Int J Clin Exp Med 2015;8(6):8442-8449
www.ijcem.com /ISSN:1940-5901/IJCEM0007993

Original Article

Accuracy of different types of computer-aided design/ computer-aided manufacturing surgical guides for dental implant placement

Wei Geng[1,2], Changying Liu[2], Yucheng Su[3], Jun Li[2], Yanmin Zhou[1]

[1]*Department of Dental Implantology Centre, Stomatology Hospital of Jilin University, Changchun 130021, Jilin Province, China;* [2]*Department of Dental Implantology Centre, School of Stomatology, Capital Medical University, Beijing 100050, China;* [3]*Department of Dental Implantology of Peking Union Medical College Hospital, Beijing 100032, China*

Received March 14, 2015; Accepted May 20, 2015; Epub June 15, 2015; Published June 30, 2015

Abstract: Purpose: To evaluate the clinical outcomes of implants placed using different types of computer-aided design/computer-aided manufacturing (CAD/CAM) surgical guides, including partially guided and totally guided templates, and determine the accuracy of these guides Materials and methods: In total, 111 implants were placed in 24 patients using CAD/CAM surgical guides. After implant insertion, the positions and angulations of the placed implants relative to those of the planned ones were determined using special software that matched pre- and post-operative computed tomography (CT) images, and deviations were calculated and compared between the different guides and templates. Results: The mean angular deviations were 1.72 ± 1.67 and 2.71 ± 2.58, the mean deviations in position at the neck were 0.27 ± 0.24 and 0.69 ± 0.66 mm, the mean deviations in position at the apex were 0.37 ± 0.35 and 0.94 ± 0.75 mm, and the mean depth deviations were 0.32 ± 0.32 and 0.51 ± 0.48 mm with tooth- and mucosa-supported stereolithographic guides, respectively ($P < .05$ for all). The mean distance deviations when partially guided (29 implants) and totally guided templates (30 implants) were used were 0.54 ± 0.50 mm and 0.89 ± 0.78 mm, respectively, at the neck and 1.10 ± 0.85 mm and 0.81 ± 0.64 mm, respectively, at the apex, with corresponding mean angular deviations of 2.56 ± 2.23° and 2.90 ± 3.0° ($P > .05$ for all). Conclusions: Tooth-supported surgical guides may be more accurate than mucosa-supported guides, while both partially and totally guided templates can simplify surgery and aid in optimal implant placement.

Keywords: Dental implant, surgical guide, computer-aided design/computer-aided manufacturing, osseointegration, tooth-supported guide, mucosa-supported guide

Introduction

The number of patients that demand fixed implant-supported prostheses has increased considerably in the past few years [1]. Osseointegration of dental implants is the most important requirement for implant-supported restorations, while optimal implant placement is critical to the esthetic and functional success of such restorations. Unfavorable implant insertion may result in adverse effects on osseointegration, long-term predictability, success, and esthetic outcomes of prostheses. Presurgical planning is essential to achieve excellent esthetic and functional outcomes with dental implants. Several factors such as the mandibular canal, maxillary sinus, and adjacent teeth need to be considered before implant surgery. Practitioners have generally used conventional dental radiographs (panoramic and periapical) [2] and conventionally fabricated surgical guides [3, 4] for implant placement. Surgical guides conventionally fabricated on diagnostic stone casts do not provide information about the varying thicknesses of the mucosa, topography of the underlying bone, or anatomical structures; furthermore, they do not remain stable during surgery. Of late, computed tomography (CT) has been introduced for presurgical implant planning. Practitioners can now simulate ideal implant placement and treatment planning, including assessment of the precise dimensions of the implant, ideal depth, and angulation, using CT scans. In addition, pros-

Table 1. Patient and treatment characteristics

	Mean	Total	Number of guides	Number of implants
Age	41.6			
Number of implants		111		
Number of subjects		24	28	111
Gender				
Male		13	16	68
Female		11	12	43
Type of edentulism				
Complete			15	59
Partial			13	52
Arch				
Maxilla			16	69
Mandible			12	42
Surgical guide support				
Mucosa			15	59
Tooth			13	52
Type of template				
Partially guided			6	29
Totally guided			9	30

thetically directed implant placement using computer software can ensure precise placement and predictable prosthetic outcomes, with the literature reporting the use of computer-aided design/computer-aided manufacturing (CAD/CAM) stereolithographic (SLA) surgical guides, which offer a significant advantage to the surgeon by improving precision and minimizing complications such as mandibular nerve damage, sinus perforation, fenestrations, and dehiscences [5, 6].

