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ORIGINAL ARTICLE

Accuracy of templates for navigated implantation made by rapid prototyping with DICOM datasets of cone beam computer tomography (CBCT)

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Abstract The aim of this study is to evaluate the accuracy of a surgical template-aided implant placement produced by rapid prototyping using a DICOM dataset from cone beam computer tomography (CBCT). On the basis of CBCT scans (Sirona® Galileos), a total of ten models were produced using a rapid-prototyping three-dimensional printer. On the same patients, impressions were performed to compare fitting accuracy of both methods. From the models made by impression, templates were produced and accuracy was compared and analyzed with the rapid-prototyping model. Whereas templates made by conventional procedure had an excellent accuracy, the fitting accuracy of those produced by DICOM datasets was not sufficient. Deviations ranged between 2.0 and 3.5 mm, after modification of models between 1.4 and 3.1 mm. The findings of this study suggest that the accuracy of the low-dose Sirona Galileos® DICOM dataset seems to show a high deviation, which is not useable for accurate surgical transfer for example in implant surgery.

Keywords CBCT · DICOM · Dental implant · Rapid prototyping

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Introduction

Nowadays, dental implants are an important therapeutic option for edentulous as well as partially edentulous patients. Adverse conditions and difficult anatomical circumstances require absolute precision for implant surgery. Advanced imaging like cone beam computer tomography (CBCT) or conventional computer tomography (CT) are well established in enhancing planning and its surgical transfer to the patient [1]. In addition, exact analysis of important anatomic structures (e.g., mandibular nerve, maxillary sinus) as well as osseous characteristics like trabecular structure, density, and volume can be executed in an optimal way. Due to the implementation of CBCT [2], three-dimensional (3D) imaging has become widely used in dental practices. The main reason might be the significantly reduced radiation exposure of patients in CBCT compared with conventional CT [3–7], while diagnostic values seem to be similar in presurgical dental implant planning according to actual investigations [8]. Furthermore, computer programs are able to improve radiographic as well as prosthetic implant planning by using template-guided surgery. This gives the surgeon the opportunity to optimize specific parameters of implantation (e.g., length, angulations, position, and caliber) [9]. Different approaches for computer-assisted implant planning, both static and dynamic, exist [10, 11]. The static systems mostly require multiple preoperative steps: First of all, a radiographic template has to be assembled. After imaging the template in position, implants are planned with software assistance. Finally, a surgical guide is produced and implants are inserted. Dynamic surgical navigation systems with computer-assisted implant planning do not need preoperative template production, but they require higher resolution of imaging, e.g., high-resolution computer tomography, which has well-known disadvantages in higher levels of exposure radiation dose [12].

The aim of this study was to minimize these procedures and improve time efficiency and accuracy by printing a navigation splint. Therefore, a template of the same material and manufacturing process we habitually utilize in performing implant surgery was directly produced using the DICOM dataset without the intermediate step of impression. This step was substituted with the use of a 3D printer to access data from the CBCT.

Materials and methods

For this study, CBCTs with Sirona Galileos® (Sirona Dental Systems, Bensheim) of ten patients were performed. Scans were made at 21 mA s and 85-kV tube voltages. In order to avoid processing artifacts, in the first part of the study, patients without restoration or few restorations and no metallic prosthesis were chosen.

DICOM datasets were utilized to produce models with a 3D printer (Spectrum Z510; Company Z Corporation, Aachen, Germany) and the plaster powder ZP130 (Fig. 1a, b). The 3D print process produces workpieces in layers. The principle of 3D print is to distribute or print a liquid binder onto a loose plaster or cellulose powder bed. The print process is based on ink jet technology. A local solidification of the powder takes place. Thus, elements of one layer are generated and combined with the subjacent layer [13]. The accuracy requirements for anatomical models lie within a range of a tenth of a millimeter [14].

All of these patients received an alginate impression of the jaws to fabricate plaster models. From these models, templates were produced by using polycarbonate (Fig. 2).

In order to be able to compare the accuracy of 3D-manufactured models to those made conventionally, the templates were placed on the 3D models to measure possible imprecisions (Fig. 3a). Before placing the templates, they were charged with silicone of low viscosity (Xantopren® blue, Heraeus Kulzer, Hanau, Germany) to detect ill-fitting areas (Fig. 3b). Once the templates hardened, the templates were removed. The silicone was cut with a scalpel, and the thickness of sections was measured. After placing the templates on 3D models, contingent discrepancy was analyzed using a caliper gauge (Mitutoyo®, Japan) (Fig. 3c). Measurement was performed in three planes (Fig. 4).

