ACCURACY ANALYSIS OF FREE-HANDED IMPLANT PLACEMENT COMPARED TO A DYNAMIC NAVIGATION SYSTEM

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ABSTRACT

Objective: The purpose of this study was to determine the platform, apical and angular accuracy of implant placement using dynamic navigation surgery, and to compare it to freehanded implant placement technique in clinically simulated model surgery. The study focused on overall accuracy measurements of implant placement by dental students relative to virtual plans on dentate models. **Methods:** Two dental students without surgical experience in Implantology placed 44 implants in sawbones models of the mandible and maxilla. Planning of all implants was performed virtually. Cone beam computed tomographic images were imported into the software and superimposed for virtual planning. The first 22 implants were placed using a free-handed technique, followed by 22 implants placed using a visible wavelength dynamic navigation system. After implant placement, CBCTs were taken. The preoperative plan and the pre and post-surgical CBCTs were comparatively analyzed after the CBCTs and the scans were mesh overlayed. The primary outcome variables were three-dimensional platform, apical and angular deviations from the virtual plan. Both techniques were compared to one another and to the published literature for implants placed using static image guided systems in model-based implant surgery. **Results:** Implants placed using dynamic image navigation are significantly ($p<0.001$) more accurate when compared with the freehanded technique disproving the null hypothesis. **Conclusion:** Dynamic navigation is accurate and holds promise for the training of novice dental surgeons.

KEYWORDS: Dental implants. Surgery, computer-assisted. Data accuracy.

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INTRODUCTION

The development of new technologies and tools for implantology has allowed dental surgeons to increase implant position accuracy and to reduce surgical complications that are not frequent but may occur during the placement of dental implants.[1] Placing implants accurately is pivotal to improving esthetic, biomechanical, and hygienic outcomes.[2] These new technologies may also offer the possibility of new ways of training novice dentist.[3,4] Implant placement should always consider the three-dimensional position of the implant; mesiodistal, buccolingual and coronoapical distances should always be evaluated prior to implant placement. Implants should be accurately placed to optimize support either from autogenous bone or by bone replacement material, such as allogeneic bone grafts.

In order to avoid esthetic or functional impairment, the implant should neither compress nor damage the surrounding anatomical structures and always respect a position compatible with the prosthetic planning for restorative rehabilitation. When fulfilled, these factors influence the long-term outcome of the final restoration.[5] Conical beam computed tomography scans (Cone Beam Computed Tomography - CBCT) have been extensively used by dental surgeons to plan and execute 3D-surgical procedures. CBCT uses low radiation doses when compared to conventional CT scans.[6] This technology facilitates planning and allows the surgeon to perform an accurate and minimally invasive surgery. The use of three dimensional CT scans allows the accurate visualization of anatomical structures, as well as the discrimination of distances, positions and bone density.[7] Intraoral optical scanning has frequently been used in implantology. The resulting intraoral optical scan files (.stl) can be superimposed on CBCT data files (.dicom) for use during treatment planning. The superimposed image files have an accuracy ranging from 38 to 332.9 µm.[8,9] In the X-Guide planning software these combined datasets do not have the radiographic artifacts caused by metals and structures that can alter the CBCT image quality. Intraoral scanning also creates a soft tissue delineation image, that when superimposed on the CT scan, allows a precise perception of soft tissue thickness relative to the bone. Modern computer-assisted surgical techniques, both static and dynamic guidance, offer new possibilities to improve implant placement. They allow the dental surgeon to visualize and plan with greater accuracy. Dynamic navigation is unique in that it allows the surgeon to visualize and use the images acquired with CBCTs, intraoral scans and their merged dataset "live". The surgeon can access and change planning if necessary during the procedure.[10,11] Currently, there are a number of guided implant placement devices and software, which are categorized as either static or dynamic. Static implant placement systems such as SurgiGuide® (Dental Realize Inc., USA), NobelGuide® (Nobel Biocare Management AG, Sweden) and Anatomage (InVivo,San Jose, CA, USA) use pre-fabricated templates and proprietary matched drill sets and metal tubes, which are placed in the surgical field during the procedure. These templates guide implant entry point, the angle, and depth of standardized proprietarily matched drills. Static guides have a number of limitations. Static guides cannot be modified once they are fabricated. Their use in the posterior of the mouth is limited by the patient's maximal mouth opening versus the total height of the bur, prolongation tube depth, plus the handpiece. They have limitations of implant diameter tube size relative to adjacent teeth and the plastic needed to retain the structure of the guide tubes. Finally, the prolongation distances of the tubes limits their use without bone reduction guides in many fully edentulous cases.[11] There are three dynamically guided implant placement systems approved for use in the United States, X-Guide® (X-Guide®, X-Nav Technologies, LLC, Lansdale, Pa) and IGI System® (Image Navigation Ltd., New York, NY) and Navident®, (ClaroNav, Toronto, Ontario Canada). They are all optically guided stereotactic surgical systems. The X-Guide® uses LEDs to project visible wavelength light. The light is reflected by surgical tracking arrays. These are categorized as "passive" arrays. One array is attached to the patient and one is on the surgeons drill. These arrays have unique patterns etched on their cylindrical surfaces. The light reflects back into two stereo cameras. The images are triangulated by the systems software algorithms to allow the position of the drill to be determined in six degrees of freedom in real time. Since the system is software driven and not limited by a prefabricated template the plan can be altered at any time by the surgeon based upon the clinical situation.[11]

