Deviation of dental implants placed using a novel 3D-printed surgical guide: An in vitro study

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Abstract

Background. There is very little literature available on the reliability of the rapid prototyping technology in the production of three-dimension (3D)-printed surgical guides for accurate implant placement.

Objectives. The aim of the study was to evaluate the deviation of implant placement performed with a surgical guide fabricated by means of the rapid prototyping technique (the PolyJet™ technology).

Material and methods. Twenty sheep mandibles were used in the study. Pre-surgical cone-beam computed tomography (CBCT) scans were acquired for the mandibles by using the Kodak 9000 3D cone-beam system. Two implants with dimensions of 4 mm in diameter and 10 mm in length were virtually planned on the 3D models of each mandible by using the Mimics software, v. 16.0. Twenty surgical guides were designed and printed using the PolyJet technology. A total of 40 implants were placed using the surgical guides, 1 on each side of the mandible (2 implants per mandible). The post-surgical CBCT scans of the mandibles were performed and superimposed on the pre-surgical CBCT scans. The amount of deviation between the virtually planned placement and the actual implant placement was measured, and a descriptive analysis was done.

Results. The results showed that the mean deviation at the implant coronal position was 1.82 ±0.74 mm, the mean deviation at the implant apex was 1.54 ±0.88 mm, the mean depth deviation was 0.44 ±0.32 mm, and the mean angular deviation was 3.01 ±1.98°.

Conclusions. The deviation of dental implant placement performed with a 3D-printed surgical guide (the PolyJet technology) is within the acceptable 2-millimeter limit reported in the literature.

Key words: dental implant, 3D-printing, cone-beam computed tomography, computer-aided design/computer-aided manufacturing

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Introduction

Osseointegration is well-known and established as the key factor for success in implant dentistry,[1–3] but nowadays, the success of dental implants should also be determined by functional and esthetic restorative objectives.[4,5] The use of three-dimensionally (3D) guided implant placement is currently recommended to achieve these objectives and avoid surgical complications, such as unfavorable anatomical structures.[6,7]

In the 21st century, digitalization plays a role in all aspects of life. It also refers to the field of dentistry. In implantology particularly, precise implant placement has become more predictable with the development of technology and with the invention of cone-beam computed tomography (CBCT) imaging in conjunction with the 3D reconstruction of structures, the virtual planning of the implant and surgical guides constructed using stereolithography (SLA).[8,9]

Compared with the conventional computed tomography (CT), CBCT generates 6 times less radiation, enabling the acquisition of the 3D images of the soft and hard tissues of the patient with lower doses of radiation.[10–12] A CBCT scan is able to show objects in 3D as precisely as a CT scan and can help replicate the tissues accurately enough to plan surgical procedures.[13,14]

There are several software programs that permit virtual implant planning by using the 3D images of CBCT scans. A virtually planned implant can later be transferred to the patient; however, the accurate transfer of a virtually planned implant to the patient is the main concern.[8,15–17]

The positioning of a virtually planned implant in the patient's mouth can be performed using a surgical guide, which can be either constructed on a cast (the conventional manual method) or created virtually by means of computer software and a milling process with the SLA technology.[18] The PolyJet™ technology is an additive manufacturing process in which inkjet technologies are used to create physical models. The head of the inkjet moves along the X and Y axes, depositing the layers of the photopolymer, which are exposed to ultraviolet lamps for curing. The layer thickness produced in this process is 16 µm, which is considered high-resolution production.[19]

The aim of the present study was to evaluate deviations in implant placement performed using a surgical guide produced by the rapid prototype technique (the PolyJet technology).

Material and methods

A total of 20 sheep mandibles were collected from typical butcher shops and scanned using the Kodak 9000 3D cone-beam system (Carestream Health Inc., Rochester, USA). The setting of the CBCT machine was standardized at 70 kV, 120 mAs. The data was saved as DICOM files and sent to the Mimics software, v. 16 (Materialise NV, Leuven, Belgium). For each of the 20 scanned mandibles, 2 implants (Neobiotech Co., Ltd., Seoul, South Korea) – 4 mm in diameter and 10 mm in length – were virtually planned on the Mimics software 3D model of the mandible.