Due to considerable discrepancies of the 3D models, the models were assessed as a source of error. As a possible factor, the same grayscale value from Sirona Galileos® for teeth and bone was detected. Thus, teeth were left out of the DICOM data and blocked on the base (Fig. 5), 3D models were refabricated and the templates repositioned. The measuring procedure was repeated as aforementioned.

Results

Ten patients (six males, four females) with a mean age of 29.9 (range, 19–46) years were included in the study. All patients with extensive dental restorations and/or disocclusion were excluded because of the radiographic artifacts.

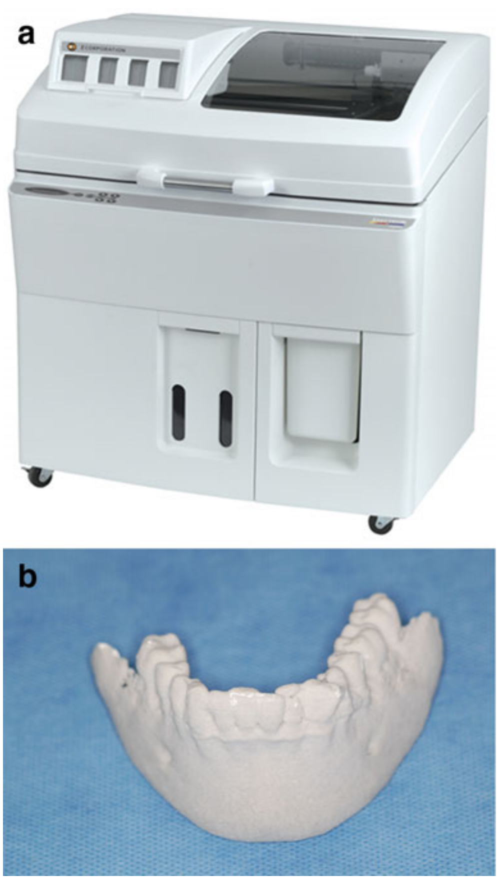

Fig. 1 a 3D printer Z 510 (Company Z Corporation, Aachen, Germany). **b** A 3D-printed model

