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Accuracy of a chairside fused deposition modeling 3D-printed single-tooth surgical template for implant placement: An in vitro comparison with a light cured template

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ABSTRACT

Purpose: To compare the accuracy of a chairside fused deposition modeling (FDM) 3D-printed surgical template with that of a light-cured template for implant placement.

Materials and methods: Twenty standard mandibular resin models with missing teeth 36 and 46 were selected. Surgical templates were fabricated using a chairside FDM 3D-printer (test group) or a light-curing 3D printer (control group) ($n = 20$/group). Forty implants were placed by a clinician blinded to group allocation. The angular, 3D, mesiodistal, buccolingual, and apicocoronal deviations at the implant base and tip between preoperative design and postoperative implant position were recorded.

Results: The mean angular (test vs control groups: 3.22° ± 1.55° vs 2.74° ± 1.24°, $p = 0.343$) and 3D deviations at the implant base (test vs control groups: 0.41 ± 0.13 mm vs 0.35 ± 0.11 mm, $p = 0.127$) and tip (test vs control groups: 0.91 ± 0.34 mm vs 0.75 ± 0.28 mm, $p = 0.150$) were similar. The mesiodistal, buccolingual, and apicocoronal deviations at the implant base and tip also did not differ significantly between groups ($p > 0.05$).

Conclusions: For single tooth gap indications, implant placement with an FDM 3D-printed surgical template was as accurate as that with a light-cured template, and more efficient.

1. Introduction

Correct implant position is critical to the esthetics and function of restorations. A ‘prosthetically driven’ implant treatment concept was proposed in 1995 (Garber and Belser, 1995), which required clinicians to consider the esthetics and function of the final restoration during implant surgery. Thus, a well-established preoperative design and an accurate transfer to surgery are needed.

With the advent of computer-aided design/computer-aided manufacture (CAD/CAM) technology, and cone beam computed tomography (CBCT), many types of software have been developed that can assist the clinician in the preoperative design (Jemt and Stenport, 2011; Van Assche et al., 2012; Vercruyssen et al., 2014). Mainly two types of technique are used to transfer the planned implant position information to the clinical situation: ‘static guidance’, which applies surgical templates; and ‘dynamic guidance’, which uses visual imaging tools on a monitor to achieve intraoperative real-time guidance (Jung et al., 2009; Jayaratne et al., 2010; Block et al., 2017). Surgical templates are more widely used, due to their low cost and high predictability (Hultin et al., 2012; D'Haese et al., 2017).

To date, numerous studies have focused on the accuracy of template-guided surgery, which refers to the deviation between the planned and final implant position (D'Haese et al., 2012). Implant placement using a surgical template can significantly improve accuracy, as compared with freehand placement, both in vitro (Vermeulen, 2017; Tan et al., 2018) and in vivo (Nickenig et al., 2010; Arisan et al., 2013). Compared with the conventional

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thermo-formed surgical guide, a digitalized surgical template can achieve even higher accuracy (Matta et al., 2017).

At present, digitalized surgical templates are mainly manufactured using additive manufacturing technology, with stereolithographic 3D printing technology — a type of light-curing 3D printing technology — being used most commonly (D'Haese et al., 2017). However, stereolithographic surgical templates mostly require the use of specific equipment in a dental laboratory, as well as a complex procedure (Hu et al., 2012; Kattadiyil et al., 2014). They require a long production time and are not suited to chairside application. On the other hand, fused deposition modeling (FDM) technology is based on a relatively simple principle, has lower costs and higher printing efficiency, and can be used for printing oral medical products with appropriate precision (Chen et al., 2016; Calcagnile et al., 2018). Current 3D-printing accuracy, which is the deviation between the printed object and standard triangulation language (STL) file dimensions, is less than 1 mm in general, and typically less than 0.5 mm (George et al., 2017). Some studies of FDM printing technology have demonstrated accuracy of around 0.1–0.5 mm (El-Katatny et al., 2010; George et al., 2017), and even 0.013 mm (Deng et al., 2017). Nevertheless, no research on, or application of, FDM technology for printing surgical guides has been reported to date.

