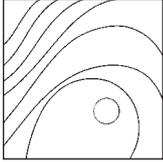


# Accuracy of Implant Placement Guided with Surgical Template: An In Vitro and In Vivo Study



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*This study evaluated the accuracy of implant placement with surgical-template guidance both in vitro and in vivo. Virtual surgical planning was performed based on the data from CBCT scans and an intraoral scanner. Surgical templates were designed according to the planned implants and manufactured with stereolithography. In vitro, 60 implants were placed in 15 resin models. In vivo, 74 implants were placed in 54 patients. The implants were scanned with CBCT postoperatively. Implant accuracy was evaluated by measuring the following parameters: central deviation at the apex and shoulder, horizontal deviation at the apex and shoulder, vertical deviation at the apex and shoulder, and angular deviation. There were statistically significant in vitro and in vivo deviations for all parameters, and the implant deviations in vivo were significantly greater than those in vitro. When using a mucosa-supported template, horizontal deviations at the apex were significantly greater than when a teeth-supported template was used. Within the limitation of the study design, inaccuracy existed in implant placement guided with a surgical template. More studies are needed to investigate the value of the procedure in future. Int J Periodontics Restorative Dent 2021;41:e55–e62. doi: 10.11607/prd.4570*

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Implant-supported oral prosthetics is characterized by its stable fixation, esthetic outcomes, and clinical predictability, and it is now routinely used as the ideal method for replacing missing teeth.<sup>1–3</sup> With proven reliability of the reconstructive techniques (including guided bone regeneration, onlay graft, sinus augmentation, distraction osteogenesis, and tissue regeneration),<sup>4</sup> the philosophy of prosthetic-driven implant placement is now widely accepted by clinicians. The positions of proposed implants are determined by the prosthodontic restoration, combining functional and esthetic considerations, which means accurate implant placement is more important than ever. Radiologic imaging allows a detailed preoperative assessment and planning, but precisely transferring the virtual plan to the surgical field via freehand is still a huge challenge for surgeons due to the complexity of anatomical structure and the inevitability of human error.

Since Materialise introduced guided drilling technology in 2002, guided surgery has been a subject of substantial interest to dental clinicians for its possible role in improving implant accuracy. At present, there are many types of surgical templates offered by implant manufacturers, image processing software companies, and rapid pro-

totyping device suppliers. These products adopt a similar workflow: virtual implantation in preoperative planning software based on image data from computed tomography (CT), and a CAD/CAM surgical template to reproduce the virtual position to an actual anatomical structure.<sup>5</sup> Surgical templates have been shown to be able to improve implant accuracy in most studies,<sup>6–9</sup> but high levels of inaccuracies are also reported where the technique was applied.<sup>10–12</sup>

Different to the early solutions, present modalities utilize new techniques, such as high-resolution CBCT radiographs, digital impression by surface scanner, and more accurate image registration by a high-performance computer. These developments reduce the number of nondigital steps in a conventional protocol and would improve the accuracy of guided surgery, at least theoretically.<sup>13</sup> Thus, opinions on the accuracy of guided surgery should regularly be updated due to the rapid advancement of technology. The present study aimed to assess the *in vitro* and *in vivo* accuracy of implant placement using a surgical template. Implant positions were determined by the prosthetics that were digitally designed with data from CBCT scans and the intraoral scanner. The surgical template was designed based on the plan and fabricated using stereolithographic prototyping.

## Materials and Methods

### *In Vitro* Study

#### Model preparation

A partially edentulous model was created by removing the bilateral second premolars and first molars in the mandible in the software (Materialise Mimics version 16.0, Materialise) using CBCT data (3D eXam, KaVo) of a volunteer. The model was printed with resin (VisiJet M3 StonePlast, 3D Systems) in a 3D printer (ProJet 3500 HD MAX, 3D Systems).

#### Surgical template fabrication

Teeth-supported surgical templates were designed in GuideMia software using the CBCT data of the resin models (Fig 1a). Four implants (Standard Plus RN, 4.1 × 10 mm, Straumann) were placed virtually. The templates were printed with resin (VisiJet M3 StonePlast) by a 3D printer (ProJet 3500 HD MAX; Fig 1b).

