Accuracy of Two Stereolithographic Surgical Templates: A Retrospective Study

Michele Cassetta, DDS, PhD;* Matteo Giansanti, DDS;† Alfonso Di Mambro, DDS;† Sabrina Calasso, DDS;‡ Ersilia Barbato, DDS, MS§

ABSTRACT

Background: The use of computer software and stereolithography for dental implant therapy has significantly increased during the last few years. The aim of this study was to evaluate and compare the mean accuracy and maximum deviations values of dental implant placement using two stereolithographic (SLA) guide systems.

Materials and Methods: Twenty patients were selected and 227 implants were inserted using bone-, tooth- and mucosa-supported SLA surgical guides. Thirty-one guides, both single- and multiple-type, were used. Some of the single-type surgical guides were fixed with osteosynthesis screws. A postoperative computer tomography (CT) was performed and an iterative closest point algorithm was used to match the jaw of the CT preoperative with the jaw of the postoperative CT. Quantitative data of each group were described. The *t*-test was used to determine the influence of the utilization of the different types of SLA on accuracy values.

Results: *t*-Test demonstrated a better accuracy of the multiple-type guides in almost all deviation values when the mucosa-supported guides were considered. Regarding the bone-supported template, the single-type fixed group showed a better accuracy while the highest values of deviation were registered by the multiple-type guides. The single-type group showed a better accuracy when the tooth support was considered.

Conclusions: The results of the present study indicated best accuracy of the single-type guide using a bone or tooth support. The multiple-type guide recorded the best accuracy data when the mucosa support was considered comparing either a fixed and a not-fixed single-type guide.

KEY WORDS: accuracy implant placement, computer-assisted, dental implants, guided surgery, stereolithographic surgical guide

Technological progress is significantly influencing implant therapy. Recent improvement in technology has made it possible to use computers not only during the planning of surgical implant placement but also in the subsequent phases, such as implant site preparation and guided insertion.[1]

Up to now, "double-purpose templates" have been used for both patient radiographic examination and evaluation and for surgery and placement of the implants.[2]

However, with this kind of preoperative planning, the third dimension of the patient's anatomy results is missing.[3] Using this method, the final position of the implant does not allow one to meet the principles of "prosthesis-driven implantology."[4,5]

This methodology, which considers not only the presence of bone structure but also the position of the teeth, combines both functional and aesthetic requirements.

To overcome these limitations, computer tomography (CT), three-dimensional implant planning software, image-guided template production techniques

*Assistant professor, Department of Oral and Maxillofacial Sciences, School of Dentistry, "Sapienza" University of Rome, Rome, Italy; †research assistant, Department of Oral and Maxillofacial Sciences, School of Dentistry, "Sapienza" University of Rome, Rome, Italy; ‡researcher fellow, Department of Oral and Maxillofacial Sciences, School of Dentistry, "Sapienza" University of Rome, Rome, Italy; §professor, Department of Oral and Maxillofacial Sciences, School of Dentistry, "Sapienza" University of Rome, Rome, Italy

Reprint requests: Prof. Michele Cassetta, V.le Cesare Pavese, 85, Rome 00144, Italy; e-mail: michele.cassetta@uniroma1.it

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and computer-aided implantology (CAI) have been introduced.[6]

The extremely rapid development of this technology, however, has led to unrealistic clinical expectations for the efficacy and ease of use of the CAI.[1]

The most recent systematic review papers[3,7,8] indicate that substantial deviations in three-dimensional directions are found between virtual planning and placed implant position.[7] This finding together with a considerable number of reported technique-related perioperative[3] and postsurgical complications leads to the conclusion that care should be taken whenever applying this technique on a routine basis.[3]

The aim of the present study is to evaluate and compare the mean accuracy and maximum deviations values of two stereolithographic (SLA) surgical guides:

- A multiple-type SLA surgical guide (SurgiGuide®, Materialise Dental, Leuven, Belgium): dental implant positioning is "partially" guided; only osteotomy sites are prepared using sequential, removable surgical drilling guides.[9]
- A single-type SLA surgical guide (External Hex SAFE®, Surgiguide, Materialise Dental): dental implant positioning is "totally" guided; one guide is used for osteotomy site preparation as well as implant insertion.[9]

MATERIALS AND METHODS

Twenty patients, partially (first Kennedy Class) or totally edentate, who needed an implant prosthetic rehabilitation, were selected at the "Sapienza" University of Rome, Department of Oral and Maxillofacial Sciences. The average age of the patients was 55 years with a sex ratio of 3:2 (male/female). Patients with unhealthy systemic health status, parafunctional habits (i.e., bruxing), poor oral hygiene, severe alveolar bone deficiencies (e.g., needing a graft bone for the implant recipient site), uncontrolled diabetes, current irradiation to the head or neck, psychological disorders, and abuse of alcohol and tobacco (evidence of heavy smoking: >10 cigarettes per day), or drug use were excluded. All patients consecutively treated with CAI between February 2004 and February 2010 were included in this retrospective study. The study was approved by the local ethical committee and conducted in accordance with the Helsinki Declaration of 1975 as revised in 2000.