The aim of this study was to evaluate the accuracy of implant placement with a new type of surgical template fabricated using FDM technology, in comparison with a frequently used, light-cured template, in an in vitro environment. Development of both templates was based on the same 3D planning. The null hypothesis was that there would be no significant difference between these two types of surgical template in terms of transfer accuracy.

2. Materials and methods

2.1. Selected models and data sets

Twenty standard mandibular resin models, produced using the same matrix, with missing teeth 36 and 46 were chosen to represent a typical clinical situation in this in vitro study (Fig. 1). Bone analog was placed under the surface of the edentulous area, to simulate class II bone quality. Surface data for the standard mandibular resin model were obtained using a 3D optical model scanner (Activity 880, Smart Optics, Bochum, Germany), and were saved as an STL file. In addition, a CBCT scan of the resin model was performed to obtain Digital Imaging and Communications in Medicine (DICOM) data, using a NewTom VGi CBCT scanner (QR srl, Verona, Italy) with the following characteristics: 0.2-mm axial thickness, 110 kV, 0.90 mA.

Fig. 1. Standard mandibular resin models with missing teeth 36 and 46.

2.2. Implant planning and surgical guide design

The CBCT and surface scan data were imported into coDiagnostiX software (coDiagnostiX 9; Dentalwings GmbH, Chemniz, Germany) according to the manufacturer's instructions. The DICOM and STL data sets were matched by point-to-point registration. Based on the quality and quantity of bone analog indicated by CT in the edentulous area, a Straumann SLA bone-level implant (Straumann AG, Basel, Switzerland), with a length of 10 mm and a diameter of 4.1 mm, was selected. After choosing the simulated crown from the software, adjusting its shape, and placing it at the midpoint of the center line of the adjacent teeth's occlusal surface, the optimal implant position was determined using the center and axis of the tooth, as well as conventional implant placement standards. Surgical templates for teeth 36 and 46, resting on the adjacent teeth, were designed to guide the implant bed preparation (Fig. 2).

2.3. Surgical template printing

The surgical templates were printed using two different 3D printers.

(1) Test group: because the FDM 3D printer used in this study could only print a three-unit template for a single missing tooth situation, the design data were first imported into Geromagic software (Geomagic 2012, Raindrop, Durham, NC, USA), and clipped into three-unit template data, which had only one mesial and one distal tooth as supporting components. Then, three-unit templates were printed using the chairside FDM 3D printer (Lingtong III, Beijing SHINO, Beijing, China), using a polylactic acid (PLA) filament, with following parameters: a layer thickness of 0.2 mm; a nozzle temperature of 200 °C; a nozzle diameter of 0.3 mm, and a deposition speed of 20 mm/s (Fig. 3).
(2) Control group: four-unit templates were printed by a light-curing 3D printer in the dental laboratory. The design data were directly transferred to the dental laboratory and the Objet30 Pro 3D printer (Stratasys Ltd, Rehovot, Israel) was used to print templates with a layer thickness of 0.016 mm and an accuracy of 0.1 mm.

After printing, metal drilling sleeves with a diameter of 5.0 mm and a height of 5.0 mm were inserted into the 40 surgical templates.

2.4. Implant bed preparation and implant insertion

Each model used two different templates to assist implant bed preparation, one from the test group and one from the control group (Fig. 4). The residual ridges of teeth 36 and 46 were randomly allocated to receive surgical templates from one of the two groups to assist implant bed preparation.

The operations were conducted by a clinician who was blinded to the grouping of this study and had been trained to place implants using both of the above template types. The clinician chose the correct drill and the corresponding drill handle, as indicated in the surgical protocol recommended by the software, and placed the cylinder of the drill handle into the sleeve in the surgical template.