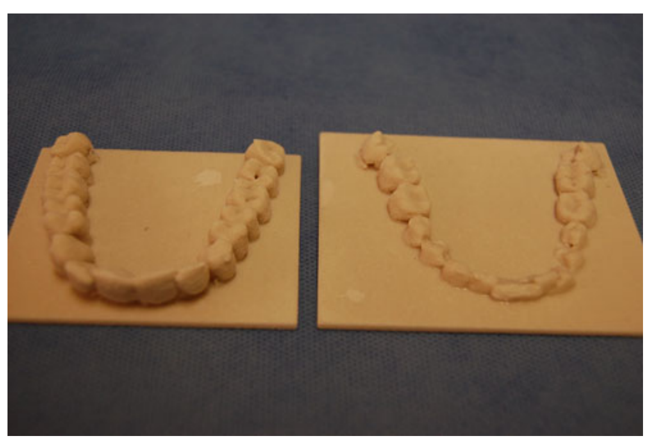

Fig. 2 The plaster models with polycarbonate templates

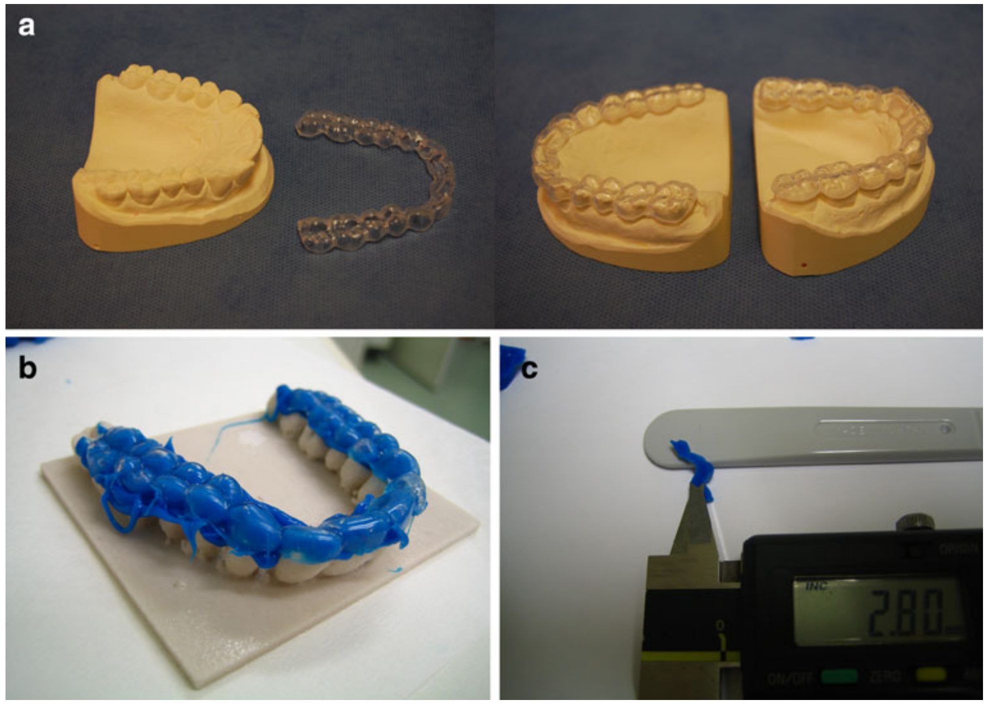

Fig. 3 **a** The placement of the templates on 3D-printed models. **b** Silicone template after positioning on models. **c** Exact measurement of discrepancy with caliper gauge

After first placing the templates and measuring deviations, major values were found in plane A with 2.69 mm (range, 2.0–3.5; SD 0.48 mm). Values of planes B and C were 0.83 (range, 0.3–1.2; SD 0.3 mm) and 0.18 (range, 0.1–0.3; SD 0.07 mm), respectively. Results are shown in Table 1. There was no correlation between age or sex of the patients and the deviations.

Due to imprecision of the 3D models, they were assessed as a source of error. As a possible factor, the same grayscale value from Sirona Galileos® for teeth and bone was detected. Thus, teeth were left out of DICOM data and blocked on the base (Fig. 5); 3D models were refabricated and the templates repositioned.

After leaving out the teeth from DICOM data and repeating the measurements, deviations were 2.32 (range, 1.4–3.1; SD 0.54 mm) in plane A, 0.63 (range, 0.2–0.8; SD 0.25 mm) in plane B, and 0.15 (range, 0.1–0.2; SD 0.05 mm) in plane C. Results are shown in Table 2.

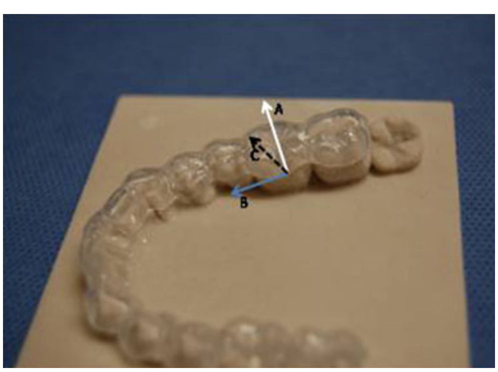

Fig. 4 Measurement in three planes

For both measurements, major values were found in plane A. For the 3D printer, inherent deviations between 0.3 and 0.4 mm are reported, which are dependent on which plane has been measured [13].

Discussion

In the clinical examination in most cases, it is not possible to estimate the bone quantity and quality due to soft-tissue profile. The patients have edentulous areas caused by, e.g., traumata, early tooth loss which causes atrophy.

Cone beam computer tomography is an important feature in preoperative planning for dental implant setting and an essential high-standard diagnostic tool, especially in difficult anatomical conditions of nerval structure or to assess the bone offer [15]. In addition, radiation exposure for patients is comparatively low and comparable to a threefold digital panoramic radiograph dose and less than a tenth of a similar field-of-view medical 64-slice CT scanner examination [6]. In order to estimate the height and width of the bone, a second or, even better, a third plane is required. In addition, affordability of CBCT equipment compared to conventional computed tomography encourages widespread use in dental practices [16–18].

In the last years, static navigation with use of drilling templates was used increasingly. This technique enables the dental surgeon to evaluate the exact implant position via backward planning, i.e., the planned tooth crown determines the position of the implant. For this purpose, three-dimensional imaging and plaster models based on jaw

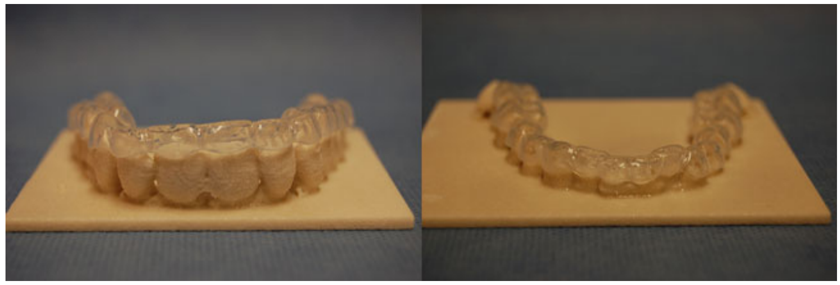

Fig. 5 The 3D-printed models with blocked basis

impressions are used to produce a surgical guidance sleeve template [19–21].