#### Implant placement using surgical template

The printed mandible model was mounted on mannequin head to simulate an intraoral situation. The surgical template was positioned in a stable manner on the mandible model to guide the drilling, from the lance drill to the final drill. The template was then removed. The implants (Standard Plus RN) were placed as planned (Fig 1c).

### *In Vivo* Study

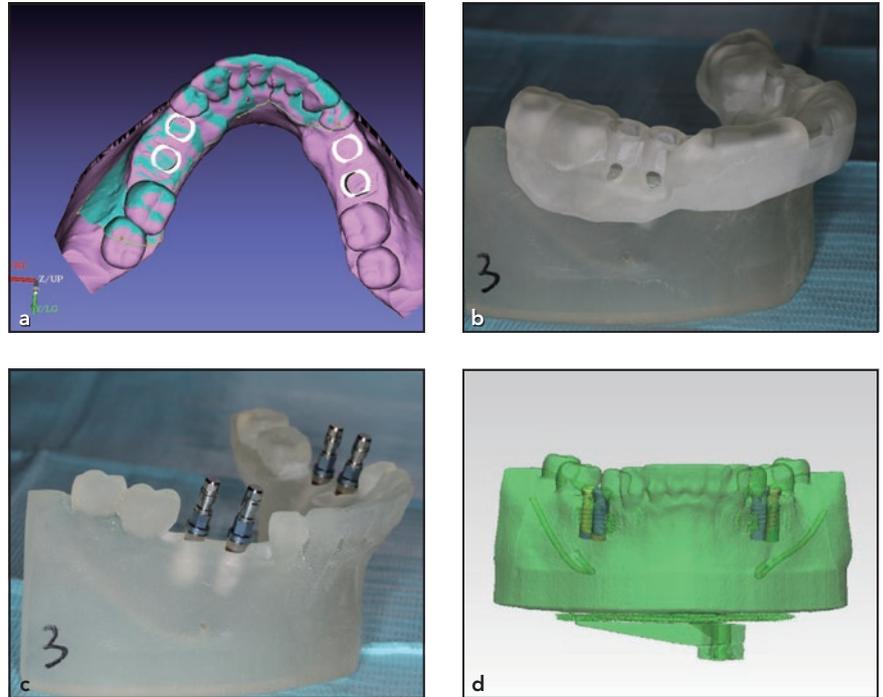
#### Patient selection

A total of 54 patients with partial or full edentulism who visited the same surgeon (M.Z.) in Stomatology Hospital of Guangzhou Medical University between August 2016 and May 2018 were included if they met the following criteria: no general disease; proper bone volume for implant-supported restoration and no need for ridge augmentation; proper mouth-opening for template seating; willingness to undergo a pre- and postoperative CBCT examination; and having a full understanding of the study protocol and providing signed informed consent.

#### Surgical template fabrication

For fully edentulous patients, a radiologic template with fiducial markers was fabricated on the plaster model of the patient. The template was scanned with CBCT by itself and with the patient (double scan technique). The soft tissue was scanned with an intraoral scanner (DL-100, Launca). Partially edentulous patients were scanned using CBCT with mouth opening. The dentition and soft tissue were scanned with an intraoral scanner. Data from both CBCTs and the intraoral scanner were imported and superimposed in the GuideMia software (Fig 2a). A tooth-supported template was used in partial-edentulism cases, and a mucosa-supported template was used in full-edentulism cases. For mucosa-supported templates, fixation pins were used. The design was fabricated using a 3D printer (ProJet 3500 HD MAX; Fig 2b).

**Fig 1** Surgical template-guided implant insertion *in vitro*. (a) The template was designed in GuideMia software, then (b) 3D printed and mounted on the resin model. (c) Implants were placed in the model using the template. (d) The postoperative CBCT scanning data was compared with the preoperative planning in the Materialise 3-matic software.



### Implant surgery

Surgery was performed under local anesthesia. A crestal incision was made on the edentulous ridge, and a full-thickness flap was elevated. The surgical template was then seated on the remaining teeth and/or mucosa (Fig 2c). Implant osteotomy was performed with template guidance from the lance drill to the final drill. The template was removed after the osteotomy. Implants were placed with torque of 35 to 40 N. Cover screws or healing caps were then engaged, and the flap was closed with tension-free sutures (Fig 2d). CBCT scans taken immediately postoperative were obtained with the same settings as the preoperative scan.