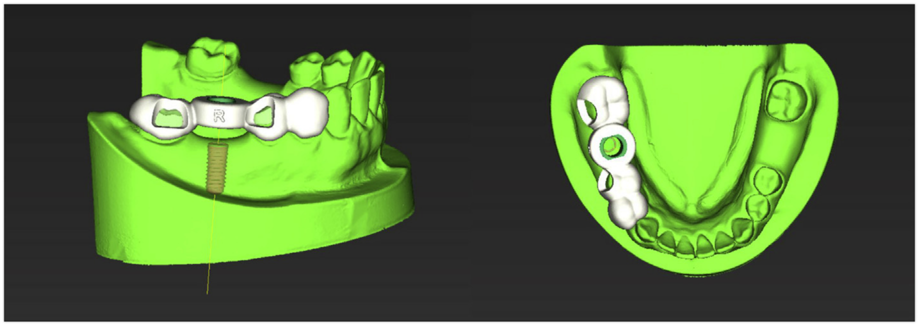

Fig. 2. The implant position for tooth 46 and view of the surgical template resting on the adjacent teeth.

The clinician drilled until the collar of the drill hit the cylinder of the drill handle in order to reach the required osteotomy depth. Then, using the profile drill and guided tap, implant beds of the required type were prepared. After implant bed preparation, implants with a 4.1-mm diameter and 10.0-mm length were inserted without templates.

2.5. Postoperative optical scan and accuracy evaluation

After all 40 implants had been placed (Fig. 5.1), the scan bodies (Straumann AG, Basel, Switzerland) were screwed onto the implants (Fig. 5.2). A second 3D optical model scan (Activity 880, Smart Optics) was performed to obtain the postoperative 3D position of the implants for each model (Fig. 5.3). The STL data were matched with the presurgical planning in the coDiagnostiX software, using point-to-point registration. The scan body was identified and used to deduce the actual implant position in the software; the planned and the placed positions of the implant were then compared. The following deviations were measured at the implant base and implant tip: angular deviation, 3D deviation, mesiodistal deviation, buccolingual deviation, and apicocoronal deviation (Fig. 6).

2.6. Statistical analyses

Statistical analyses were performed using SPSS software (IBM SPSS Statistics v20.0; IBM Corp). The assumption of normality was justified because the values did not have extreme outliers. Descriptive statistical methods were used for evaluations. All values were expressed as means ± standard deviations. Paired-samples *t*-tests were used to compare the accuracy of the two different surgical template groups. A p-value < 0.05 was considered significant.

3. Results

A total of 40 implants were inserted into 20 models. All deviation values were used as absolute values; thus, the distance from the position of the placed implants to their planned position was measured, without consideration of direction. These details can be found in Table 1.

No statistically significant difference in accuracy was found between the test group and the control group for any of the parameters.

4. Discussion

FDM technology was used to fabricate surgical templates, and the accuracy of these templates for implant placement was compared with that using a light-cured 3D-printed surgical

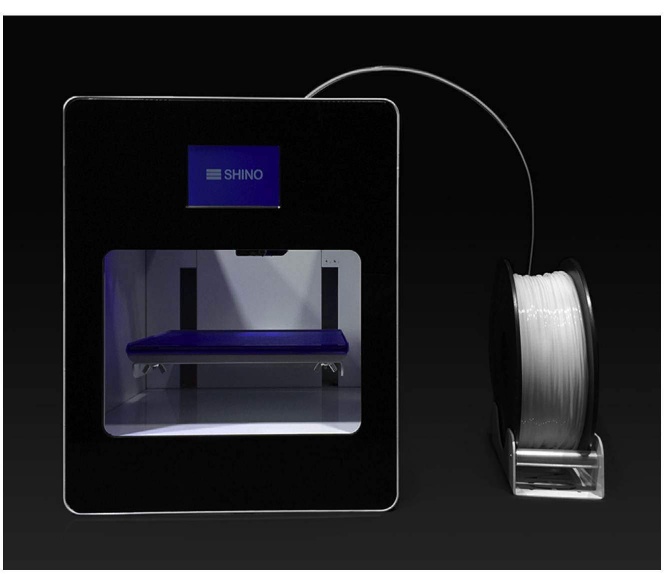

Fig. 3. FDM printer (Lingtong III, Beijing SHINO, China).