The accuracy of implant placement with the use of tooth-supported surgical guides is reportedly superior to that with the use of bone- and mucosa-supported guides [6, 7]. However, few studies have reported about the accuracy of partially guided and totally guided templates.

The aim of the present study was to evaluate the clinical outcomes of implants placed using different types of CAD/CAM surgical guides, including partially guided and totally guided templates, and to determine the accuracy of the different guides.

Materials and methods

The study protocol was approved by the ethical committee of the Capital Medical University.

In total, 24 patients (13 men and 11 women; mean age, 41.6 ± 15.2 years; range, 25-65 years) with missing teeth or edentulous jaws who provided voluntary consent to undergo dental implant treatment were recruited from the Department of Dental Implantology, Centre of Beijing Stomatological Hospital (**Table 1**). Uncooperative patients, those with systemic diseases such as uncontrolled diabetes, those with a history of radiation to the head and neck region, those who required bone grafting at the implant recipient site because of a compromised bone volume, and those with restricted mouth opening that would compromise surgery were excluded.

The procedure followed for each patient is described below.

First, a radiopaque diagnostic template or a template of the patient's existing dentures (partial or total) was fabricated to understand the patient's esthetic and functional requirements.

Second, a CT scan of the patient's arch was obtained using a cone beam CT device (Quantitative Radiology, Verona, Italy). The radiopaque diagnostic template was used during CT imaging.

Third, digital three-dimensional (3D) CT-based surgical planning was undertaken. The computer program Simplant® uses the original CT data in the Digital Imaging and Communications in Medicine (DICOM) format to produce axial, 3D, panoramic, and cross-sectional images, all of which are visible at the same time in four interactive windows on a computer monitor (**Figure 1**). With this software, implants are virtually placed according to the bone anatomy and prosthetic design.

Fourth, CAD of the surgical guide was undertaken (**Figure 2**), where the clinician designed the drilling template in a CAD environment, followed by CAM of the surgical guide to transfer the digital plan to the surgical environment.

Fifth, computer-aided surgery was completed. All surgeries were performed under local anesthesia using primacaine. Two different types of surgical guides, namely tooth-supported and mucosa-supported guides, were used during implant placement. A total of 111 implants (Straumann, Swiss) were placed using flapless surgery (**Figure 3**).