All the patients were informed of the study protocol and signed an informed consent form. The surgical interventions were performed by the same operator who performed the virtual surgical planning (MC) using an implant planning software (SimPlant®, Materialise Dental). The attending clinician was an expert in implant dentistry but not in CAI. The protocol employed in this clinical study was composed of an integrated treatment sequence that involved the following steps:

1. Construction of a radiopaque diagnostic template, the so-called scanno-guide, which was an exact replica of the temporary removable prosthesis, partial or total, accepted by the patient that answered to the aesthetic and functional requirements.[10]
2. CT scan of the patient's arch, performed with spiral CT devices (Asteion Multi, Toshiba Medical Systems, Rome, Italy). The scans included the scanno-guide of the patients' prosthesis to integrate the anatomic data with the functional and esthetic determinants.
3. Digital three-dimensional CT-based surgical planning. The computer program employed in the present study uses the original CT data, in Digital Imaging and COmmunication in Medicine (DICOM) format, to produce axial, three-dimensional, panoramic, and cross-sectional images, all of which are visible at the same time in four interactive windows on a computer monitor. With this software, implants are virtually placed according to bone anatomy and prosthetic design.
4. Computer-aided design (CAD) of SLA surgical guide; the clinician in the CAD environment designs the drilling template according to the patient's prosthetic and anatomical requirements.
5. Computer-aided manufacturing of SLA surgical guide to transfer the digital planning to the surgical environment. The surgical guides were classified in accordance to the type of supporting anatomic structure (bone, mucosa, teeth). In all cases, the teeth-supported guides used were free-ending templates and were seated and stabilized with the help of natural teeth. The bone-supported guides required an open flap reflection. The mucosa and teeth-supported guides permitted a flapless/transmucosal approach.

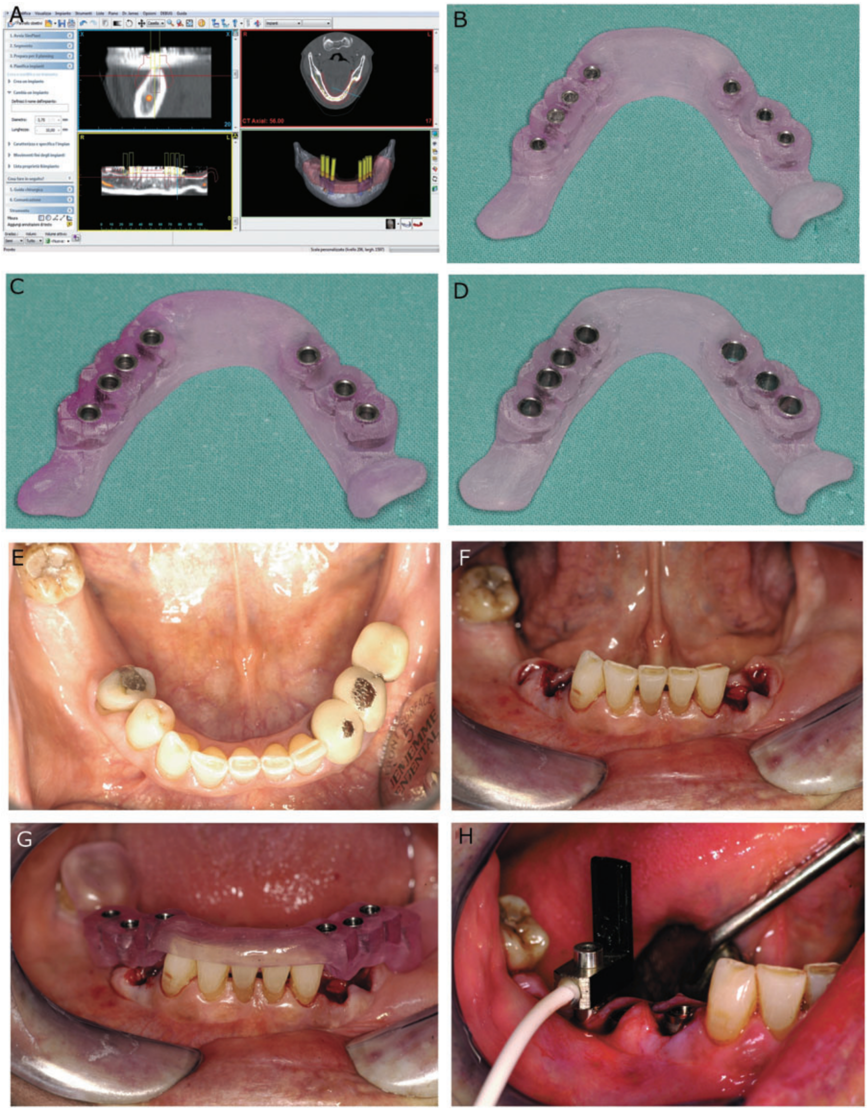

Figure 1 *A*, Treatment planning and virtual implant placement using 3D computer simulation software and CT scans, according to bone anatomy and prosthetic design. *B*,*C*,*D*, The multiple-type SLA surgical templates, teeth-supported, including successive drill tubes prepared according to the implant system's surgical drill diameters. The inner diameter of the tube ranged from 2.00 mm to 3.7 mm. *E*, Intraoral image of the partially edentulous patient who required the extraction of 3.4, 3.5, 4.4, 4.5 and the insertion of seven implants in healthy post-extractive sites. *F*, The patient after extractions. *G*, The positioning of the first multiple type SLA surgical template with an inner tube diameter of 2.2 mm. *H*, Implants placed, the implant stability was evaluated using the resonance frequency analysis.

In 10 patients (group A), a multiple-type SLA surgical guide was used (15 templates; 116 implants). The surgical guides were employed in each patient to accommodate the three specified drills of increasing diameters used for osteotomy preparation. No stabilization screws were used. Countersinking was not performed. Fixtures were then inserted without the surgical guide (Figure 1).