A total of 40 virtual implants were planned (Fig. 1). The data was transformed into STL files and sent to the Centre for Biomedical and Technology Integration (CBMTI) Sdn. Bhd, at the Institute of Postgraduate Studies (IPS) of the University of Malaya in Kuala Lumpur, Malaysia, to design and print surgical guides for each mandible by using the PolyJet technology (Solid Concepts Inc., Valencia, USA).

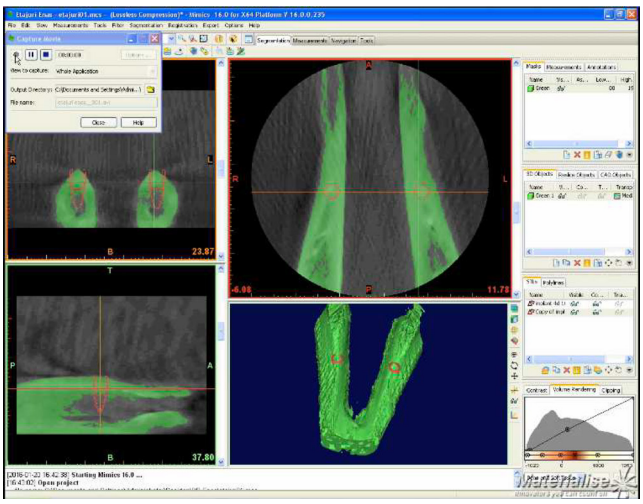

Fig. 1. Screenshot of virtual implant planning with the Mimics software

A total of 20 surgical guides were designed to accept a series of 5 stainless steel drill guides (sleeves) to accommodate 1.9-, 2.2-, 2.9-, 3.4-, and 4-millimeter twist drills. Each mandible sample was fixed on a plastic plate by using the ProBase® cold-cure acrylic resin (Ivoclar Vivadent Inc., Schaan, Liechtenstein) for drilling and scanning. Two implants were placed on the right and left sides of each mandible (Fig. 2).

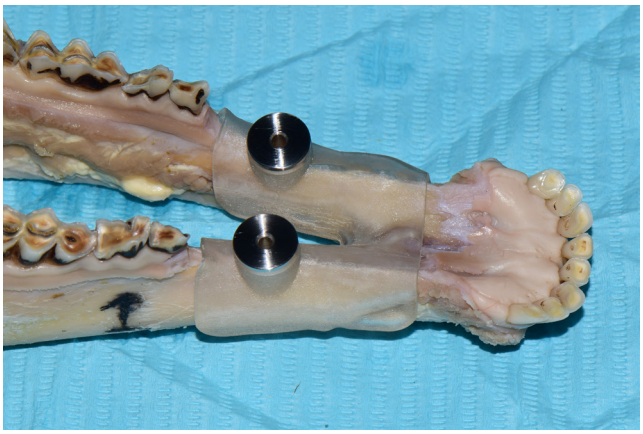

Fig. 2. 3D-printed surgical guide and the drilling guides fitted on a mandible

Post-surgical CBCT scans were taken, adhering to the same position and settings of the machine as those used to perform pre-surgical CBCT scans. The data was sent to the Mimics software. The pre- and post-surgical 3D models were superimposed (Fig. 3), and the implant deviations in the coronal, apex, depth, and angular positions were measured using the Mimics software. The data was collected and a descriptive statistical analysis was done using IBM SPSS Statistics for Windows, v. 24.0 (IBM Corp., Armonk, USA).

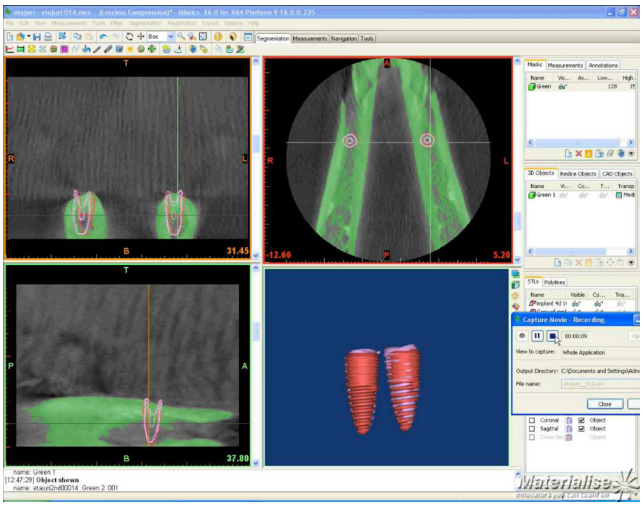

Fig. 3. Screenshot of the Mimics software showing the positions of the virtual and the placed implants after superimposing

Results

The implant deviation recorded at the coronal position ranged from 0.68 mm to 3.85 mm. The apex deviation ranged from 0.09 mm to 3.91 mm. The depth deviation ranged from 0.02 mm to 1.19 mm. The recorded angular deviation ranged from 0.38° to 6.72° (Table 1).