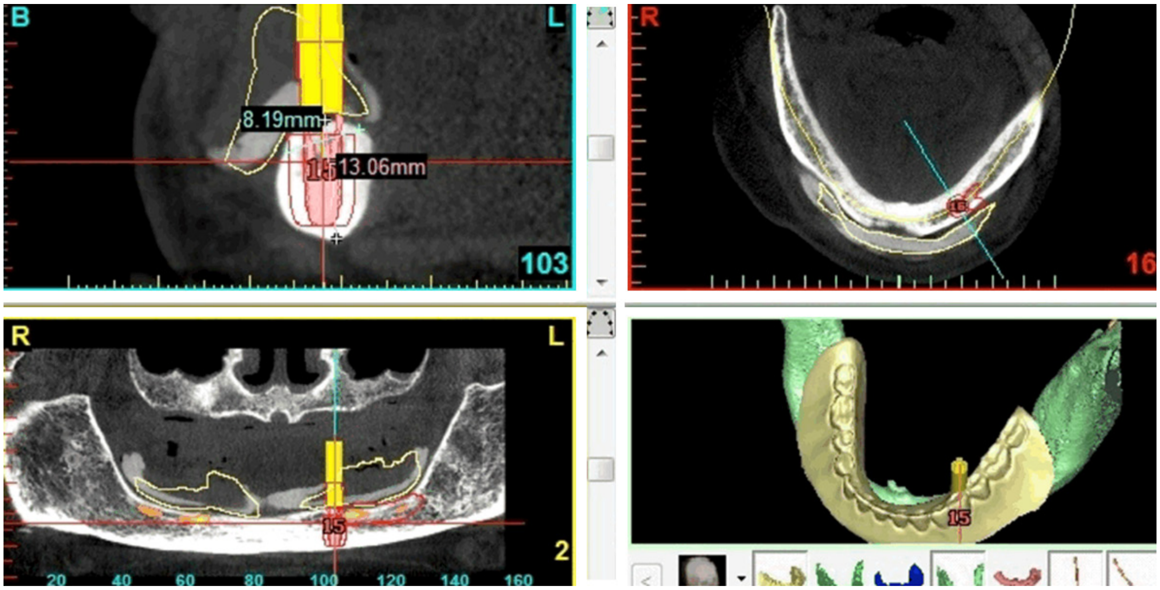

Figure 1. Treatment planning and implant selection using a computer program (Simplant®) and cone beam computed tomography (CBCT) scans.

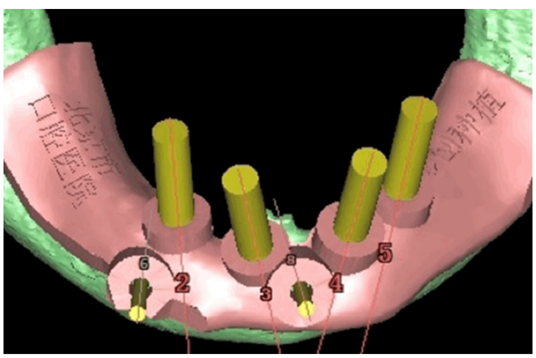

Figure 2. Computer-aided design of the surgical guide.

Figure 3. Surgery is completed using the computed-aided design/computer-aided manufacturing (CAD/CAM) surgical guide.

The sixth step included postoperative CT and matching. Postoperative CT was performed using the same preoperative CT parameters. The Simplant® software, which matched the pre- and postoperative CT images, was used to compare the locations and axes of the planned and placed implants (**Figure 4**).

Measurement methods

For each planned and placed implant, two points were located (x, y, and z co-ordinates) on their long axes. The first was at the center of the most coronal portion (neck) of the implant and the second was at the center of the apex of the implant. The position and angulation of the placed implant relative to those of the planned implant were determined, with deviations calculated by measuring the distance between the centers of the planned and placed implants and the angle between the long axes of the planned and placed implants, respectively (**Figure 5**).

Statistical analysis

Data were evaluated using SPSS software (Statistical Package for Social Science, IBM Corporation, NY, USA). The quantitative data for each group are expressed as mean values with standard deviations. The Kolmogorov-Mirnov test showed that the data were nonparametrically distributed. An independent-samples

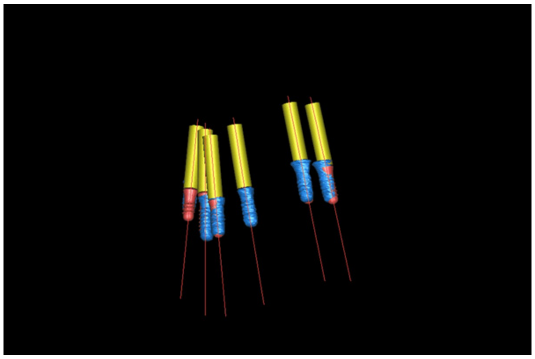

Figure 4. Matching procedure using Simplant® software. The planned implants are shown in red and the placed implants are shown in blue.

t-test was used for comparisons between the planned and placed implants in terms of the angular deviations and deviations in position at the neck and apex. All tests were two-tailed, and a *P*-value of < .05 was considered statistically significant.

Results

In total, the 111 implants were placed without any complications. Of these, 52 were placed using tooth-supported surgical guides for partially edentulous patients and 59 were placed using mucosa-supported guides for completely edentulous patients (**Table 1**).

The mean angular deviations of the placed implants were 1.72 ± 1.67 and 2.71 ± 2.58 with the tooth-supported and mucosa-supported SLA surgical guides, respectively, while the mean deviations in position were 0.27 ± 0.24 mm and 0.69 ± 0.66 mm at the neck and 0.37 ± 0.35 mm and 0.94 ± 0.75 mm at the apex, respectively. The mean depth deviations were 0.32 ± 0.32 mm with the tooth-supported guide and 0.51 ± 0.48 mm with the mucosa-supported guide. All these values were significantly different (*P* < .05) between the tooth-supported and mucosa-supported surgical guides (**Table 2**).