A single-type SLA surgical guide was used for another 10 patients (16 templates; 111 implants). This completely guided implant system allowed for controlled osteotomy site preparation and implant placement in three dimensions. Specific cylinders are embedded within the acrylic resin guide to accommodate drill handles or implant mounting that intimately engage the cylinders. The first drill used is a mucotome, with an outer diameter of 4.00 mm to punch and remove gingival soft tissue. In some cases, the bone- or mucosa-supported template, after punching the gingival tissues, was properly fixed to the jaw (group B1: single type – fixed guide) using at least three fixation screws

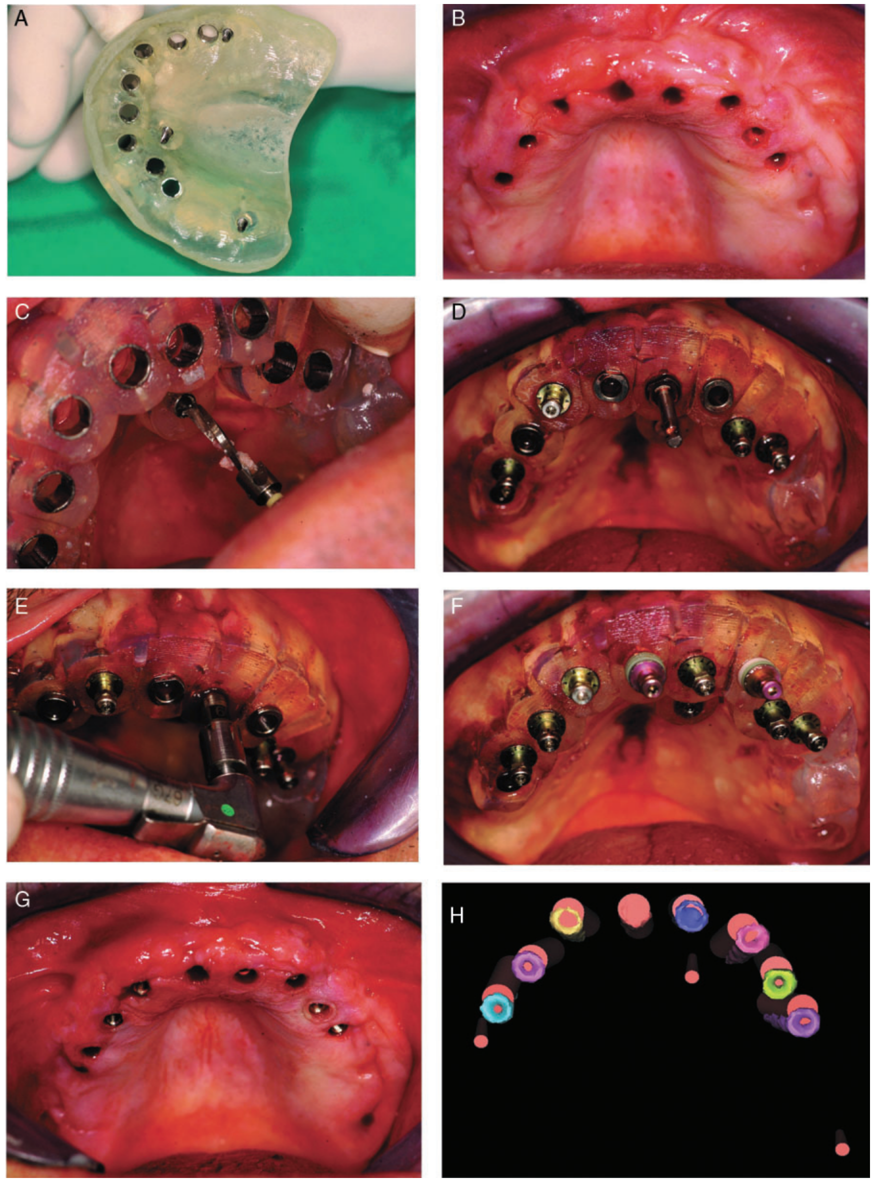

Figure 2 *A*, A mucosa-supported single-type SLA surgical template for the insertion of eight implants and three fixation screws in a completely edentulous patient. *B*, The tissue punch before surgical template fixing. *C*, Site preparation of the fixing screw using a 2.00 mm diameter drill. *D*, The implant sites preparation using drills with physical stops. *E*, The mechanical implant insertion using specific delivery mounts. *F*, Implant holders of different lengths have allowed the insertion of the implants to a controlled angulation and apico-coronal depth. *G*, The absence of bleeding after removal of the surgical guide. *H*, The matching procedure with 3D simulation software; planned implants are represented in brown and placed implants are represented by various color.

(Figure 2). In the other cases, the surgical template was manually held in place by the surgeon (group B2: single type – not fixed guide) (Figure 3).

Osteotomy site-specific drills with vertical stops to control apico-coronal site preparation were then used. Only two size types of single-use drills with physical stops were used: pilot drill (diameter 2.00 mm [top]/2.80 mm [bottom]) and final drill (diameter 3.15 mm [top]/2.80 mm [bottom]). Countersinking was not performed.

Implant placement was performed using specific delivery mounts (implant holder: length from 4 mm to 15 mm) to a controlled angulation and apico-coronal depth, which was set by the computerized three-dimensional plan.

6. Computer-aided surgery: 227 implants (P1H, Plan 1 Health-Amaro, Udine, Italy), cylindrical, with an external hexagon (diameter ranging from 3.75 mm to 4.00 mm and length ranging from 10 mm to 18 mm) were inserted in partially

