Accuracy of Implant Placement Using a CAD/CAM Surgical Guide: An In Vitro Study

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Purpose: *To determine and compare the accuracy of an advanced surgical template based on computer-aided design/computer-assisted manufacture (CAD/CAM) with the conventional surgical template in different respects such as entry point, length, and osteotomy angle.* ***Materials and Methods:*** *Computed tomography (CT) scanning of a dentate epoxy mandible was performed and its three-dimensional computerized model was simulated. Sixteen rapid-prototyped models were fabricated and divided into two groups. In the first group, a radiographic template was fabricated and placed on the model during CT scanning and then was modified to the conventional surgical template form. In the second group, a coordinate measuring machine was used to reformat a nonanatomic radiographic template fabricated by a stereolithographic machine, and four implants were planned and then placed in the jaw. The differences between planned and actual mesiodistal and buccolingual entry points, lengths, and angles of the implants were measured. Statistical analysis was performed with the Mann-Whitney and Friedman tests to detect differences between groups.* ***Results:*** *The average differences between the planned and actual entry points in the mesiodistal and buccolingual directions, lengths, and angles of the implants and the osteotomy showed a considerable reduction in the CAD/CAM group versus the conventional group (*$P < .005$*).* ***Conclusion:*** *The accuracy of implant placement was improved using an innovative CAD/CAM surgical template.* Int J Oral Maxillofac Implants 2011;26:520–526

Key words: *computed tomography, computer-aided design, coordinate measuring machine, dental implants, stereolithography, surgical templates*

During treatment with dental implants, planning and surgical positioning of the implants must be accurate because of the patient's anatomic limitations and restorative requirements.[1] However, the abilities of the clinicians (eg, the surgeon and prosthodontist) also play a crucial rule in achieving surgical and prosthetic success.[2] To increase the predictability of success, it is essential to place implants properly.[3] Several techniques have been developed to facilitate clinical implant placement, including palpation of the ridge, use of an osteometer, diagnostic casts, assessment of the maxillomandibular relationship, radiographs, and other methods.[4–6]

Placement of implants has been planned and facilitated by means of simple periapical and panoramic radiographs for years.[3] However, surgical templates have attracted a great deal of interest as a means to achieve more precise placement of implants at the surgical site because both the restorative plan (ie, the biomechanical and esthetic requirements) and the internal anatomy (ie, bone volume and position of vital structures) need to be taken into account.[7,8]

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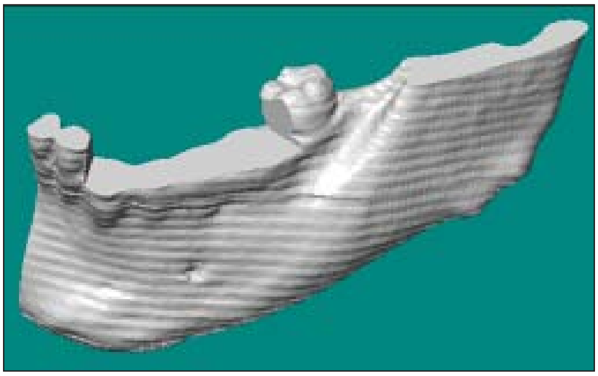

Fig 1 The canine, premolars, and first molar have been eliminated from the three-dimensional model of the jaw using Solid View software.

Fig 2 Implant holes are prepared along the long axes of the teeth.

Fig 3 *(Left)* The implant holes are transferred to a nonanatomic template.

Surgical templates and anatomic models can be fabricated with the assistance of computers. Treatment planning decisions made with computer-aided design (CAD) can be easily transferred to the surgical treatment phase, which can be performed, in turn, with computer-assisted manufacture (CAM).[5] It has been mentioned that CAD can be conducted through reading and interpreting multiplanar computed tomography (CT) scans, making measurements, and evaluating anatomic relationships by placing virtual images on the screen.[9–15] In the CAM process, stereolithography can be used for fabrication of three-dimensional surgical templates.[1] The method involves a laser beam that travels above photosensitive liquid acrylic, which allows the surgical template to be polymerized in layers according to the planned design. Then, stainless steel tubes are inserted in the spaces that represent implant locations. After insertion of the tubes, the surgical template is ready for use.

