Research article

Accuracy of guided osteotomy using dental implant treatment-planning software in combination with an optical scan of a dental cast

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Abstract

Background and objectives. The advent of the mainstream use of diagnostic cone beam computed tomography (CBCT) and software-driven stereolithography (STL) for rapid prototyping of three-dimensional (3D) object models has achieved new levels of precision in dental implant treatment planning. The objective of this study was to assess the accuracy of using such software as a mode of capture to reproduce the optical scanning data to be used in STL surgical-guide fabrication.

Materials and Methods. We conducted an *in vitro* "case series" comprising 5 stone casts (made from impressions of partially edentulous patients) in which arbitrary holes were drilled to simulate implant osteotomies. These casts with the holes were optically scanned, and the scan data imported into an implant treatment-planning software package that was used to fabricate drill guides via rapid prototyping on a 3D printer. These guides were then used to drill a second smaller hole within each corresponding simulated osteotomy, and the discrepancies between the center points of superimposed holes were assessed by light microscopy and metrology software.

Results. The discrepancies at the implant entrance center points ranged from 0.09 to 0.23 mm; calculated angular discrepancies at the depth of the osteotomy relative to entrance-point centering were all < 1 mm (maximum = 0.73 mm) for a 16-mm implant depth.

Discussion and conclusions. These findings suggest a level of accuracy for the software, optical scan-generated data, and STL modeling that would yield clinically acceptable results.

Keywords. Cone beam computed tomography, dental implants, osteotomy, software, three-dimensional printing.

1. Introduction

The combination of treatment planning software with optical scanning is an interesting evolution of the implant placement planning. The precision of these techniques, both at the surgical **[1]** and prosthetic steps **[2]**, needs always to be investigated, to validate any new approach and clinical application. This pilot study was designed to identify the accuracy of making a guided osteotomy by using a treatment planning software program in combination with an optical scan of a dental cast in the process of three-dimensional (3D) rapid prototyping of a surgical guide via stereolithography (STL).

A number of recent systematic reviews have analyzed studies that used cone beam computed tomography (CBCT) systems and, in some cases, optical tracking devices **[1]**, with respect to achievement of high implant survival rates comparable to those of conventionally placed implants (91-100%)**[1]**, in addition to a 96.6% overall mean survival rate over 1 year **[3]**. An additional review by Neugebauer et al. **[4]** suggested that intraoperative optical tracking systems offer greater accuracy than surgical guide systems. Jung et al. pointed out the need to consider the radiation exposure required for CBCT **[3]**.

Van der Zel **[5]** recently reviewed a combined scanning protocol that incorporates optical scanning of casts, guides and occlusal registrations that are geometrically matched to CBCT data, resulting in a higher level of accuracy in an STL-produced surgical guide than via use of CBCT data alone. The author noted that such combined technology affords greater control over not only implant placement, but over prosthesis design as well **[5]**. So, while there appears to be some movement in the direction of incorporating data from optical scans into the 3D treatment-planning process with the goal of improving accuracy of implant placement, data are scarce in regard to optical scanning as a supplementary modality in implant treatment planning.

The current study was designed to evaluate a laboratory method of obtaining a more precise assessment of the accuracy of execution of an osteotomy, based on a data set obtained with an optical scan, and verified by data from measurements obtained from stereolithographic (STL) surgical guides that were produced for experimental osteotomies using the treatment-planning software.

2. Materials and Methods

Impressions were made from 5 partially edentulous patients and used to produce dental stone casts. In each edentulous area, an arbitrary hole approximately 5 mm in diameter and 3 mm in depth was drilled, for a total of 9 experimental osteotomy sites. The casts were then optically scanned using the 3Shape D800 scanner (3Shape A/S, Copenhagen, Denmark). The scan files where then imported into the Blue Sky Plan program (version 2.19) Blue Sky Bio, LLC, Grayslake, IL, USA), and osteotomies were planned in the software to be exactly in the centers of the arbitrary osteotomies in the casts.

Drill guides were then printed using an Objet model 250 3D printer (Stratasys Ltd., Edina, MN, USA) to fabricate the guides from Med610 biocompatible resin (Stratasys Ltd., Edina, MN, USA), in an STL-based rapid prototyping technique. Titanium sleeves (iDent, Ft. Lauderdale, FL, USA) were inserted in the printed guides. These guides were then used to drill a second set of osteotomies of smaller diameter, one within each larger arbitrary osteotomy. At completion, each edentulous site had a larger arbitrary osteotomy, and a smaller osteotomy within it that was created using an optical scan-generated STL-printed guide.