The mean deviations in position were 0.54 ± 0.50 mm at the neck and 0.81 ± 0.64 mm at the apex for the 29 implants placed using a partially guided template, with a mean angular deviation of 2.56 ± 2.23. The corresponding values for the 30 implants placed using a totally guided template were 0.89 ± 0.78 mm, 1.10

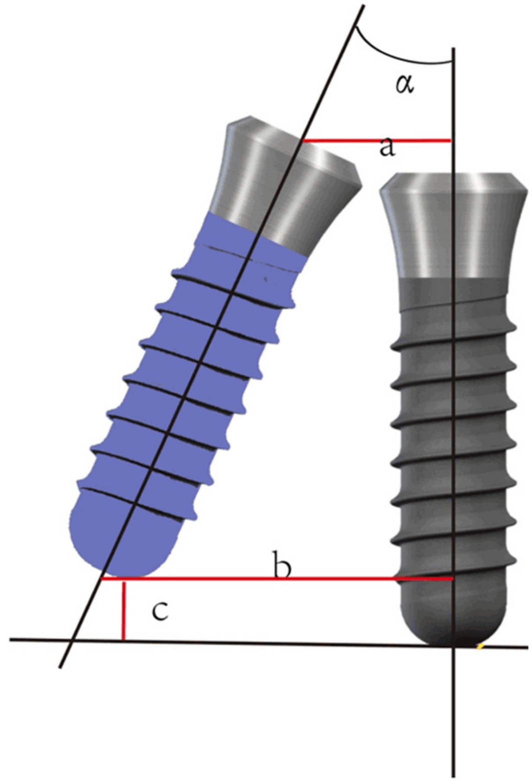

Figure 5. Matching procedure between planned (gray) and placed (blue) implants. α represents the angular deviation of the axis of the placed implant relative to the axis of the planned implant. a is the distance between the planned and placed implant at the neck; b is the distance between the planned and placed implant at the apex; and c is the deviation in depth of the placed implant relative to the depth of the planned implant.

± 0.85 mm, and 2.90 ± 3.0°, respectively. There were no significant differences (P > .05) in any parameter between the two templates (**Table 3**).

Discussion

Two different techniques have been developed for computer-aided surgery [8], which can be performed using a static surgical template that reproduces the virtual implant position directly from CT data and does not allow for intraoperative modification of the implant position or a surgical navigation system (dynamic guide) that reproduces the virtual implant position directly from CT data and allows for intraoperative changes in implant position [9]. CAD/CAM surgical guides allow the clinician to satisfy both functional and esthetic demands and ensure precise placement and predictable prosthetic outcomes.

Table 2. Deviations with mucosa- and tooth-supported guides

Surgical guide support	Number of implants	Angular deviation (mm, M ± SD)	Deviation at neck (mm, M ± SD)	Deviation at apex (mm, M ± SD)	Depth deviation (mm, M ± SD)
Mucosa-supported	59	2.71 ± 2.58	0.69 ± 0.66	0.94 ± 0.75	0.51 ± 0.48
Tooth-supported	52	1.72 ± 1.67	0.27 ± 0.24	0.37 ± 0.35	0.32 ± 0.32
P-value		0.046*	0.003*	0.001*	0.045*

*$P < .05$; M ± SD, mean ± standard deviation.

Table 3. Deviations with partially and totally guided templates

Type of template	Number of implants	Angular deviation (mm, M ± SD)	Deviation at neck (mm, M ± SD)	Deviation at apex (mm, M ± SD)	Depth deviation (mm, M ± SD)
Partially guided	29	2.56 ± 2.23	0.54 ± 0.50	0.81 ± 0.64	0.31 ± 0.72
Totally guided	30	2.9 ± 3.0	0.89 ± 0.78	1.10 ± 0.85	0.24 ± 0.54
P-value		0.645	0.073	0.162	0.669

M ± SD, mean ± standard deviation.