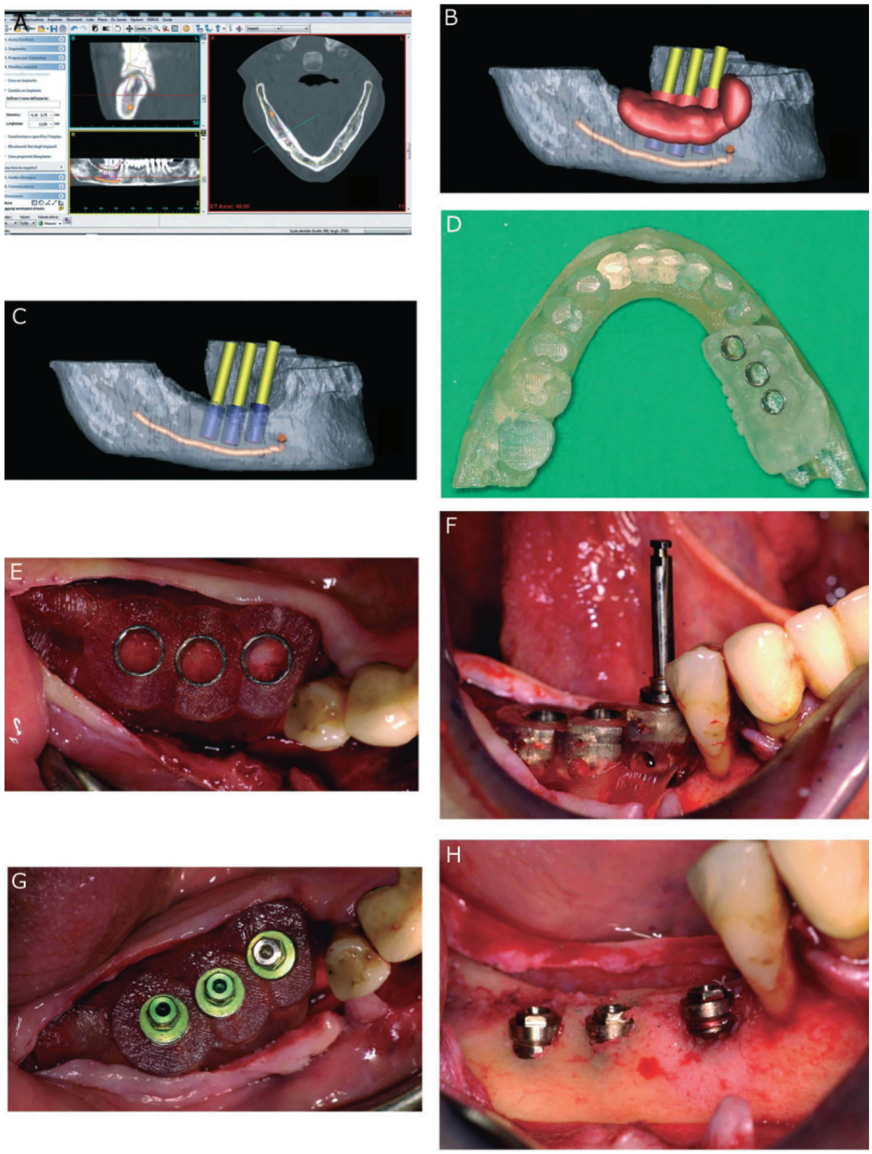

Figure 3 *A*, The surgical planning of the insertion of three mandibular implants using the SimPlant® software. On the computer monitor are visible, in four interactive windows, axial, 3D, panoramic and cross-sectional images. *B*, The planned implants in a 3D image; using this software, it is easy to highlight the course of the mandibular nerve. *C*, The project of the bone-supported single-type SLA surgical template in CAD. *D*, The CAD-CAM bone-supported single-type SLA surgical template and the SLA model of the lower jaw. *E*, The positioning of the bone-supported surgical template after the incision and the raising of a muco-periosteum flap. Fixing screws were not used. *F*, The implant site preparation using site-specific drills with vertical stop. *G*, The implants insertion using the implant holders. *H*, The implants placed.

and completely edentulous patients using SLA templates.

7. As described by D'Haese and colleagues,[11] a postoperative CT was undergone by all patients and an iterative closest point algorithm was used to match the jaw of the CT preoperative with the jaw of the postoperative CT (the software runs until it finds the best overlap between the images of preoperative and postoperative jaws) (Figure 4A). This allowed a comparison of the planned implants with the placed ones (Figure 4B) and the determination and calculation of four parameter deviations (i.e., global apical and coronal, depth, lateral, and angular deviation) by using their three-dimensional coordinates at apical and coronal level[11] (Figure 4C). All parameters except the angular deviation were determined for both the coronal and the apical centers.[11] The global deviation was defined as the three-dimensional distance between the coronal (or apical) center of the corresponding planned and

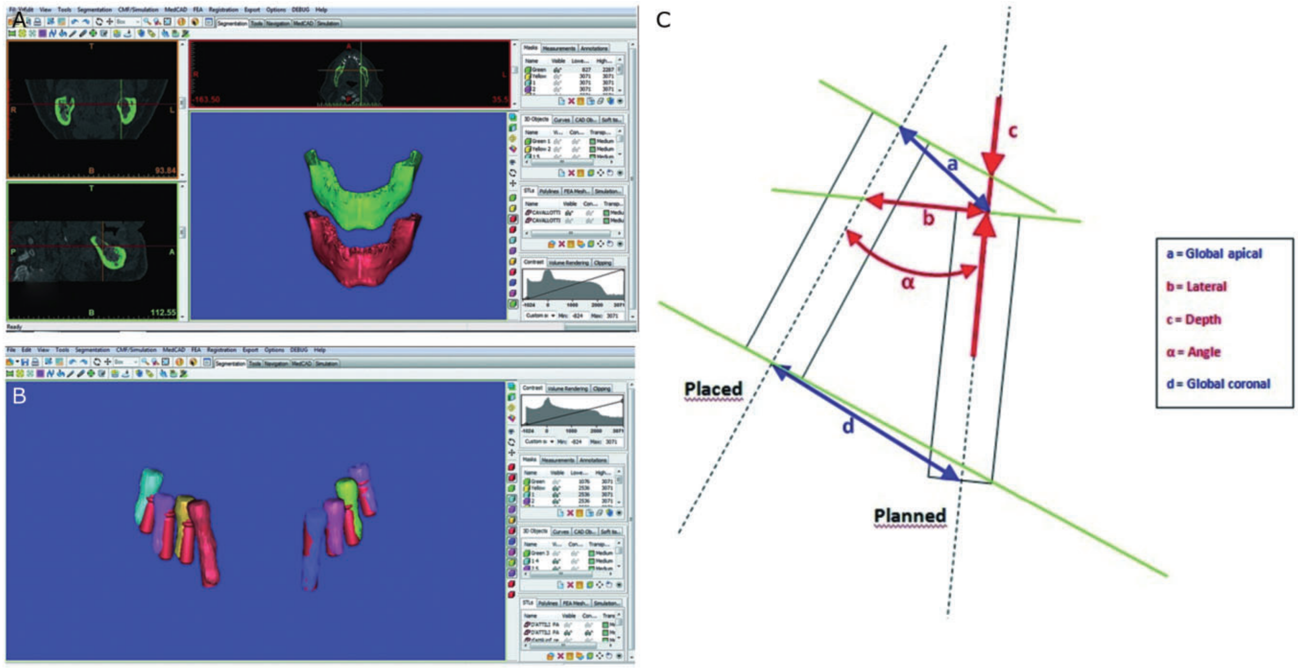

Figure 4 The match between the virtually planned and the in vivo placed implants. *A*, Three-dimensional evaluation of global apical and coronal, depth, lateral and angular deviation. *B*, Overlap between the images of pre- and post-operative jaws. *C*, Overlap between placed and planned implants.

