aspect.8,12,19,21–23 The recommended safety zone was not surpassed in any of the 15 casts, with the maximum deviation being 1.74 mm.

The mean angular, coronal, and apical precision were 1.22 degrees, 0.33 mm, and 0.42 mm, respectively, which seems better compared to the trueness. However, precision represents the repeatability of implant placement, influenced by the stability of the guide and the tolerance of the metal sleeve toward the drills. It does not include the errors from the 3D printing process.
Most of the implants (73%) were positioned less deep in the bone compared with the virtual plan. This corresponds to the findings by Verhamme et al, who found that 74% of the implants in their in vivo study were located insufficiently deep in the bone. This could be explained by the collection of debris as a result of the drilling process. When considering the precision, none of the placed implants exceeded the depth of the planned implant. Nonetheless, all implants reached their final position as determined by the implant driver. Another explanation is that the guide was not fully seated on the cast, although the guide was transparent and a visual assessment was made.

Abduo and Lau found that the seating of 3D-printed guides was more difficult compared with their milled counterparts. This might be caused by the curing and postprinting process (removing support structures, cleaning, and curing), which may induce minor deformations. Curing of the separate layers causes shrinkage and polymerization stress, which is transferred to the already-cured part, inducing internal stress and distortion. In contrast, a milled guide is made of a fully processed acrylic and therefore will not shrink. Also, the milling process eliminates all undercuts. This might improve the seating of the guide, although the difference with the printed guides was rather small and clinically insignificant, since it has no effect on the positioning of the implant.

Overall, correct seating of the guide is more difficult in the front compared with the posterior area. The present study tried to counteract this phenomenon by using a partial guide, not including the anterior region, but all guides still demonstrated some friction during seating. El Kholy et al found no difference in the fit between a full arch and a partial guide, supported by three teeth in the posterior area. The color map displayed larger deviations toward the edge of the guide and in the area surrounding the metal guide sleeve, although most deviations were < 250 µm. In comparison, Abduo and Lau reported a mean internal fit of 230 µm for a DLP printed full-arch guide, whereas Rubayo et al reported a difference of 48 µm using an SLA printer. Similar to the present findings, the deviations were more pronounced at the edges of the guide. However, deviations up to 100 µm have possibly no clinical negative effect.

The dimensional accuracy of the guide also depends on the quality of the printing process and thus the 3D printer. In this study, the Asiga MAX UV printer was used to produce the guides. In comparison to four other 3D printers, Asiga MAX UV demonstrated the highest accuracy. Interestingly, inexpensive 3D printers were no less accurate than more expensive devices.

It was striking that the apex of all implants was located more buccally compared to their planned counterparts. This is in accordance with other clinical in vivo studies, whereby it is assigned to the angle in which the bur is brought into the mouth, with restrictions of the mouth-opening and lip tension. However, these factors were not valid in the present in vitro study. To prevent buccal displacement and to maintain the correct direction, Yeung et al recommended performing bone tapping, which was also performed in the present study. Tan et al also stated that errors could be minimized by using shorter drills or making the distance from the sleeve to the bone smaller. Derksen et al investigated different implant lengths and found that accuracy decreased when the implant length increased. This was also reported by D’haese et al based on the results of an in vivo study with multiple implants in an edentulous maxilla.

Since only small deviations were found between the virtually planned and placed implants, one could raise the question if it would be feasible to prefabricate a provisional restoration based on the data of the virtual plan. Few case reports have been published in which a provisional crown was fabricated prior to surgery. In all cases, the provisional crowns were successfully connected to the implants, with only minor adjustments. Zhang et al included 11 patients and concluded that the prefabrication of a provisional crown was feasible for immediate anterior restorations under fully guided surgery and that deviations in implant placement had no clinical effect on the seating of the provisional crowns. More clinical studies are necessary to confirm these findings.

Since this was an in vitro study, there are some limitations in comparison to an in vivo situation. Patient-related factors can contribute to an underestimating of the deviations. Movement by the patient during surgery, limited visibility for the surgeon due to bleeding, or limited mouth opening may affect the clinical procedure. Also, the printed casts might be harder to drill into compared with human bone, which is softer. Therefore, a clinical in vivo study, using the current protocol, will be performed in the near future, taking these variables into account.
CONCLUSIONS

Desktop 3D-printed tooth-supported guides demonstrate an acceptable fit and acceptable level of accuracy for single implant placement.

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