The purpose of this study was to assess the accuracy of placing dental implants using a simulated clinical scenario and comparing this newly designed CAD/CAM surgical template with a conventionally produced template. The accuracy of entry points, angulations, and lengths of the implants were compared between the conventional and CAD/CAM methods.

MATERIALS AND METHODS

A CT scan file of a dentate patient was selected from the CT scan archive. The CT data were reformatted into a computerized three-dimensional model by Materialise software (Magics, Mimics, version 2003). Four teeth (left canine, left premolars, and left first molar) and the right side of the mandible were eliminated using Solid View software (version 2000.1) (Fig 1). With these digital data, 16 hemimandibles with an edentulous space were fabricated by stereolithographic rapid prototyping (SLA 5000, 3D Systems). A scanographic template (anatomic template) and a nonanatomic template were fabricated for the left side of one arch. Then the templates were processed and adjusted on the model. A box was filled with polyvinyl siloxane (Speedex, Coltene). Then, one-fourth of the arch was inserted into polyvinyl siloxane such that the occlusal surface of the surgical template was aligned with the floor. This was done to prevent any interference with CT imaging. The box was then attached to the milling machine stage and implant holes were drilled along the long axes of the teeth in the anatomic and nonanatomic scanographic templates in the same directions and positions (Figs 2 and 3). The anatomic template was coated with barium sulfate liquid (Darupakhsh)

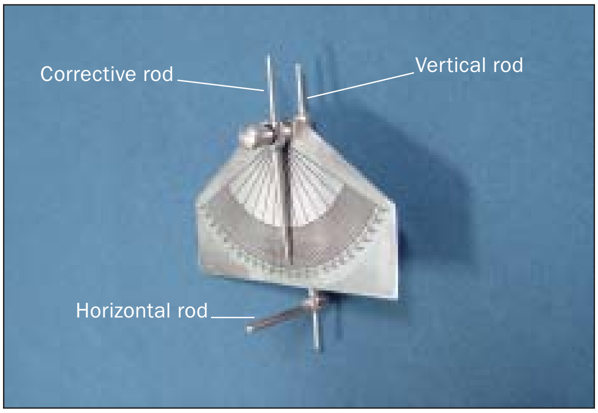

Fig 4 Designated tool to correct implant holes in the surgical template.

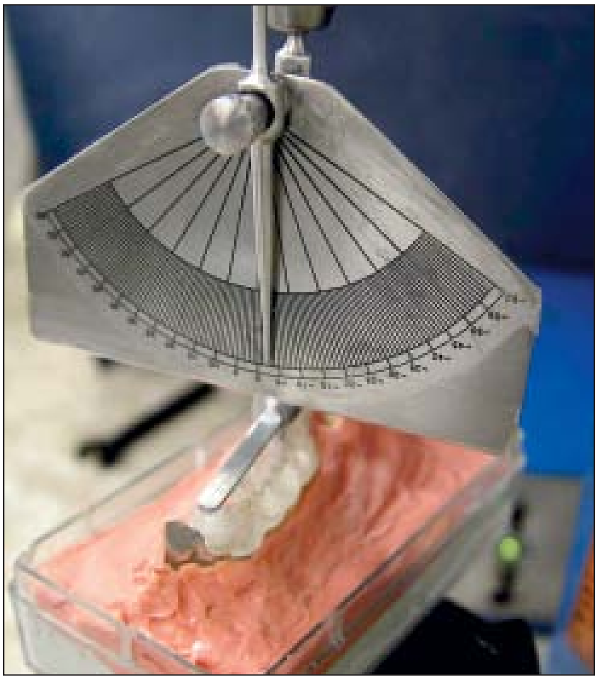

Fig 5 *(Right)* Correction of the implant paths with the special measurement tool.