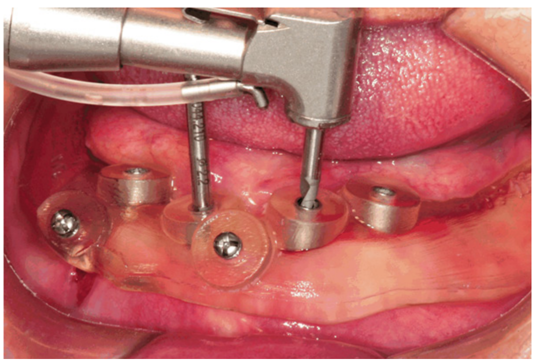

Figure 6. The partially guided surgical template is often designed with a single pilot drill guide.

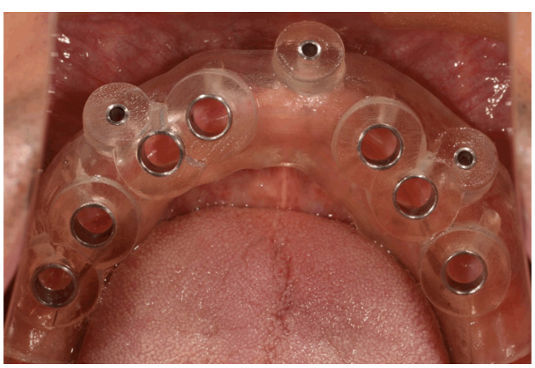

Figure 7. The totally guided surgical template is designed and used for osteotomy site preparation and implant delivery. Osteotomy sites are prepared using sequential, removable surgical drilling guides.

Figure 8. A tooth-supported surgical guide is seated and stabilized with the help of natural teeth.

CAD/CAM surgical guides include a partially guided template (**Figure 6**), whereby only the osteotomy site is prepared using a pilot drill guide, and a totally guided template (**Figure 7**), whereby one guide is used for osteotomy site preparation as well as implant delivery. Osteotomy sites are prepared using sequential, removable surgical drilling guides (generated using computer software and through the process of SLA) [10]. Because the use of surgical templates may affect cooling during osteotomy, partially guided surgical templates are often designed with a single pilot drill guide to avoid bone burns. Moreover, because surgery using a surgical template is often compromised by the size of the patient's mouth opening, a single drill guide can make preparation easier. The use of a totally guided template may further minimize access points and angular deviations because of the potential influence of operator positioning errors while using more than one guide or during manual implant placement. In this study, both partially guided and totally guided surgical templates were used. However, no significant difference was observed in the outcomes achieved with these two templates. Partially guided templates can also facilitate optimal implant placement and can simplify the surgical procedure. In this study, micro-movements of the surgical guides were observed during implant placement, and this may have increased the deviation values. The use of a partially guided template can minimize these micro-movements. Inherent errors such as those caused by guide micro-movements and those caused by the influence of bone density should be considered when calculating the deviations with both approaches.

Surgical guides are supported by the teeth, bone, or mucosa [11, 12]. In this study, tooth-supported (**Figure 8**) and mucosa-supported guides (**Figure 7**) were used for edentulous patients. Significant differences were observed between tooth- and mucosa-supported surgical guides, with the former showing greater accuracy than the latter, which showed micro-movements because of mucosal flexibility. Tooth-supported surgical guides are relatively more stable. In Ozan's study [6], the angular deviations of the placed implants relative to the positions of the planned implants were 2.91 ± 1.3°, 4.63 ± 2.6°, and 4.51 ± 2.1° with tooth-, bone-, and mucosa-supported SLA surgical guides, respectively. They also found that the tooth-supported guides were more accurate. Recently published studies indicate that the use of computer-aided surgical systems for dental implant bed preparation and implant placement results in an average deviation of <1 mm in implant position and a <5° angular deviation [13, 14]. Moreover, in a review of the literature on the accuracy of computer-designed SLA surgical guides for oral rehabilitation using dental implants [15], one in vitro study reported a mean apical deviation of 1.0 mm, three ex vivo studies reported a mean apical deviation of 0.6-1.2 mm, and six in vivo studies reported an apical deviation of 0.95-4.5 mm. Turbush [7] observed the accuracy of implant placement using the three types of surgical guides in vitro and found a mean angular deviation of 2.2 ± 1.2. The mean deviations in position were 1.18 ± 0.42 mm at the neck and 1.44 ± 0.67 mm at the apex for all 150 implants [7].