### Accuracy Analysis

The preoperative software planning (GuideMia) and the postoperative CBCT scans were imported in Materialise Mimics. The images were aligned based on the cusps of adjacent teeth (Fig 1d). The measurements were conducted in Materialise 3-matic software. The deviations were evaluated using seven parameters: central deviation at apex, central deviation at shoulder, horizontal deviation at apex, horizontal deviation at shoulder, vertical deviation at apex, vertical deviation at shoulder, and angular deviation (Fig 3). The values were standardized by the actual implant dimensions.

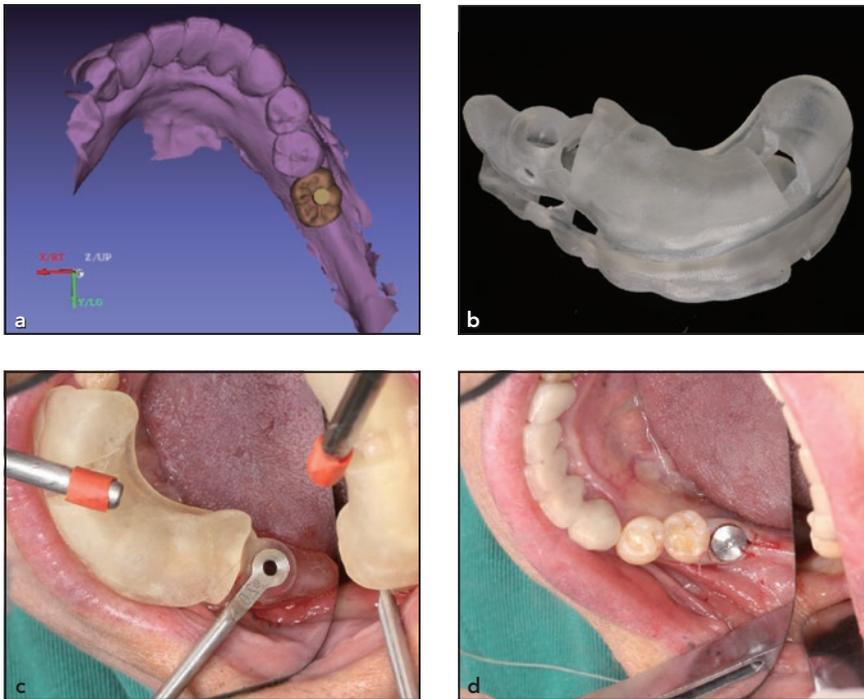
### Statistical Analysis

Statistical analysis was conducted using SPSS version 22.0 for Windows (IBM). Deviations were presented as mean, minimum and maximum values, SDs, and 95% confidence intervals (95% CIs). Statistical significance of deviation was assessed using one-sample *t* test with 0 as the hypothetical value. Statistical differences between groups were assessed using unpaired *t* test. A probability level of 0.05 was regarded as significant in all tests.

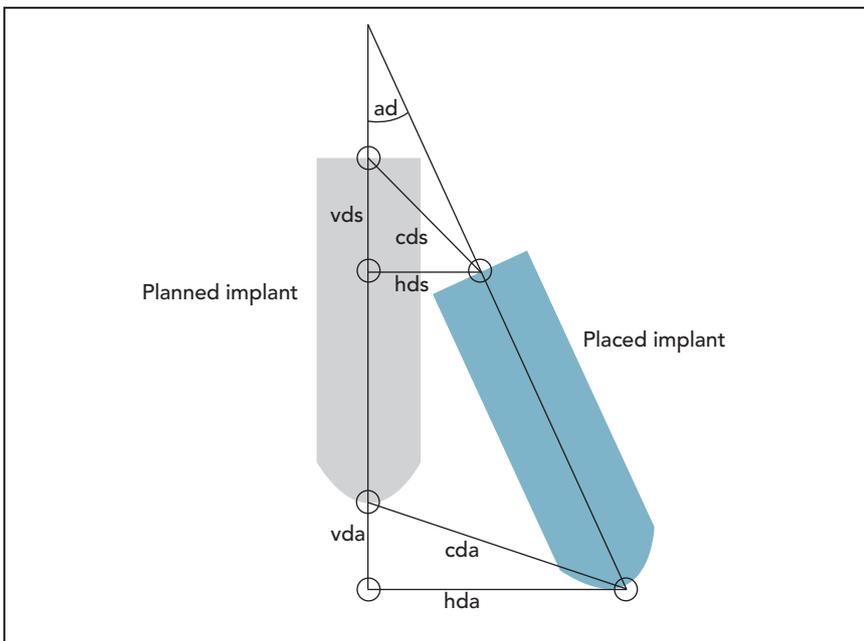
## Results

### *In Vitro* Study

A total of 60 implants were placed in 15 resin mandibular models. All templates achieved stable seat-