Rapid-prototyping systems like 3D printers are effective tools for quick product development [22]. Over the last few years, 3D printer technology has made significant contributions regarding print rates and print cost in rapid-prototyping procedures [23]. The increasing choice of available materials and the numerous finishing processes available for the produced parts greatly increases the range of the application areas for 3D printers [24, 25]. This is explicitly compounded by combining rapid prototyping with cone beam computed tomography [26, 27]. For some applications, it is important to keep the printed output as close as possible to the 3D computer model, for example, a close fit between produced parts or definite models of anatomic structures. The goal here is to print models with a high-contouring accuracy.

The intention of this study was to reduce treatment times and labor resource by formulating a different method for model fabrication. The template could be produced on machined models or even produced by direct fabrication, as recently described [20]. This could potentially allow for treatment times to be reduced. In addition, extraction of one of the planning steps may also elaborate on accuracy. Simultaneously, 3D image data for implant planning might avoid bone augmentation in certain situations by taking optimal advantage of the bone available [15].

Schneider et al. reviewed eight studies with 321 computer-guided template-based implant sites, where the overall mean error was 1.07 mm at the entry point and 1.63 mm at the apex [15]. As the deviation accumulates up to the apex, discrepancies in the apical region in this study could accumulate to 4 mm. If adjacent to important anatomical structures like the inferior alveolar nerve or the maxillary sinus, this could result in significant iatrogenic complications.

The results of this study showed intolerable imprecision of the templates fabricated by the 3D printer in planes A and B. While deviations in plane C might be borderline acceptable, those more than 1 mm are not. Four possibilities have to be considered as a cause for the high deviation:

(a) CBCT is not an adequate imaging modality for template-based implant planning with the standard dose. Which often does not come into consideration because CBCT is a well established and, in many cases, documented tool especially for this purpose [1, 20, 28, 29].
(b) Sirona Galileos® is not a suitable device. This cannot be regarded as a valid argument either, as accuracy of Galileos within the SICAT® study of Dreiseidler et al. [8] corresponds to the most favorable results for computer-aided surgery published so far, and the authors used the same scanning parameters used in this study.
(c) The 3D-printed parts do not correspond accurately to the data records. As there are deviations between 0.3 and 0.4 mm reported in the literature with the printer used in this study dependent on which plane has been measured [13], this might be one potential source of error. However, compared to the much higher deviation of the template, the printer cannot be solely responsible.

Table 1 Deviations of templates after placement on models

Age	Sex	A	B	C
30	m	3.1	1.0	0.3
32	m	2.0	0.3	0.1
19	f	2.8	0.8	0.2
25	m	2.2	0.3	0.1
21	f	2.4	0.7	0.1
35	f	2.6	1.0	0.2
42	m	3.2	1.1	0.2
31	m	3.5	1.2	0.3
46	f	2.1	0.8	0.1
18	m	3.0	1.1	0.2

Table 2 Deviations of templates after leaving out teeth and replacement on models

Age	Sex	A	B	C
30	m	2.8	0.8	0.2
32	m	1.4	0.2	0.1
19	f	2.4	0.6	0.2
25	m	1.9	0.2	0.1
21	f	2.0	0.5	0.1
35	f	2.1	0.8	0.2
42	m	3.0	0.8	0.1
31	m	3.1	0.9	0.2
46	f	1.8	0.6	0.1
18	m	2.7	0.9	0.2

(d) Since there is no particular cause for the high deviation, it seems to be an accumulation of slight discrepancies, which results in a significant aberration. There are different studies using CAD/CAM technologies for planning and performing implant surgery, especially in difficult anatomical situations with adequate accuracy [20, 21, 30, 31]. Advantages of this technique are computer-based presurgical planning, a minimally invasive flapless procedure, minimal postoperative disorders, rapid recovery, and the option for an immediate regain of occlusal function. On the other hand, errors in the fabrication process of templates, such as deformation of stereolithographically produced surgical guides, may lead to unfavorable clinical outcomes, as recently described [32]. Besides, too high expenditure of time and subsequent overspending have to be considered [26]. Additionally, present studies use multislice CT datasets for working with CAD/CAM technologies [20, 31, 33], which strongly limits the application as a matter of routine because of higher radiation exposure and lower availability in dental practice.

Conclusions

As our study demonstrates, assembling models by a 3D printer with plaster powder and the DICOM dataset of a Sirona® Galileos CBCT does not achieve adequate accuracy to fabricate templates as a navigation device for implantology. Further studies are necessary to find an accurate combination of imaging and rapid prototyping for preoperative planning of template-based implantology to improve and to reduce time for this procedure.

Conflict of interest The authors declare that they have no conflict of interest.

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