Errors include those caused by the CT procedure, including the steps of image acquisition and data processing [16-18], those caused by the type of guide, and potential mechanical errors [19]; these errors, along with those related to manufacturing and fixation of the surgical guide, may result in deviation. Cassetta found that guide fixation (fixed vs movable), supporting arch (maxilla vs mandible), and bone density also influenced intrinsic errors, during an assessment of the clinical relevance of potential mechanical errors in SLA surgical templates. The use of fixed surgical guide results in better accuracy compared with the use of movable surgical guides. When an SLA surgical guide was used in the maxilla, the positional accuracy was significantly better than that when the guide was used in the mandible [19]. However, Vieira's study showed mean positional deviations at the cervical, middle, and apical implant portions of 2.17 ± 0.87, 2.32 ± 1.52, and 2.86 ± 2.17 mm, respectively, in the maxilla and 1.42 ± 0.76, 1.42 ± 0.76, and 1.42 ± 0.76 mm, respectively, in the mandible. The angular deviations were 1.93 ± 0.17° and 1.85 ± 0.75° in the maxilla and mandible, respectively. Although the positional deviations differed significantly between arches, the angular deviation did not [20]. There was a significant linear correlation between the angular deviation and bone density at the implant level. Furthermore, a mean intrinsic error of 2.57 was mathematically determined after considering only the angular deviation, which was not influenced by other variables [19]. The intrinsic error was a significant factor among all the variables that could potentially affect the accuracy of computer-aided implant placement.

While the risk of deviation and errors remains, CAD/CAM surgical guides have led to optimal clinical results because of the efficacy and ease-of-use of this technology [16, 21, 22]. Compared with conventional implantation techniques, the use of CAD/CAM surgical guides result in improved precision in terms of position, angulation, and depth of implant placement. One limitation is the radiation exposure during pre- and postoperative CT scanning, which is required to evaluate the precision of planned and placed implants. Clinicians should carefully assess any risks to patients before surgery.

Conclusions

The findings of our study suggest that CAD/CAM surgical guides can improve the precision of dental implant placement. Tooth-supported surgical guides may be more accurate than mucosa-supported guides, while partially guided templates can provide the same outcomes as totally guided templates, thus simplifying the surgical procedure.

Acknowledgements

This work was supported by grants from the Specialized Research Fund for the Doctoral Program of Higher Education of China (20120061110077 to Y.Zhou).

Disclosure of conflict of interest

None.

Address correspondence to: Dr. Yanmin Zhou, Department of Dental Implantology Centre, Stomatology Hospital of Jilin University, Changchun 130021, Jilin Province, China. Tel: 86-431-88796-025; Fax: 86-431-88975348; E-mail: dentistzhouym@126.com