Fig. 4. The two different surgical templates resting on adjacent teeth. On the left is the light-cured, 3D-printed template for the control group and on the right is the FDM chairside 3D-printed template for the test group.

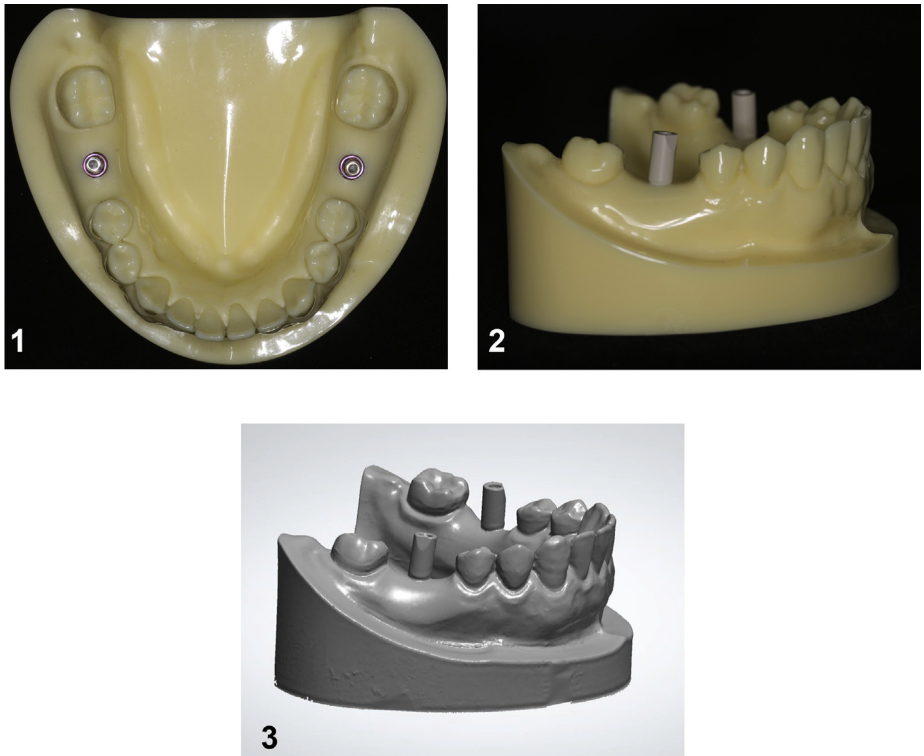

Fig. 5. 1. Placing of implants on the model, 2. The scan bodies are screwed onto the implants, 3. 3D view of the postoperative optical model scan.

template. The results showed that the two template types had similar accuracy.

To our knowledge, no previous report has described using FDM 3D-printed templates to assist implant bed preparation, or compared this with light-cured 3D-printed templates. FDM is an efficient 3D-printing technology (Chen et al., 2016; Calcagnile et al., 2018): under the control of a computer, the printer nozzle moves in a horizontal direction during material extrusion. After completing a printed layer, the printing platform descends vertically to the next layer, and thus a 3D structure is accumulated layer by layer. The material used in this study was PLA, a biocompatible polymer extracted from corn, which can be used in a number of biomedical applications (Pang et al., 2010; Madhavan et al., 2010; Molinero-Mourelle et al., 2018).