Table 1. Deviations of implant placement performed using a 3D-printed surgical guide

Deviation	Minimum	Maximum	*M*	*SD*
Coronal [mm]	0.68	3.85	1.82	0.74
Apex [mm]	0.09	3.91	1.54	0.88
Depth [mm]	0.02	1.19	0.44	0.32
Angular [°]	0.38	6.72	3.01	1.98

M – mean; *SD* – standard deviation.

Discussion

The average linear and angular deviations found in this study were within the clinically accepted limit, and are comparable to the previously published results.[20–23] Accordingly, it can be suggested that the use of the rapid prototype technology to produce virtually planned and designed surgical guides following virtual implant placement is a potentially promising technique that can assist surgeons in placing implants in more precise positions.

Unlike previous studies, which used cast models[24,25] or cadaver jaws,[26,27] this study used sheep mandibular bones to simulate in vivo the drilling of a natural bone. In addition, the sheep mandibular bone has an adequate height and a sufficient edentulous area between the anterior and posterior teeth.

For each mandible, the distance between the planned and the actually placed implant axis was measured at 4 points – the linear distance between the central axis at the platform and the apex, the angular deviation and the depth deviation – with the use of the Mimics software.[25,27]

The present study demonstrates the deviation of implant placement performed using a surgical guide (prototype) following 3D virtual planning. The results showed that the mean deviation at the implant platform was 1.82 ±0.74 mm, the mean deviation at the implant apex was 1.54 ±0.88 mm, the mean depth deviation was 0.44 ±0.32 mm, and the mean angular deviation was 3.01 ±1.98°.

In a previous in vivo study, the distance between the virtually planned implants and the implants placed using an SLA surgical guide was evaluated.[28] The results showed a mean deviation between the planned and the positioned implants of 1.45 ±1.42 mm at the implant platform, 2.99 ±1.77 mm at the apex and an angular deviation of 7.25 ±2.67°.[28] In comparison, our results showed smaller deviations between the planned and the positioned implants, with smaller standard deviations (*SD*s).

It seems that the implant deviation is influenced by the surgeon's experience. Our findings show slightly higher deviations than those presented by Noharet et al.[27] This is because in their study, an experienced surgeon placed all dental implants,[27] while in our study, an inexperienced clinician performed implant placement. This factor has been discussed in other studies, where it was found that the accuracy of implant placement is affected by the surgeon's experience.[29,30]

The implant deviations demonstrated in the present study were slightly higher than those in an in vitro study by Pettersson et al., in which 150 implants were placed in plastic models by using surgical guides designed according to virtual planning.[25] In their study, the implant deviation at the platform was 0.59 ±0.60 mm, with 0.73 ±0.73 mm at the apex, –0.51 to –0.52 mm in depth, where the actually placed implants did not reach the depth of the virtually planned implants, and the angular deviation of 0.61 ±1.27°. In that study, the surgical guide was designed with 3 anchor pins to stabilize it while drilling.[25] In contrast, the surgical guide in the current study was designed without any stabilizing pin, which might have had an effect on the stability of the guide during drilling, resulting in more implant deviations. Additionally, the diameters of the sleeves used in our study were bigger by about 0.2 mm than the drill diameters, which may have contributed to slightly higher deviations. Moreover, sheep mandibular bones are hard and stiff, requiring

more force during drilling than the plastic models used by Pettersson et al., which the authors said were easy to drill.[25] Thus, the model material could also have contributed to higher implant deviations in our study.

In a recent systematic review and meta-analysis of 2,238 implants placed using surgical guides, the mean linear coronal deviation was 1.04–1.44 mm and 1.28–1.58 mm at the apex, while the average angular deviation was 3.00–3.96°.[31] Therefore, the results of the present study did not differ much from the clinical situation.

Conclusions

Within the limitations of this study, it can be concluded that surgical guides produced using the rapid prototype technique (the PolyJet technology) can be applied to minimize the implant placement deviation. However, further clinical trials are suggested.

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