**Fig 2** Surgical template-guided implant insertion in vivo. (a) The template was designed based on the data from both CBCT scans and the intraoral scanner, then (b) 3D printed with resin and (c) mounted intraorally. (d) The template-guided implant was placed.



**Fig 3** Measurement of implant deviations of the seven observed parameters. *cda* = central deviation at apex; *cda* = central deviation at shoulder; *hda* = horizontal deviation at apex; *hds* = horizontal deviation at shoulder; *vda* = vertical deviation at apex; *vds* = vertical deviation at shoulder; *ad* = angular deviation.

ing on the models. No discernable movement was noticed in any of the templates. The actual position deviated from the planned position for all seven parameters. These deviations between planned and postoperative implant positions are summarized in Table 1.

#### *In Vivo Study*

A total of 74 implants were placed in 54 patients. All templates were seated intraorally without any discernable movement. All implants were placed, integrated, and received prosthetics as planned. No cases of nerve damage, sinus perforation, or bone wall dehiscence were reported. The deviations between planned and postoperative implant positions were statistically significant for all seven parameters

**Table 1 Implant Deviations In Vitro**

	Minimum	Maximum	Mean	SD	95% CI		P
					Lower	Upper	
hds, mm	0.00	1.37	0.33	0.31	0.25	0.41	< .001
hda, mm	0.04	1.87	0.59	0.41	0.49	0.70	< .001
vds, mm	0.01	1.93	0.71	0.51	0.59	0.84	< .001
vda, mm	0.03	1.93	0.68	0.51	0.56	0.81	< .001
cds, mm	0.13	1.93	0.88	0.43	0.78	0.99	< .001
cda, mm	0.19	2.21	1.00	0.48	0.88	1.11	< .001
ad, degrees	0.02	5.51	2.14	1.38	1.81	2.50	< .001

CI = confidence interval; cda = central deviation at apex; cds = central deviation at shoulder; hda = horizontal deviation at apex; hds = horizontal deviation at shoulder; vda = vertical deviation at apex; vds = vertical deviation at shoulder; ad = angular deviation.

**Table 2 Implant Deviations In Vivo**

	Minimum	Maximum	Mean	SD	95% CI		P
					Lower	Upper	
hds, mm	0.01	3.49	0.89	0.64	0.75	1.03	< .001
hda, mm	0.00	3.38	1.06	0.72	0.90	1.22	< .001
vds, mm	0.00	3.52	0.93	0.79	0.76	1.10	< .001
vda, mm	0.00	3.45	1.04	0.84	0.86	1.24	< .001
cds, mm	0.25	3.80	1.45	0.81	1.27	1.63	< .001
cda, mm	0.09	4.74	1.62	0.90	1.42	1.81	< .001
ad, degrees	0.00	9.26	3.27	2.47	2.72	3.84	< .001

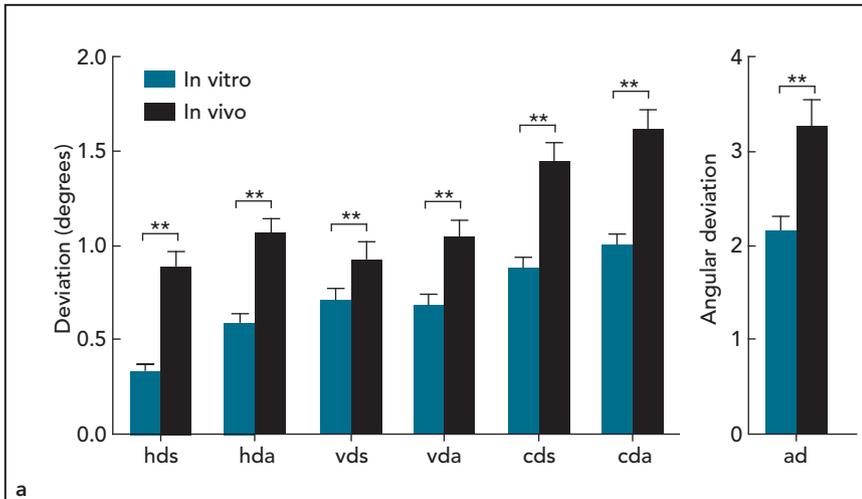
CI = confidence interval; cda = central deviation at apex; cds = central deviation at shoulder; hda = horizontal deviation at apex; hds = horizontal deviation at shoulder; vda = vertical deviation at apex; vds = vertical deviation at shoulder; ad = angular deviation.