Fig 6 Digitizing the nonanatomic template with the optical measuring technique (ATOSII).

and was scanned by the CT scanner in 1-mm intervals (Siemens SOMATOM; kV = 120, mAs = 185). During CT scanning, the occlusal plane was placed perpendicularly with respect to the floor, similar to the patient's occlusion. Reformatted CT scans were used for evaluation and calculation of the correct angles of the template channels. To increase the reliability of measurements, the degree of correction in the holes was measured in the reformatted CT by three people and the mean angle was calculated. A measurement tool for correcting the holes was designed and used to modify the implant paths. The measurement tool included the following parts: *(1)* a horizontal rod, *(2)* a vertical rod, *(3)* a corrective rod, and *(4)* a scale plate (Fig 4). The bottom of the vertical rod was inserted in the template channel so that the horizontal rod was parallel with the central fissure or the buccal side of the teeth (Fig 5). The corrective rod was adjusted to the desired implant directions according to the corrective angles used. The pilot drill was inserted in the mandible, and the position of the milling machine stage was moved until the upper head of the corrective rod was parallel with the pilot drill. The previous template channels were filled with a self-polymerizing acrylic resin and new template channels were prepared in the desired directions with a 2.2-mm pilot drill (ITI System, Institut Straumann). This corrected anatomic surgical template was then ready to use in selected jaws.

To fabricate the CAD/CAM template, the nonanatomic guide was digitized by an ATOSII camera (optical measuring technique; GOM mbH, Braunschweig, Germany) (Fig 6). The ATOS system was used to digitize the objects and process the data into an STL data set. Some reference points were applied to the model. By means of the photogrammetry camera and its supplied software, the coordinates of the reference points were measured with good accuracy. Three reference markers were applied to each added part. At this stage, a second series of images was obtained and the visible reference point coordinates were measured on these

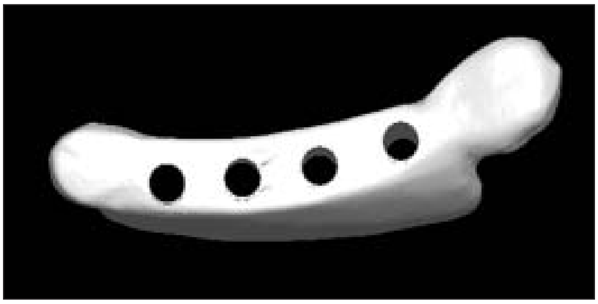

Fig 7 Computerized model of the nonanatomic template in IGES format.

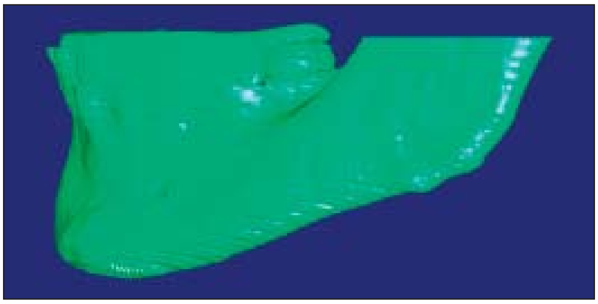

Fig 8 Guide assembled on the model in Solidworks software in SLD format.

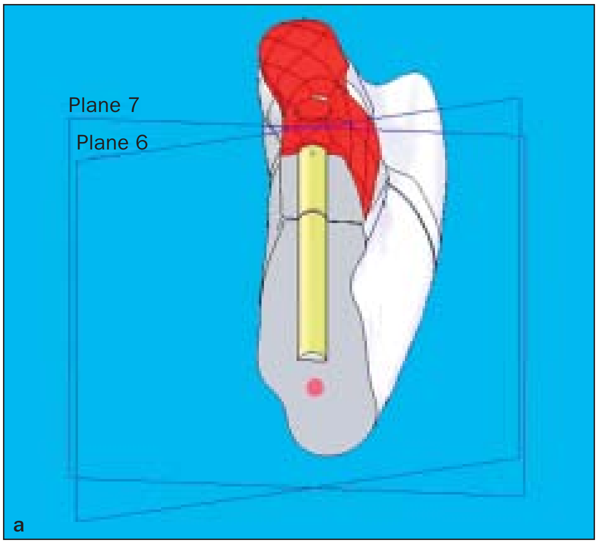

Fig 9 *(a)* The drilling directions and implant lengths are determined in Solidworks software; *(b)* an image of a stent designed by Solidworks software.