placed implants (Figure 4C). Next, the angular deviation was calculated as the three-dimensional angle between the longitudinal axis of the planned and placed implant[11] (Figure 4C). To establish the lateral deviation, a plane perpendicular to the longitudinal axis of the planned implant and through its coronal center was defined and was referred to as the reference plane.[11] The lateral deviation was calculated as the distance between the coronal center of the planned implant and the intersection point of the longitudinal axis of the placed implant with the reference plane[11] (Figure 4C). The depth deviation was calculated as the distance between the coronal center of the planned implant and the intersection point of the longitudinal axis of the planned implant with a plane parallel to the reference plane and through the coronal center of the placed implant[11] (Figure 4C).

Statistical Analysis

Data were evaluated using a statistical analysis software (SPSS®, Statistical Package for Social Science, IBM Corporation, Armonk, NY, USA).

Quantitative data of each group were described with frequency distribution, mean values, standard deviations, and median values. Accuracy data were illustrated using box plots.

The *t*-test was used to determine the influence of the utilization of the different types of multiple-type guides (mucosa-, teeth-, bone-supported) or single-type guides (fixed mucosa-supported, fixed bone-supported, not-fixed mucosa-supported, not-fixed bone-supported, teeth-supported) on accuracy values. The significance was set at $p \leq .05$.

Scatter plot was used to evaluate intra-operator variability of accuracy and to determine whether a learning curve was present. The deviation values for every group were regressed versus time (number of computer-guided surgery performed). Once again, significance threshold values were set to "$p \leq .05$."

RESULTS

Patients and Implants

In group A, the number of CAI interventions was 14, totaling 116 planned and inserted implants.

In group B1, the number of CAI interventions was eight, totaling 57 planned and inserted implants, and in group B2, there were eight CAI interventions, with 54 planned and inserted implants.

TABLE 1 Patient and Treatment Characteristics

	Templates					
	Single-Type Guide Not Fixed		Single-Type Guide Fixed		Multiple-Type Guide	
Average age of patients	55		58		54	
Number of implants	54		57		116	
	Number of Templates	Number of Implants	Number of Templates	Number of Implants	Number of Templates	Number of Implants
Sex						
Male	3	27	8	57	7	66
Female	5	27	–	–	8	50
Type of edentulism						
Total	4	37	8	57	10	88
Partial	4	17	–	–	5	28
Arch						
Upper arch	3	29	5	39	8	67
Lower arch	5	25	3	18	7	49
Surgical technique						
Flapless	5	45	7	48	11	94
Open flap	3	9	1	9	4	22

There was no anesthesia, paresthesia, abnormal hemorrhages, sinus pathologies, or complication related to inaccurately placed implants.

Patient and treatment characteristics of the 20 adults included in this study, divided in the single groups, are summarized in Table 1.

Accuracy

Group A. A total of 116 implants were available for a comparison of accuracy via image registration technique. The global (coronal and apical), angular, depth, and lateral deviations were determined.

Mean global deviation between planned and placed implants at the coronal and apical ends of the implants were 1.47 mm (range: 3.88–0.17; SD: 0.68) and 1.83 mm (range: 6.41–0.07; SD: 1.03), respectively. The mean angular deviation was 5.09 degrees (range: 21.16–0.10; SD: 3.70), the mean depth deviation was 0.98 (range: 3.53–0.02; SD: 0.71), and the mean lateral deviation was 0.97 (range: 3.15–0.08; SD: 0.52).

Group B1. A total of 57 implants were available for a comparison of accuracy via image registration technique; the global (coronal and apical), angular, depth, and lateral deviations were determined.

In group B1 (57 implants; eight templates), the mean global deviation between planned and placed implants at the coronal and apical ends of the implants were 1.49 mm (range: 3.00–0.13; SD: 0.63) and 1.90 mm (range: 3.98–0.44; SD: 0.83), respectively. The mean angular deviation was 3.93 degrees (range: 14.34–0.28; SD: 2.34), the mean depth deviation was 0.85 (range: 2.29–0.03; SD: 0.63), and the mean lateral deviation was 1.04 (range: 2.57–0.12; SD: 0.64).

Group B2. In group B2 (54 implants; eight templates), the mean global deviation between planned and placed implants at the coronal and apical ends of the implants were 1.55 mm (range: 2.79–0.13; SD: 0.59) and 2.05 mm (range: 4.23–0.34; SD: 0.89), respectively. The mean angular deviation was 5.46 degrees (range: 15.25–0.10; SD: 3.38), the mean depth deviation was 0.63 (range: 1.58–0.05; SD: 0.43), and the mean lateral deviation was 2.05 (range: 4.23–0.34; SD: 0.89).

The deviation values, as clearly demonstrated by box plots (Figure 5), are similar for each group and do not indicate a higher accuracy value for any data type.