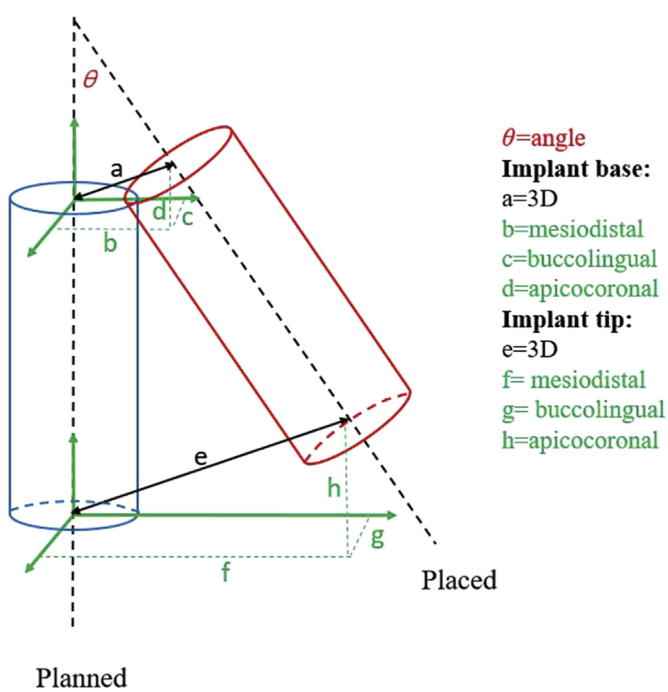

Fig. 6. Schematic diagram of accuracy evaluation. The position of the placed (red) implant was compared with that of the planned (blue) implant.

The FDM 3D printer used in this study is 33 cm long, 27 cm wide, and 28 cm high (smaller than the usual 3D-printer), creates no pollution, and is suitable for chairside applications. The average time required for printing a template using an FDM 3D printer is 30 min. On the other hand, for light-cured 3D-printed templates, the design data normally need to be transferred to the dental laboratory, where the template is printed by the technician before being sent back to the clinic. This requires more time (typically 7 business days) (Kattadiyil et al., 2014) and more procedures. Compared with light-cured 3D-printed templates, the process for manufacturing FDM templates is therefore simpler and more efficient.

In a previous study, Fernández-Gil et al. (Fernandez-Gil et al., 2017) reported mean deviations of 0.44 mm for the implant base, 0.79 mm for the tip, and 2.16° for the angle when using a tooth-supported, light-cured 3D-printed guide on resin mandibles. Turbush and Turkyilmaz (2012) reported 3D deviation of 1.00 ± 0.33 mm at the implant base, 1.15 ± 0.42 mm at the tip, and an angular deviation of 2.26° ± 1.30° for tooth-supported templates, in an in vitro study. Widmann et al. (2015) evaluated the accuracy of image-fused, light-cured 3D-printed templates and reported a mean 3D deviation of 0.21 ± 0.10 mm (range: 0.00–0.48 mm) at the implant base and 0.32 ± 0.17 mm (range: 0.03–0.75 mm) at the implant tip. The mean angular deviation was 0.85 ± 0.59° (range: 0.00–2.50°). The mean depth deviation

Table 1
Accuracy of the different parameters evaluated for the FDM 3D-printed template and light-cured 3D-printed template groups, in absolute values.

Deviation parameter		FDM 3D-printed template				Light-cured 3D-printed template				*p*-value
		Mean	SD	Min	Max	Mean	SD	Min	Max	
Angular (°)		3.22	1.55	1.00	6.90	2.74	1.24	0.50	4.80	0.343
Implant base (mm)	3D	0.41	0.13	0.16	0.66	0.35	0.11	0.20	0.64	0.127
	Mesiodistal	0.28	0.14	0.04	0.52	0.21	0.13	0.03	0.44	0.157
	Buccolingual	0.22	0.14	0.04	0.47	0.19	0.13	0.01	0.45	0.383
	Apicocoronal	0.11	0.08	0.00	0.29	0.11	0.09	0.00	0.36	0.842
Implant tip (mm)	3D	0.91	0.34	0.34	1.38	0.75	0.28	0.21	1.17	0.150
	Mesiodistal	0.60	0.33	0.10	1.13	0.48	0.30	0.01	0.91	0.285
	Buccolingual	0.58	0.34	0.04	1.10	0.45	0.32	0.00	1.17	0.243
	Apicocoronal	0.12	0.08	0.02	0.27	0.12	0.09	0.01	0.35	0.915