images. Using the points on the model, obtained with two sets of measurements, the second set of points was transformed into the coordinate system that had been defined previously by the first measurement. In the next step, all the measurement points were changed to IGES format with Rapid Form software (version 2001), and, consequently, the IGES format was changed to SLD format using Solidworks software (version 2001, Solidworks) (Fig 7). This guide model was assembled on the jaw model (Fig 8). The implant access holes were evaluated and the implant paths and lengths in each site were determined. The implants would extend no further apically than 2 mm coronal to the mandibular canal, and the diameter of implant holes was increased to 4 mm (Fig 9). This model, designated the *gold standard* model, was filed and applied for evaluating the results. After the implant paths and lengths were designated, the CAD/CAM surgical template was fabricated using a stereolithographic rapid prototyping machine (Fig 10). Then, stainless steel sleeves were fabricated in two different sizes to be used as guides for the implants. The sleeves were then inserted into the CAD/CAM template. The sleeves kept the planned implant lengths and diameters. For the anatomic surgical template, the implant paths were modified via measuring the CT scan file. For the stereolithographic template, the incremental guiding tube diameters, fabricated by CAD/CAM techniques, were used.

Fig 10 The guide has been fabricated by a stereolithographic machine.

Eight experienced surgeons performed osteotomies on the jaws. The jaws were inserted in a glass box during surgery. In the first group, the surgeons used the CT scan data to determine the lengths and diameters of the implants. For the second group, the paths and lengths were determined by the use of the sleeves, as drilling was performed to the length of the sleeves and the surgeons only changed the sleeves and drills.

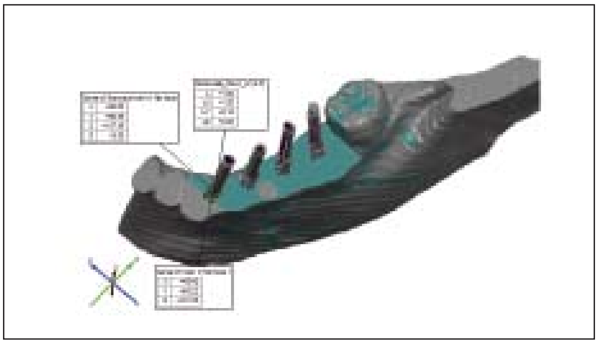

Fig 11 Superimposition of the computerized models of the osteotomized jaw on the CAD data and calculation of differences in mesiodistal and buccolingual directions.

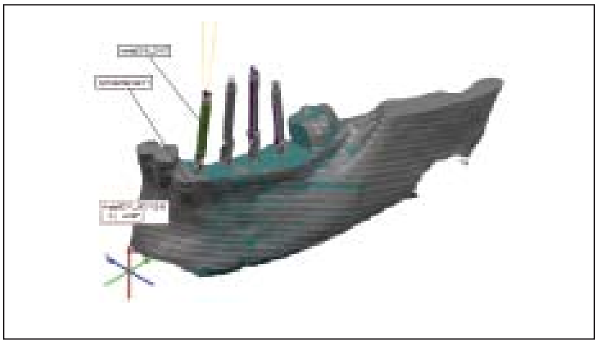

Fig 12 Superimposition of the computerized models of the osteotomized jaw on CAD data and calculation of angle differences.

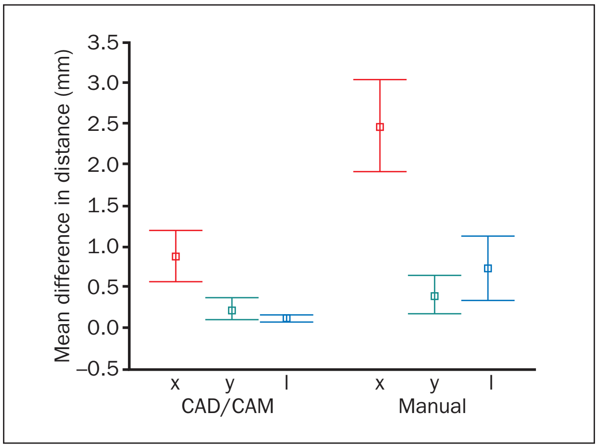

Fig 13 Overall mean distances between the center of the CAD implants and the center of the actual osteotomies. Error bars indicate 95% confidence intervals (x = mesiodistal; y = buccolingual; l = length). N = 8 in each group.