Paired comparisons (*t*-test) between the different mucosa-supported guides demonstrate better accuracy of group A guides versus group B1 guides with a

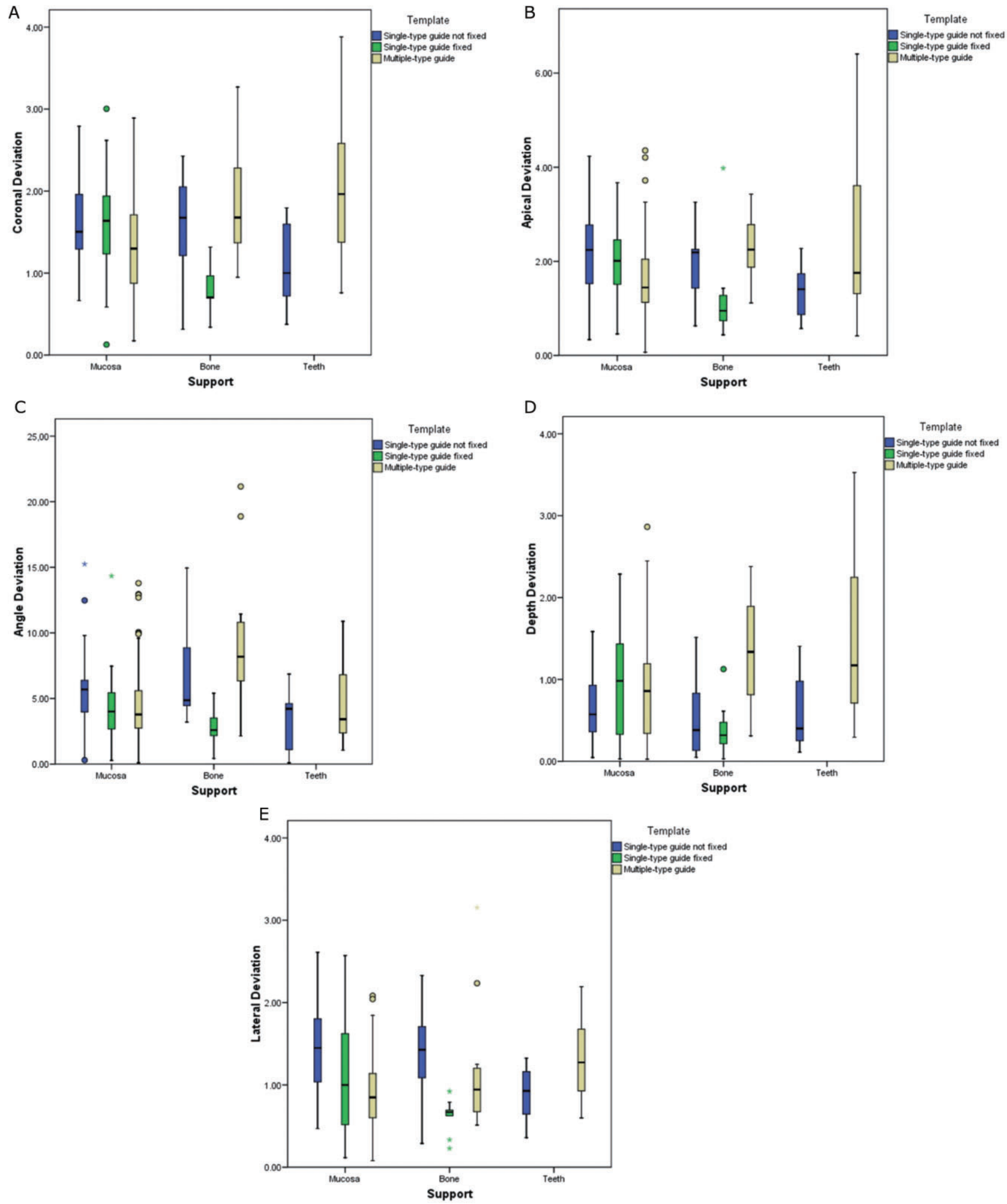

Figure 5 The accuracy data is illustrated using box-plots showing median, quartile, and extreme values of deviation, it is possible to point out the absence of large variations between different groups: *A*, global coronal deviation; *B*, global apical deviation; *C*, angular deviation; *D*, depth deviation; *E*, lateral deviation.

TABLE 2 *t*-Test between the Mucosa-Supported Templates of the Three Groups

Mucosa-Supported Template	Single-Type Guide Not Fixed versus Multiple-Type Guide			Single-Type Guide Not Fixed versus Single-Type Guide Fixed			Multiple-Type Guide versus Single-Type Guide Fixed		
	Sig. (*p*)	Difference	SD	Sig. (*p*)	Difference	SD	Sig. (*p*)	Difference	SD
Coronal deviation (mm)	.004	0.33	0.11	.871	0.020	0.12	.004	−0.30	0.10
Angular deviation (deg)	.045	1.18	0.58	.033	1.27	0.58	.836	0.10	0.49
Apical deviation (mm)	.001	0.58	0.17	.259	0.20	0.18	.010	−0.38	0.14
Lateral deviation (mm)	.000	0.55	0.01	.017	0.33	0.14	.027	−0.22	0.10
Depth deviation (mm)	.105	−0.17	0.10	.027	−0.27	0.12	.369	−0.01	0.11

statistically significant difference when coronal ($p = .004$), apical ($p = .010$), and lateral ($p = .027$) deviation are considered (Table 2).

Group A guides also demonstrate a better accuracy versus group B2 guides with statistically significant difference when coronal ($p = .004$), angular ($p = .045$), apical ($p = .001$), and lateral ($p = .000$) deviations are considered. (Table 2).

The *t*-test shows a better accuracy of group B1 guides versus group B2 guides with statistically significant differences when angular ($p = .033$) and lateral ($p = .017$) deviations are considered (Table 2).

Regarding the bone-supported templates, group B1 guides show better accuracy compared with group A guides, with statistically significant differences in all deviation values; comparing group B2 guides with group A guides, the former shows a better accuracy with statistically significant difference only when the depth deviation value is considered ($p = .026$). Group B1 guides show a better accuracy compared with group B2 guides with statistically significant when considering coronal ($p = .005$), angular ($p = .010$), and lateral ($p = .002$) deviations (Table 3).