Paired-samples *t*-test, $\alpha = 0.05$; Min: minimum; Max: maximum; SD: standard deviation.

was 0.07 ± 0.07 mm (range: 0.00–0.32 mm). In another study, experienced surgeons used surgical templates for single-space units in models, and reported a mean lateral deviation of 0.36 mm at the implant base and 0.41 mm at the implant tip; the mean depth deviation was 0.56 mm both at the implant base and tip, and the mean angular deviation was 1.70° (Vermeulen, 2017). The template-guided implant placement in our study achieved similarly high accuracy as that obtained in these earlier studies.

The final difference between the preoperative design and actual implant position is based on the accumulation of many possible deviations. Deviations can occur in image acquisition, template fabrication, fit of the surgical template on the remaining teeth, template movement, and surgical transfer (Valente et al., 2009; Dreiseidler et al., 2012; Widmann et al., 2015). Artifacts from dental restorations can significantly influence the quality of CT images. Image errors reportedly reach mean values ranging from 0.06 mm to 0.54 mm (Eggers et al., 2008; Loubele et al., 2008). During template fabrication, changes in the dimensions of the resin can influence accuracy (Matta et al., 2017). Imperfect adaption of the planned implant and the corresponding sleeve, burr, drill handle, drill cylinder, and other material may also cause inaccuracies during the surgical phase (Schneider et al., 2015). Some studies have demonstrated that the tolerance of the surgical instruments could affect the accuracy of guided implant placement, which has been termed ‘intrinsic error’, and can result in angular deviation of 2.57° (Cassetta et al., 2013, 2015). Additionally, some studies have found that the operator's experience level influences accuracy (Cushen and Turkyilmaz, 2013; Vermeulen, 2017).

It should be noted that the accuracy of template-guided implant placement in vitro studies is generally better than that of in vivo clinical studies (Tahmaseb et al., 2014). In a clinical context, more errors can occur at the posterior site due to the difficulty in gaining access for drilling, the small interarch space, diminished visibility, the impact of blood or saliva, and the different diameters of the implant sleeve and drill (Park et al., 2017).

This study had four limitations. First, other than the differences with respect to clinical applications, a bone analog simulating class II bone quality was used, whereas differences in bone quality within the osteotomy site crucially influences accuracy of implant placement (Widmann et al., 2015). Second, due to printing accuracy limitations, the FDM 3D printer used in this study can only print three-unit templates for a single missing tooth context. Although including two to three adjacent teeth for single-tooth implant is generally considered to be sufficient for secure positioning (Kurbad, 2017), additional supporting teeth can be beneficial for stabilization. The difference in the length of the templates (three units in the test group and four units in the control group) may have affected accuracy. In this study, no statistically significant difference in accuracy was found between the test group and the control group. If the FDM printer could print four-unit templates with high precision, the accuracy of guidance could be higher. Third, the templates discussed in this study were suitable for single missing tooth situations. Fourth, the implant placements were carried out without template guidance.

Further research is needed for cases of multiple missing teeth and those involving full guidance.

5. Conclusion

In this in vitro study, implant placement using an FDM chairside 3D-printed surgical template yielded a similarly high accuracy as obtained with a light curing 3D-printed template for indication single tooth gap, but with improved efficiency. Although this model study cannot fully simulate a clinical situation, it demonstrated the feasibility and reliability of using an FDM guide plate in clinical applications to some extent. Future research is needed to verify whether the technique is suitable for complex clinical situations.

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Conflicts of interest

The authors report no conflicts of interest related to this study.

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