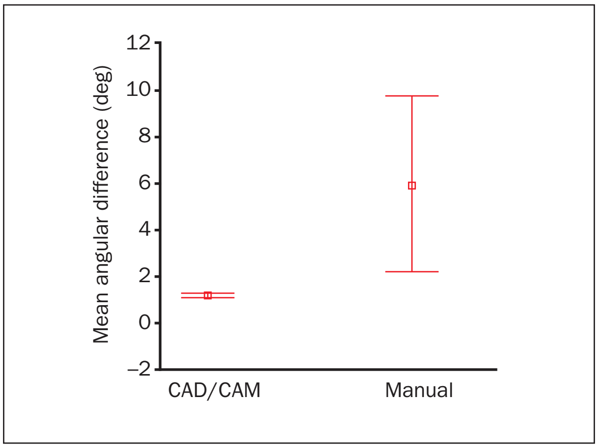

Fig 14 Mean angles between the planned implants and implant preparation. Error bars indicate 95% confidence intervals .N = 8 in each group.

A coordinate measuring machine was used to optically scan all jaws. The computerized models of the osteotomized jaw were superimposed on the CAD model (the gold standard) and the accuracy of the entrance point mesiodistally and buccolingually, the length, and the angle of each implant was measured by ATOS software (version 6) (Figs 11 and 12). The application of this method facilitated the calculation of angular differences in three dimensions. These measurements were repeated twice and the mean value was calculated for further analysis. The distances between the centers of the mesiodistal and buccolingual positions were calculated. In addition, the angles formed between the CAD implants and the corresponding osteotomies were calculated mathematically.

The consistency between actual and planned implant lengths and angles was statistically analyzed based on the Mann-Whitney and Friedman tests. All statistical testing was conducted at the 95% level of confidence.

RESULTS

In this study, the actual placement of implants was compared to a CAD/CAM model, which had been designated as the gold standard. The average center of the osteotomy in the mesiodistal (red line) and buccolingual (green line) directions and the length (blue line) were all decreased in magnitude from the first group (ie, manual) to the second group (ie, CAD/CAM) (Fig 13). However, only the difference in mesiodistal position was significant ($P < .005$). The standard deviations varied from 0.68 to 0.38 for the mesiodistal position and 0.27 to 0.17 for the buccolingual position through the use of a CAD/CAM template. Nineteen of the 32 drilled holes taken from the first (manual) group matched the planned implant length, while all the holes taken from the second (CAD/CAM) group showed the same length (Fig 13). Angular accuracy was 5.9 ± 4.5 degrees and 1.2 ± 0.08 degrees for the first and second groups, respectively. Angular differences and standard deviations were decreased in the second group ($P < .005$) (Fig 14).

Table 1 Transfer Error During the Use of CT Scan Analysis, CAD/CAM Templates, and an Optical Tracking System Between Planned and Actual Implant Positions and Angulations

Study	CT scan analysis	CAD/CAM templates	Optical tracking system
Sarment et al[1]	1.5 ± 0.7 mm 8 ± 4.5 deg	0.9 ± 0.5 mm 4.5 ± 2 deg	
Naitoh et al[15]	0.3 ± 0.6 mm 5 ± 3.5 deg		
Besimo et al[11]	0.6 ± 0.4 mm in max 0.3 ± 0.4 mm in mand		
Van Steenberghe et al[10]		0.8 ± 0.3 mm 1.8 ± 1 deg	
Di Giacomo et al[9]		1.45 ± 1.42 mm 7.25 ± 2.67 deg	
Fortin et al[7]			0.2 mm 1.1 deg
Birkfellner et al[16]			1.23 ± 0.28 mm
Present study	2.4 ± 0.68 mm mesiodistal 0.39 ± 0.27 mm buccolingual 0.7 ± 0.46 mm (length) 5.9 ± 4.5 deg	0.88 ± 0.38 mm mesiodistal 0.22 ± 0.17 mm buccolingual 0.11 ± 0.05 mm (length) 1.2 ± 0.08 deg	