The single-type guide shows better accuracy when the tooth support is considered with statistically significant differences in coronal ($p = .012$) and depth deviations ($p = .032$). All single-type tooth-supported guides were not fixed (Table 4).

Correlating the angular deviation values with time variable, indicating the number of computer-guided surgeries performed by the surgeon, the intra-operator variability analysis did not indicate a clear learning curve. In the scatter plots, the clusters shaped by the values of the 227 implants inserted from 2004 to 2010 appeared completely dispersed on the graph, indicating an absence of a linear association between them. Consequently, the time variable was evaluated as having a minor impact (Figure 6).

DISCUSSION

In recent years, CAI has helped to avoid anatomical complications using a minimal invasive surgery and a very accurate placement of oral implant and to achieve the immediate loading of the implants using a prefabricated fixed prosthetic reconstruction.[12] However, the risk of deviation using SLA guides for the placement of dental implants is substantial.

TABLE 3 *t*-Test between the Bone-Supported Templates of the Three Groups

Bone-Supported Template	Single-Type Guide Not Fixed versus Multiple-Type Guide			Single-Type Guide Not Fixed versus Single-Type Guide Fixed			Multiple-Type Guide versus Single-Type Guide Fixed		
	Sig. (*p*)	Difference	SD	Sig. (*p*)	Difference	SD	Sig. (*p*)	Difference	SD
Coronal deviation (mm)	.895	−0.03	0.27	.005	0.80	0.25	.001	0.84	0.23
Angular deviation (deg)	.679	−0.79	1.90	.010	4.70	1.60	.003	5.49	1.67
Apical deviation (mm)	.957	−0.01	0.29	.115	0.73	0.43	.030	0.74	0.33
Lateral deviation (mm)	.141	0.38	0.25	.002	0.82	0.22	.050	0.44	0.28
Depth deviation (mm)	.026	−0.59	0.25	.557	0.12	0.20	.006	0.71	0.24

TABLE 4 ***t*-Test between the Teeth-Supported Templates of the Two Groups**

	Single-Type Guide versus Multiple-Type Guide		
Teeth-Supported Template	Sig. (*p*)	Difference	SD
Coronal deviation (mm)	.012	−0.98	0.36
Angular deviation (deg)	.269	−1.53	1.34
Apical deviation (mm)	.078	−1.22	0.66
Lateral deviation (mm)	.062	−0.39	0.19
Depth deviation (mm)	.032	−0.91	0.39

Many methods have been used to measure deviations, both analog and digital, complicating the comparison between the results obtained by various authors.

Komiyama and colleagues[13] recently described a model matching method for assessment of accuracy in order to eliminate from the results the influence of the patient's movement during the CT scan[14] and the excessive exposure of radiation on the patient. The authors[13] compared two plaster models, one created from the surgical template and the other made from impressions on coping attached to the implants in patients at ≥1-year follow-up, but further refinement of the method is required to minimize the errors that arise during the matching procedure due to the absence of reference points.[13]

Up to now, the CT matching technique is the most common method used to evaluate the positional deviation between the virtually planned and clinically inserted implants.

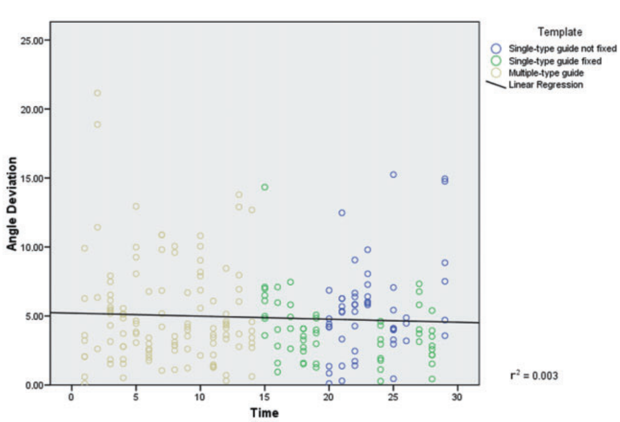

Figure 6 Scatter plots depicting the fitted learning curve regarding angular deviation (time indicates the number of computer-guided surgery performed by surgeon). The value of R^2 (linear regression) points out the absence of a linear association and a low impact of the time variable on the angular deviation values.

Taking into consideration only the deviation data obtained from those clinical studies that used an image-processing software to match preoperative planning with postoperative images, the results are poor.

In a clinical study, Ozan and colleagues[15] described the use of an SLA guide in the insertion of 110 implants. The preoperative and postoperative CT images were fused using a three-dimensional software to compare the locations and axes of planned and placed implants. After the matching procedure, the angular deviations of the placed implants with the tooth-, bone- and mucosa-supported SLA surgical guides were 2.91 degrees ± 1.3 degrees, 4.63 degrees ± 2.6 degrees, and 4.51 degrees ± 2.1 degrees, respectively. The mean deviations in distance between the planned and placed implants at neck and apex were 0.87 ± 0.4 mm and 0.95 ± 0.6 mm for the tooth-supported, 1.28 ± 0.9 mm and 1.57 ± 0.9 mm for the bone-supported, and 1.06 ± 0.6 mm and 1.6 ± 1 mm for the mucosa-supported SLA surgical guides.

Accuracy data regarding multiple-type guides were described by Valente and colleagues[16]

Eighty-nine implants were compared via the image registration technique. Mean lateral deviations between planned and placed implants at their coronal and apical ends were 1.4 mm and 1.6 mm, respectively. The mean depth deviation was 1.1 mm, and the mean angular deviation was 7.9 degrees.[16]

Comparable data were reported by Arisan and colleagues[17] The authors reported the deviation data of 279 implants placed by multiple or single bone-, tooth-, and mucosa-supported SLA surgical guides.[14] Considering the bone-supported guides, the mean deviation values were 5 degrees ± 1.66 degrees and 4.73 degrees ± 1.28 degrees angular, 1.70 ± 0.52 mm and 1.56 ± 0.25 mm at the implant shoulder, and 1.99 ± 0.64 mm and 1.86 ± 0.4 mm at the implant tip for multiple and single SLA surgical guides, respectively.[17] There was no statistically significant difference in the angular and linear deviation between the two system bone-supported guides.