The casts were then mounted on a paralleling table, and each site was aligned under a digital microscope camera in such a way that the long axes of the holes were in line with the optical axis of the microscope.

The images were analyzed with an edge-detecting metrology (field-of-view) software (ZView DMP2000, ZView Inc., Huntington Beach, CA, USA). The observed alignments of the center points of the arbitrary and the guided holes were reproduced in this software, and the

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discrepancies between the center points of the larger and smaller holes at the entrance point of each site were calculated using the software.

In addition, the angular discrepancy was calculated by extrapolating the maximum deviation at different depths using the following formula:

$$(\sin A * \text{depth}) = \text{discrepancy at that depth}$$

where A is the acute angle formed by the treatment-planned long axis of the osteotomy and depth represents the length of the deviated long axis that passes through the smaller hole drilled using the surgical guide.

3. Results

The discrepancies between the entrance points of the arbitrary osteotomies and the actual osteotomies made with a surgical guide ranged from 0.09 and 0.23 mm with a mean of 0.162 mm.

Table 1 summarizes the distances in mm from the center points of these circles that represent the diameters of the superimposed larger and smaller holes. The largest discrepancy between larger- and smaller-hole center points was 0.23 mm (230 µm). **Table 2** lists the calculated values for the discrepancies in angulation between the software-produced STL guides and the optically-scanned long axes at the 9 osteotomy sites.

	Site 1	Site 2	Site 3	Site 4	Intra-case mean	Intra-case median	Intra-case SD
Case 1	0.15				N/A		N/A
Case 2	0.21	0.23	0.19	0.22	0.2125	0.215	0.0171
Case 3	0.12	0.14			0.13	0.13	0.0141
Case 4	0.09				N/A		N/A
Case 5	0.11				N/A		N/A
Site mean	0.136	0.185	N/A	N/A			
Site median	0.12	0.185	N/A	N/A			
Site SD	0.0467	0.064	N/A	N/A			
					Total Osteotomies (N=9)		
					Mean	0.162	
					Median	0.15	
					SD	0.052	

Site 1-Site 4, arbitrary osteotomy drilled in dental cast; SD, standard deviation.

Table 1. Observed discrepancies between center points of simulated osteotomies and secondary holes drilled within them using surgical guides fabricated with treatment-planning software and 3D rapid-prototyping.

Depth of osteotomy (mm)	Discrepancy (mm)*
8.0	0.47
10.0	0.53
11.5	0.58
13.0	0.63
16.0	0.73

* Discrepancy calculated by the formula: (sin A × depth), where A is the acute angle formed by the treatment-planned and surgical guide-generated long axes, and depth (deviated and longer of the 2 axes) is represented by the hypotenuse (side h) of a right triangle formed by extrapolating the acute angle (angle A) between these two axes. Discrepancy is represented by side a, shortest side of triangle (see Figure 1).

Table 2. Calculated discrepancies at various depths, based on osteotomy entrance center-point data.

In addition, we attempted to extrapolate from the observed data the maximal discrepancy at the tips of osteotomies of different depths, not just at the entrance point. To assess what might approximate a worst-case scenario, the osteotomy with the largest discrepancy was selected.

The height of the surgical guide was measured to be 6 mm. The assumption was made that the hole in the guide was properly positioned, and the discrepancy was the result of a skewing of the angle of the osteotomy from the experimentally-determined ("ideal" or "treatment-planned") long axis. Such a deviation in parallelism from the planned path would likely produce the greatest drilling inaccuracy, and concomitant risk. Based on this assumption, the angle for the hole with the largest discrepancy would be approximately 2 degrees. At the largest calculated angle, the greatest discrepancy was 0.73 mm, at the tip of a projected 16-mm osteotomy; most of the inaccuracy resides at entrance point **(Table 2)**.

Figure 1 illustrates the trigonometric angular relationship between the ideal and deviated long axes at an extrapolated osteotomy depth (corresponding to an implant fixture length of 16 mm) to calculate the maximum observed discrepancy (0.73 mm), using the formula given above. The sine of angle A multiplied by the depth of the guide-deviated osteotomy path (16 mm) gives the length of side b (BC), or the discrepancy at that depth **(Figure 1)**.