(Table 2). For all parameters, the in vivo deviations were statistically significantly greater than in vitro deviations (Fig 4a). A mucosa-supported template was used to place 53 implants, and a tooth-supported template was used to place 21 implants. Horizontal deviations at the apex were significantly greater when mucosa-supported templates were used than when teeth-supported templates were used (Fig 4b), but no significant difference was found for any other parameter.

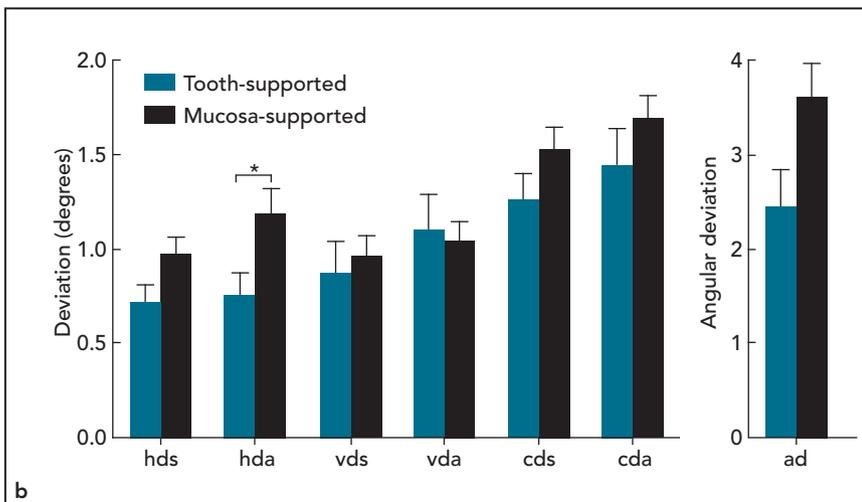
## Discussion

Methods for transferring the virtually planned implant position to the clinical situation can be categorized as either a surgical template (static guidance) or real-time tracking (dynamic navigation).<sup>14</sup> The present study aimed to assess implant accuracy using surgical templates in vitro and in vivo. In the present protocol, implant positions were planned based on digitized patient information, and the planned position was transferred to the surgical field with

a 3D-printed template. The results showed that the average deviations between planned and postoperative implant positions were  $0.88 \pm 0.43$  mm at the shoulder and  $1.00 \pm 0.48$  mm at the apex, with  $2.14 \pm 1.38$  degrees of angulation in vitro. The in vivo deviations were  $1.45 \pm 0.81$  mm,  $1.62 \pm 0.90$  mm, and  $3.27 \pm 2.47$  degrees, respectively. This implant accuracy was similar to earlier reports: Previous studies indicated that with the application of surgical template, the average implant deviation is within 1.48 mm at the



**Fig 4** (a) Comparison of implant deviations between in vitro and in vivo experiments. For all seven parameters, in vivo deviations were statistically significantly greater than in vitro deviations. (b) Comparison of deviations between implants using tooth-supported and mucosa-supported templates. Of the seven parameters, horizontal deviation at the apex was statistically significantly greater when using a mucosa-supported template as opposed to a teeth-supported template. cda = central deviation at apex; cds = central deviation at shoulder; hda = horizontal deviation at apex; hds = horizontal deviation at shoulder; vda = vertical deviation at apex; vds = vertical deviation at shoulder; ad = angular deviation. \* $P < .05$ . \*\* $P < .01$ .



apex and 1.18 mm at the shoulder, with 4.21 degrees of angulation.<sup>15</sup> However, it is important to understand that deviations cannot be eliminated completely.