DISCUSSION

The incorporation of treatment planning modified by CAD/CAM offers significant advantages, including the evaluation of three-dimensional anatomy and the fabrication of anatomic site models and bone-supported surgical templates. Other advantages are shorter surgery times, shorter treatment times, minimization of intraoperative radiography during implant placement, less invasive surgical techniques (eg, flapless surgery with less swelling and pain and faster initial healing times), prefabrication of a definitive prosthesis, and immediate use of a fixed prosthesis.[5,17] Furthermore, the surgical guides help clinicians place dental implants of the appropriate lengths in the appropriate positions.

Based on the results of the present study, it was noted that the differences between planned and actual implant positions and angulations with the CAD/CAM method were smaller than those placed using a conventional planning method. Table 1 summarizes the results obtained in this study and compares them to previous studies. As seen, the difference in mesiodistal position obtained in the present study was similar to and even in some cases more accurate than in previous works, in which commercially recognized software packages were used to fabricate the surgical template.[1,9,10] Some of the details of the relevant works are explained in the following for comparison.

Sarment et al[1] reported the fabrication of a template with SimPlant software (Materialise Dental). They found a statistically significant improvement in all measurements when a stereolithographic surgical template was used versus conventional templates. The average distance between the planned and actual osteotomies was 1.5 ± 0.7 mm in the conventional group and 0.9 ± 0.5 mm in the stereolithographic group. The angular deviations in the conventional group and the stereolithographic group measured 8 ± 4.5 degrees and 4.5 ± 2 degrees from the planned angles, respectively. Despite a lack of any specialized software, the present results show very good agreement with the data of Sarment et al.[1] In another in vitro study carried out by van Steenberghe and coworkers,[10] LITORIM software (Leuven Information Technology Based Oral Rehabilitation by Means of Implants) was utilized for fabrication of templates, and the average differences between the planned and actual implants in the maxilla and in the planned and actual implant axes were consistent with our results. Moreover, another report on the application of stereolithographic surgical templates by Di Giacomo et al[9] observed similar values for angular differences between the planned and actual implant axes and for the difference in distance between the planned and actual positions of the implant shoulder.

It is worth noting that the length, angle, and proper position of an implant play critical roles in the placement procedure. The results of the present study found that the difference between the planned and actual implant position was 0.11 mm, appreciably less than the well-known standard "safety zone" of 2 mm coronal to the mandibular canal. Furthermore, according to the data indicated in Table 1, the accuracy of angle and position was reasonably appropriate.

The clinical importance of these results may be relevant in such situations when multiple parallel but distant implants are placed, and where the degree of accuracy is critical for prosthetic restoration. Reangulation or replacement of removable wearing parts could be reduced by the use of more accurate surgical implant placement.[18,19]

The degree of difference between the proposed and actual implant direction may be influenced by various factors, such as construction accuracy of the template, surgical accuracy when using these templates, accuracy of the study model, accuracy of the stereolithographic machines, and measurement accuracy.[15] The main drawback of the surgical template resides in possible movement of the template during surgery and reproducibility of the splint position between the CT exam and surgery.

Because of the excellent accuracy of the method discussed in the present study, it can be used for any available implant systems, because the sleeves can be made according to the drill size and the planned implant lengths. Future clinical studies employing a greater number of patients should be performed to evaluate the true impact of the present stereolithographic surgical template on implant therapy.

CONCLUSION

A surgical template fabricated through computer-aided design/computer-assisted manufacture (CAD/CAM) was presented as a useful tool for implant placement. According to the CAD/CAM-assisted implant placement used in the present study, the average differences in entry points in the mesiodistal and buccolingual directions, implant lengths, and insertion angles between the planned implant sites and the actual osteotomies were considerably lower versus the conventional surgical guide. With the method described here, the flapless surgical technique for oral implant placement may be promoted and the invasiveness of surgical techniques may be reduced. The system tested is reliable for the preoperative assessment of both the number and locations of implants and implant size(s) needed, as well as potential anatomic complications. The presented method is very useful for fabrication of templates in dentistry because it can eliminate dependency on commercial companies and can be used in a variety of clinical situations.

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