Figures 2 and 3 show photographs with measurement outputs from microscopic alignment of the larger and smaller osteotomy holes in the cast of one case (Case #1), delineated by circles and lines representing diameters and center points of each.

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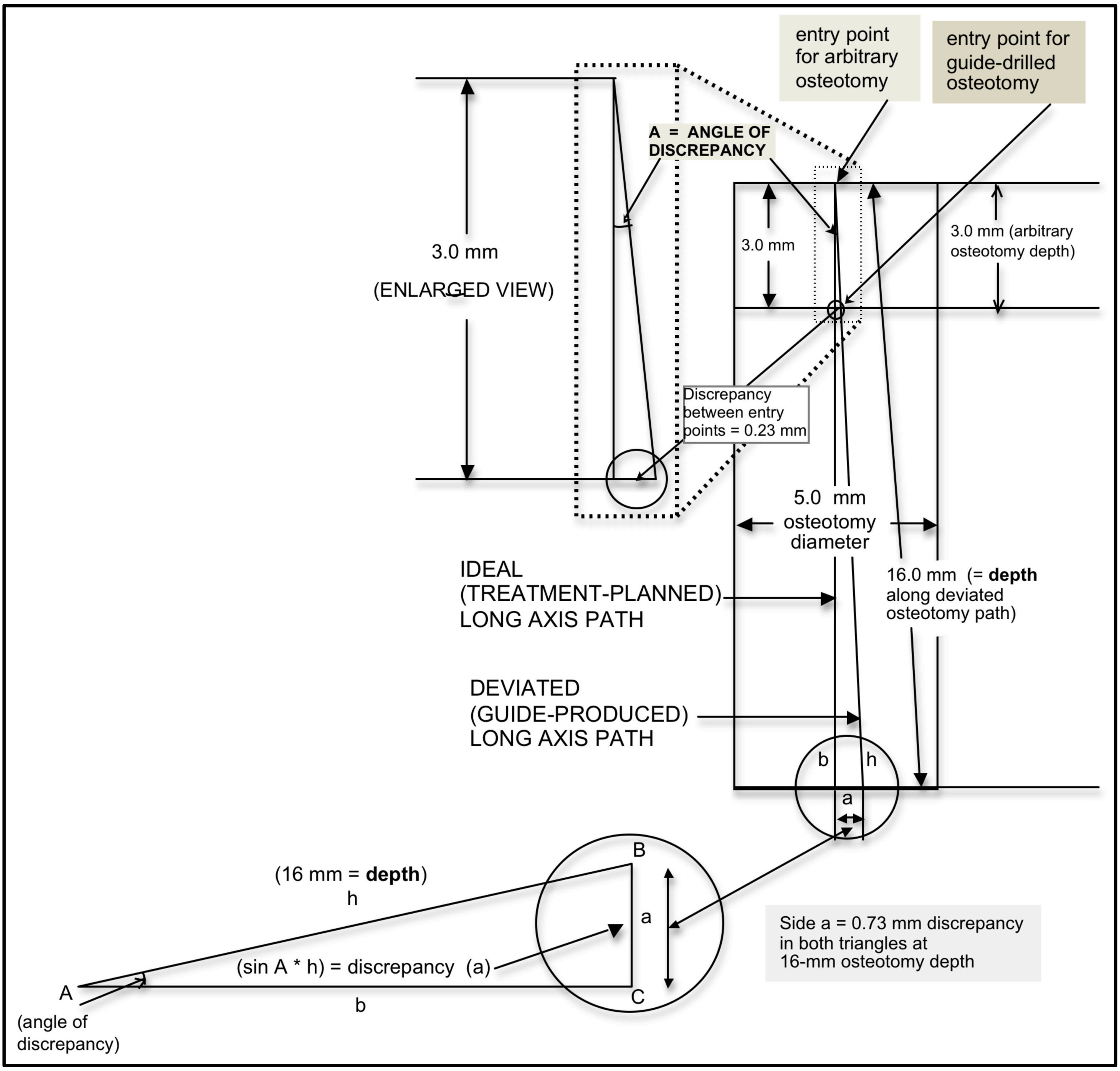

Figure 1. Angular relationship between treatment-planned and deviated osteotomy long axes at the maximum extrapolated osteotomy depth (16 mm to the implant tip) to calculate the maximum observed discrepancy (0.73 mm), using the formula (sin A * deviated osteotomy depth) = discrepancy expected at that extrapolated depth (side a; see Table 2).