The maximum deviation might be more important as a factor to evaluate a surgical assisting tool. In the present study, the maximum in vivo angular deviation was as high as 9 degrees, which could only be compensated with an angled abutment, and resulted in nonaxial implant loading. In a systematic review on template-guided surgery,

a maximum angular deviation of 24.9 degrees was recorded,<sup>16</sup> which is quite unlikely for any trained oral surgeon. During guided surgery, the drills are directed mechanically by the template, and the operation field is covered by the template. As a result, errors could not be easily observed by the operator during surgery. Furthermore, as the template is fabricated preoperatively, intraoperative adjustment of the surgical protocol is nearly impossible. The benefits and difficulties with surgical templates should be

seriously considered before use. In accordance with earlier reports,<sup>17</sup> the accuracy in vitro was significantly greater than in vivo, which can be explained by better access, better visual control of the handpiece, and the absence of patient movement, saliva, and blood in vitro. More importantly, errors in vitro imply that implant deviation is inevitable with the present template-guided protocol, even though all conditions are well-controlled. Errors occur in each step of the procedure, from acquisition of CT and surface scan images

and data processing, stereolithographic surgical template production, intraoperative stability of the template, tolerance of the metal sleeve, to human errors during the surgery. CBCT is proven to be reliable for preoperative assessment, but an average linear error of 1.4% exists in CBCT mandibular measurements.<sup>18</sup> Digital impressions acquired with surface scanning showed better accuracy compared to conventional impressions, but a linear error of 0.17 mm was reported for full-arch measurements using an oral scanner.<sup>19</sup> Furthermore, the registration of both CBCT and oral scanning data in virtual planning generally requires some manual processing when selecting the starting points,<sup>20</sup> while a fully automatic approach could lead to a mean matching error of 2.3 mm.<sup>21</sup> In regard to template production, the manufacturer lists the 3D printer's accuracy as 0.2%, which equates to a minimal error of 0.2 mm in a 100-mm-long template.<sup>22</sup> Another important error source might be the microgap of the metal sleeve.<sup>23</sup> The metal sleeves provide mechanical drill guidance and determine the site, depth, and direction of the osteotomy. To ensure free rotation of the drills in the sleeve, the sleeve has to be slightly larger than the drills. The gap between the sleeve and drill increases due to mechanical wear of everyday use and eventually leads to angle deviation. The deviation could be exaggerated by combining other intrinsic and extrinsic errors of the guiding system. These technical errors are cumulative, iterative, and set the upper

limit of the accuracy level, as shown in the present study's *in vitro* analysis. Based on the actual oral condition of patients, surgical templates are designed as tooth-supported, mucosa-supported, bone-supported, or special-supported (mini implant or fixation pin). Clinical studies have shown that bone-supported templates have greatest inaccuracy compared with other modes of support. Mucosa-supported templates are used when the remaining teeth are too few to provide necessary stability and are mostly used in fully edentulous patients. The accuracy of mucosa-supported templates is related to the number of fixation pins used,<sup>24</sup> but it would be inconvenient for the surgeon to continuously check the implant preparation site when using fixation pins. The existing literature tend to support that there are no significant differences between mucosa- and tooth-supported templates regarding implant accuracy, measured as deviations in the apex, shoulder, and angulation.<sup>25</sup> In the present study, tooth- and mucosa-supported templates were used to treat edentulism. Statistically significant differences between the two template types was only found in horizontal deviation at the apex. These results suggest that the level of accuracy using a mucosa-supported template was comparable with a tooth-supported template if fixation pins were used properly.

Although improvements in implant accuracy were reported where template-guided surgery was applied, there is no decisive evidence indicating that template-guided

surgery is superior to conventional procedures in terms of safety, treatment outcomes, morbidity, and efficiency.<sup>13</sup> In the present study, acquisition and processing of the clinical data, preoperative planning, and template designing and manufacturing were performed in a digital fashion. For all outcome measurements, there were statistically significant deviations, and errors with potential clinical significance were noticed. Limited to the relatively small sample of this study, the accuracy-related results were not sufficient to confirm the positive effect of guided surgery on implant precision. The value of template-guided surgery should be investigated further with larger samples and additional long-term clinical evaluations.

## Conclusions

In the present study, implants were placed with the guidance of surgical templates fabricated with a digitalized protocol. The results revealed a significant deviation related to the surgical template both *in vitro* and *in vivo*. Within the limitation of the study design, inaccuracy existed in template-guided surgery. More studies are needed to verify the value of the procedure further.

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