References

[1] Bornstein MM, Halbritter S, Harnisch H, Weber HP, Buser D. A retrospective analysis of patients referred for implant placement to a specialty clinic: indications, surgical procedures and early failures. Int J Oral Maxillofac Implants 2008; 23: 1109-1116.
[2] Gahleitner A, Watzek G, Imhof H. Dental CT: Imaging technique, anatomy, and pathologic conditions of the jaws. Eur Radiol 2003; 13: 366-376.
[3] Pramono C. Surgical technique for achieving implant parallelism and measurement of the discrepancy in panoramic radiograph. J Oral Maxillofac Surg 2006; 64: 799-803.
[4] Lal K, White GS, Morea DN, Wright RF. Use of stereolithographic templates for surgical and prosthodontic implant planning and placement. Part I. The concept. J Prosthodont 2006; 15: 51-58.
[5] Nickenig HJ, Eitner S. Reliability of implant placement after virtual planning of implant positions using cone beam CT data and surgical (guide) templates. J Craniomaxillofac Surg 2007; 35: 207-211.
[6] Ozan O, Turkyilmaz I, Ersoy AE, McGlumphy EA, Rosenstiel SF. Clinical Accuracy of 3 Different Types of Computed Tomography-Derived Stereolithographic Surgical Guides in Implant Placement. J Oral Maxillofac Surg 2009; 67: 394-401.
[7] Turbush SK, Turkyilmaz I. Accuracy of three different types of stereolithographic surgical guide in implant placement: an in vitro study. J Prosthet Dent 2012; 108: 181-188.
[8] Hämmerle CH, Stone P, Jung RE, Kapos T, Brodala N. Consensus statements and recommended clinical procedures regarding computer-assisted implant dentistry. Int J Oral Maxillofac Implants 2009; 24 Suppl: 126-131.
[9] Cassetta M, Stefanelli LV, Giansanti M, Di Mambro A, Calasso S. Depth deviation and occurrence of early surgical complications or unexpected events using a single stereolithographic surgi-guide. Int J Oral Maxillofac Surg 2011; 40: 1377-1387.
[10] Mandelaris GA, Rosenfeld AL, King SD, Nevins ML. Computer-guided implant dentistry for precise implant placement: combining specialized stereolithographically generated drilling guides and surgical implant instrumentation. Int J Periodontics Restorative Dent 2010; 30: 275-281.
[11] Van Assche N, Vercruyssen M, Coucke W, Teughels W, Jacobs R, Quirynen M. Accuracy of computer-aided implant placement. Clin Oral Implants Res 2012; 23 Suppl 6: 112-123.
[12] Verhamme LM, Meijer GJ, Bergé SJ, Soehardi RA, Xi T, de Haan AF, Schutyser F, Maal TJ. An Accuracy Study of Computer-Planned Implant Placement in the Augmented Maxilla Using Mucosa-Supported Surgical Templates. Clin Implant Dent Relat Res 2014; [Epub ahead of print].
[13] Ersoy AE, Turkyilmaz I, Ozan O, McGlumphy EA. Reliability of implant placement with stereolithographic surgical guides generated from computed tomography: clinical data from 94 implants. J Periodontol 2008; 79: 1339-1345.
[14] Van Assche N, Van Steenberghe D, Guerrero ME, Hirsch E, Schutyser F, Quirynen M, Jacobs R. Accuracy of implant placement based on pre-surgical planning of three-dimensional cone-beam images: a pilot study. J Clin Periodontol 2007; 34: 816-821.
[15] D'haese J, Van De Velde T, Komiyama A, Hultin M, De Bruyn H. Accuracy and complications using computer-designed stereolithographic surgical guides for oral rehabilitation by means of dental implants: a review of the literature. Clin Implant Dent Relat Res 2012; 14: 321-335.
[16] Arisan V, Karabuda ZC, Ozdemir T. Accuracy of two stereolithographic guide system for computer-aided implant placement: a computed tomography-based clinical comparative study. J Periodontol 2010; 81: 43-51.
[17] Valente F, Schiroli G, Sbrenna A. Accuracy of computer-aided oral implant surgery: a clinical and radiographic study. Int J Oral Maxillofac Implants 2009; 24: 234-242.

[18] Park C, Raigrodski AJ, Rosen J, Spiekerman C, London RM. Accuracy of implant placement using precision surgical guides with varying occlusogingival heights: an in vitro study. J Prosthet Dent 2009; 101: 372-381.

[19] Cassetta M, Di Mambro A, Giansanti M, Stefanelli LV, Cavallini C. The intrinsic error of a stereolithographic surgical template in implant guided surgery. Int J Oral Maxillofac Surg 2013; 42: 264-275.

[20] Vieira DM, Sotto-Maior BS, Barros CA, Reis ES, Francischone CE. Clinical accuracy of flapless computer-guided surgery for implant placement in edentulous arches. Int J Oral Maxillofac Implants 2013; 28: 1347-1351.

[21] D'Haese J, Van De Velde T, Komiyama A, Hultin M, De Bruyn H. Accuracy and com-plications using computer-designed stereo-lithographic surgical guides for oral rehabilitation by means of dental implants: a review of the literature. Clin Implant Dent Relat Res 2010; 14: 321-335.

[22] Cassetta M, Giansanti M, Di Mambro A, Calasso S, Barbato E. Accuracy of Two Stereolithographic Surgical Templates: A Retrospective Study. Clin Implant Dent Res 2013; 15: 448-459.