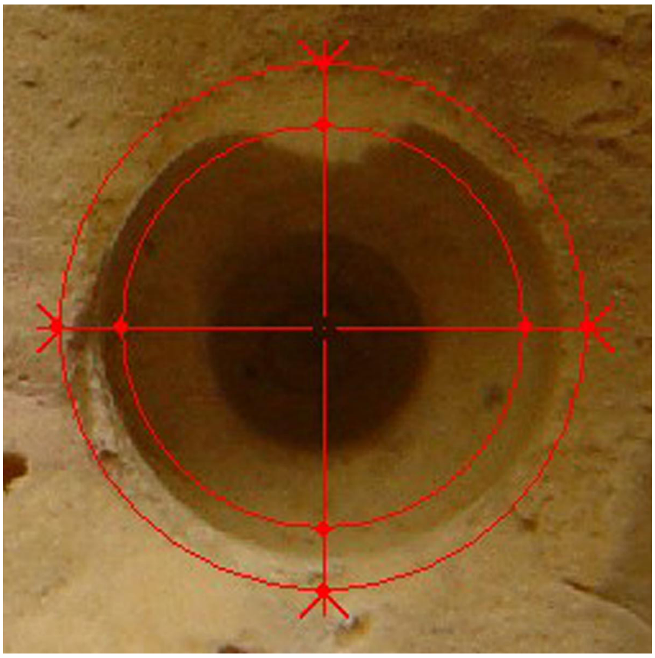

Figure 2. Dental stone cast with metrology software markings showing center of arbitrary osteotomy (larger hole). Comparison with hole drilled using guide printed from treatment-planning software reflects discrepancy between centers of this hole and larger (arbitrary) osteotomy.

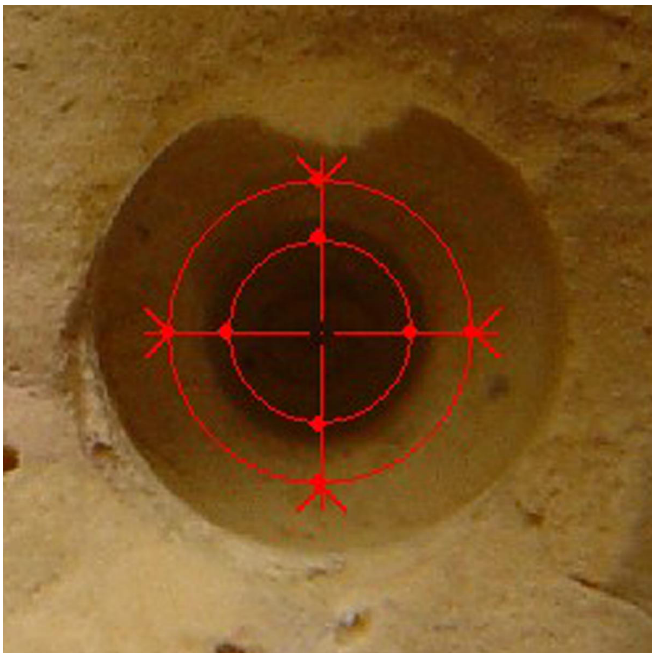

Figure 3. Dental stone cast with metrology software markings showing center of hole drilled using guide printed from treatment-planning software (smaller hole). Comparison with larger (arbitrary) osteotomy reflects discrepancy between centers of this hole and smaller hole (drilled with software-printed guide).

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4. Discussion

To our knowledge, this pilot study is the first assessment of the accuracy of implant treatment-planning software used to reproduce the entrance center point of a modeled osteotomy based solely on an optical scan.

Based on these *in vitro* observations (and extrapolations made from them), the observed maximum discrepancy of 230 μm in the placement of an osteotomy entrance point translated to a maximum discrepancy of less than 1 mm (0.73 mm) at an extrapolated osteotomy depth of 16 mm. The actual expected deviation is probably less, because the entrance of the hole in the guide will probably also shift in the direction of the discrepancy. If that is the case, the angular discrepancy would be less, resulting in a smaller deviation of the executed apical area of the osteotomy from the treatment-planned path.