Regarding the mean deviation values of implants placed using tooth-supported guide, single or multiple, the same authors[17] revealed that the angular deviation was 3.5 degrees ± 1.38 degrees and 3.39 degrees ± 0.84 degrees, and the linear deviation was 1.31 ± 0.59 mm and 0.81 ± 0.33 mm at the implant shoulder and 1.61 ± 0.54 mm and 1.01 ± 0.4 mm at the implant tip, respectively.

Linear deviation differences for implants placed using multiple and single SLA tooth-supported surgical guides were statistically significant.[17]

The mean angular and linear deviations of implants that were placed using multiple mucosa-supported guides were 4.23 degrees ± 0.72 degrees and 1.24 ± 0.51 mm at the implant shoulder and 1.4 ± 0.47 mm at the tip, respectively.[17] A smaller angular and linear deviation were observed for single mucosa-supported guides (2.9 degrees ± 0.39 degrees and 0.7 ± 0.13 mm at the implant shoulder and 0.76 ± 0.15 mm at the implant tip), which differed significantly from the other guides.[17]

The smallest deviations were observed by Arisan and colleagues[17] for implants placed using "a single" SLA mucosa-supported guide as a result of the lack of interference or slight guide movements in fully edentulous cases in which the guides were firmly fixed by osteosynthesis screws.[17]

The use of a single guide throughout an osteotomy of a specific drill kit and the integration of a depth-control mechanism has been recommended by the same authors to reduce deviations and to ensure a safe osteotomy and accurate positioning of the implants.[17]

D'Haese and colleagues,[11] in a prospective clinical study on the accuracy of a "single" mucosa-supported SLA surgical guide used in fully edentulous maxillae, described the deviation values measured between 77 planned and placed implants. The authors used a software (Mimics®, Materialise) to fuse the images of the virtually planned and actually placed implants. The global coronal deviation ranged from between 0.29 mm and 2.45 mm (SD: 0.44 mm), with a mean of 0.91 mm; the mean angle deviation was 2.60 degrees (range 0.16–8.86 degrees; SD: 1.61 degrees); the mean apical deviation was 1.13 mm (range 0.32–3.01 mm; SD: 0.52 mm). The authors asserted that the deviation values of the study were somewhat lower than previously published because only full, mucosa-supported guides were used. These guides, in fact, covering a maximum of soft tissues, increased the fit and were in addition properly fixed onto the supporting soft tissues using sufficient fixation screws.

As stated by other authors,[17] the results of the present study show a better accuracy of the single-type guide, fixed with osteosynthesis screws, compared with single-type guide not fixed, using any type of support.

These results probably arise by the lack of interference or slight guide movements when the guide is firmly fixed by screws, but the data that contrast with the results of previous studies are a greater accuracy of multiple-type guide when considering the mucosal support.

As stated by Valente and colleagues,[16] CAI involves a sequence of diagnostic and therapeutic events, and error can arise at different stages. Therefore, the described cumulative loss of accuracy is indeed the sum of individual errors. One of these is the mechanical error caused by the bur-cylinder gap, which can be defined as an intrinsic error of the surgical guide. The multiple-type surgical guide used in the present study is equipped with 5-mm long guiding cylinders with an inner diameter that is 0.15 to 0.20 mm larger than the respective bur. This tolerance theoretically allows a deviation angle of approximately 2.29 degrees, which at a hypothetical distance of 20 mm from the cylinder results in a lateral deviation of approximately 1 mm.[16]

The single-type surgical guide is a completely guided implant system that allows a controlled osteotomy site preparation and the implant placement in three dimensions. Specific cylinders (master tubes) are embedded within the acrylic resin guide to accommodate drill handles or implant mounting that closely engage the cylinders.

To determine mathematically the intrinsic error of the single-type surgical guide, it is necessary to consider the tolerance between the master tube of the guide, the internal tube, and the drills.

The master tube is a 5-mm long cylinder with an inner diameter of 4.2 mm; inserted into this cylinder is the internal tube that is a drill-guiding cylinder with an external diameter that is 0.2 mm smaller than the master tube. This is the first tolerance.

A second factor that must be taken into consideration is the tolerance between the internal tube (with an inner diameter of 3.2 mm) and the drills and likewise, between the internal tube and the implant holder.

The presence of these tolerances may explain the data in the present study; in fact this tolerance among the various components of the single-type of surgical guides may cause a decrease in accuracy.

Despite the risk that deviation using SLA guides for the placement of dental implants could be substantial, as demonstrated by the present and other studies, the three-dimensional approach, using surgical templates, defined by Fortin and colleagues[18] as semi-active systems, provides good predictability regarding anatomic complications and implant sizes.

CONCLUSIONS

The deviations between the planned and placed implant is the sum of the cumulative errors throughout the computer-aided implant placement cascade and errors can arise at different stages.

The results of the present study indicate a best accuracy of SLA single guide when a bone or tooth support was chosen.

The multiple SLA guide recorded the best accuracy data when the mucosa support was considered comparing either a fixed and a not-fixed "single" guide.

These findings contrast with the reasonable evidence that when a single SLA mucosa-supported guide was used, there was a lack of interference and/or limited movements of the guides (firmly fixed by osteosynthesis screws) in fully edentulous cases. However, a critical phase is the proper guide positioning in the mouth, and an error could arise when the guide is fixed.

Another source of inaccuracy is then the mechanical error caused by the gap between the different components of single-type SLA surgical templates, which can be defined as an intrinsic error, which could explain the lower accuracy of the single guides mucosa-supported.

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