To our knowledge, this is the first quantitative assessment of discrepancies between observed osteotomy dimension and the recreation thereof via software-driven rapid prototyping. Using a somewhat similar design, a study published in 2003 by Sarment et al. **[6]** used CBCT measurements to compare accuracies of conventional versus STL surgical guides, which were used by five different surgeons to prepare implant osteotomies on epoxy mandibular models. For the conventional (control) surgical guides, they reported a distance between planned and actual osteotomy of 1.5 mm at the entrance point and 2.1 mm at the apex. When the STL (test) guide was used, they observed a reduction in these measurements to 0.9 mm and 1.0 mm, respectively. Reduced variations were also observed within surgeons and between surgeons, for the stereolithographic guide **[6]**. While similarly small discrepancy values were observed with STL guides in both studies, variables assessed in that study and ours - while instructive - are difficult to compare because of dissimilarities in study design. While that study assessed the basic concept of rapid prototyping as offering an advantage over conventional surgical guides, our study assessed the reproducibility of measurement precision strictly within the scenario of STL guides, afforded by the specific software we tested.

Data from studies in minipigs suggested that typical treatment planning should maintain an interimplant distance of at least 1.5-2 mm **[7,8]**. For clinical treatment planning in the esthetic zone, Tarnow et al. recommended maintaining 3 mm between implants **[9]**. If these guidelines are followed in the treatment-planning process, such minimal angulation discrepancies would probably be well within a clinically acceptable range **(Table 2)**. Taken together, these findings suggest a relatively high level of accuracy for the software used to produce the guides, as well as for the STL rapid-prototyping process itself.

For the most accurate data capture possible, one can easily envision intraoral optical scanning at the osteotomy level as a means for obtaining precise geometric parameters for actual implant placement. Impracticalities associated with obtaining such measurements in the surgical setting are equally easy to envision. Alternatively, fabrication of an STL guide and using it to place the implant could be followed by an optical scan of the completed implant and cover screw (or a longer screw seated in the implant's internal threads to extend the measurable axis and angulation), which could then be superimposed on the software-derived plan. Data from the two modalities could then be compared.

Other alternatives to direct intraoral scanning to reproduce or recreate the angulations of the osteotomy could use laboratory casts with the implant analogs attached. This would involve creating a pre-treatment cast, drilling a simulated osteotomy as in the current study, and making the second hole inside it, followed by fabrication of a post-

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placement cast of the implant with its analog attached. A laboratory scanner could then be used to superimpose the inserted implant-analog position with the original optically scanned cast, to assess the accuracy captured by the treatment-planning software.

Based on such hypotheses, some reproducible modality to compare clinically the predicted angulation with actual positioning of the implant is a viable next step. The clinical implications of these findings will need to be assessed by using this technique as guidance for the actual placement of implants - importantly - in combination with CBCT scanning, in situations presenting a variety of clinical and/or anatomic variables arising from assessing both modalities together.

5. Conclusion

The maximum discrepancy between cast intra-osteotomy center points at the implant entrance was 0.23 mm (230 µm), suggesting that the secondary hole drilled with the software-produced surgical guide was accurate. Calculated discrepancies at the implant tip relative to the entrance-point centering were all less than 1 mm, even at a maximum implant length of 16 mm and at an angle of 2 degrees.

Using an optical scan of a cast to generate data for importation to treatment-planning software is a highly accurate technique for creating a surgical guide. This method could be used in conjunction with CBCT to produce clinically acceptable results in regard to alignment of the osteotomy entrance point. Combining CBCT with optical scan data in subsequent studies will be essential to verify optimized fit of the surgical guide, and any consequently observed clinical improvement in drilling precision.

The primary limitation of this pilot study is that only the entrance point of the osteotomy was evaluated, and that measurements of discrepancies at the implant tip - and thus, the implant axis angulations - were obtained by extrapolation. Such discrepancy values might be tested by optical scanning of experimental osteotomies drilled at greater depths, corresponding to actual implant fixture lengths. Further studies are necessary to evaluate the accuracy of implant axis angulation relative to osteotomy depth, with the objective of developing a safe and standardized clinical protocol for actual implant placement using this approach.

Disclosure of interests

The authors have no conflict of interest to report.

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