The dynamical implant placement software alerts the surgeon through screen prompt alerts, about key factors such as proximity to adjacent anatomical structures, and the position, angle and depth of the planned implant. Flap design can then be minimized reducing surgical time and post-surgery morbidity, such as pain and swelling.[12]

Dynamically guided implant systems have another unique advantage over static guides. The surgeon can evaluate the accuracy of tracking in real time. After the drill is measured by the system the surgeon performs a "system check" by touching a known anatomic structure on the patient. The surgeon visualizes that spot in the patients' mouth and on the computer screen. If they are identical the surgeon knows the system if functioning optimally. If there is a discrepancy the surgeon can adjust the tracking system. The system check can be performed at any time during surgery in seconds. Static guides do not allow this visual check as the template obscures the surgical view unless it is removed.[11]

Ergonomic problems affect most dentists some time in their careers. Dental surgeons bend to examine the patient's mouth repeatedly during surgical procedures at the expense of their posture, causing problems in the lumbar muscles, spine, neck and arms.[13] Image-guided surgical techniques allow the surgeon to adopt a more comfortable position either sitting or standing since he/she constantly watches the computer screen and rarely bends to look in the patient's mouth.

For the work described here, we used a visible wavelength dynamic navigation system which has navigation system software that allows superimposition of intra-oral scans on CBCT images, creating a 3D view of anatomical structures and allowing precise planning of implant placement. The software also allows a unique single screen 360° image view of the oral anatomy and drill position during surgery in one screen. This allows implant position, angle and depth to be determined. Since the procedures are carried out without changing the surgeon's position relative to the patient, implant placement becomes more comfortable for the surgeon.

The purpose of this study is to determine the platform, apical and angular accuracy of implant placement using dynamic image navigation surgery compared to freehanded implant placement technique in clinically simulated model surgery. The study will focus on overall accuracy measurements of implant placement by dental students relative to virtual plans on dentate models. The null hypothesis: There is no difference in accuracy as measured by the primary outcome variables, of implants placed with a freehand technique and those placed with dynamic image navigation. The primary outcome variables are three-dimensional platform, apical and angular deviations from the virtual plan.

METHODS

In this study two dental students, one in the third and the other in the fourth year of dental school, were selected to conduct the tests; both students had no previous experience with implant placement. Test Devise ConFiguretion The test device is a visible wavelength dynamic image navigation system X-Guide® (X-Guide®, X-Nav Technologies, LLC, Lansdale, Pa). The system operates on the principle of triangulation of optically acquired images by calibrated stereo cameras (Figure 1). Two dynamic reference frames (DRF) are tracked by the system. One DRF is rigidly attached to the patient's teeth. The second is rigidly attached to the surgeon's drill. The system uses tracking data to project the image of the drill position in real time to assist the surgeon in placing the implant in its planned position. The implant position is based upon the pre-operative CBCT that is imported

Figure 1:
Image navigation devise.

Model and implants Eight dentate (four mandibular and four maxillary) custom polyurethane models (25 – 35 lb./ft3, 0.40– 0.56g/cm3) (Sawbones®, Washington, USA) were selected for the experiment. These models were developed to simulate the morphology of the bone and its physical characteristics. The models had available space for implant placement at the posterior and anterior regions (Fig 2). The implants placed were internally hexed, parallel wall 4.0 x 13mm implants (Certain Prevail®, Zimmer Biomet, Inc., USA).

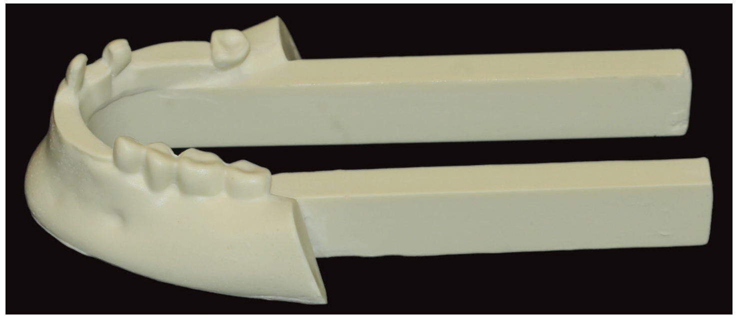
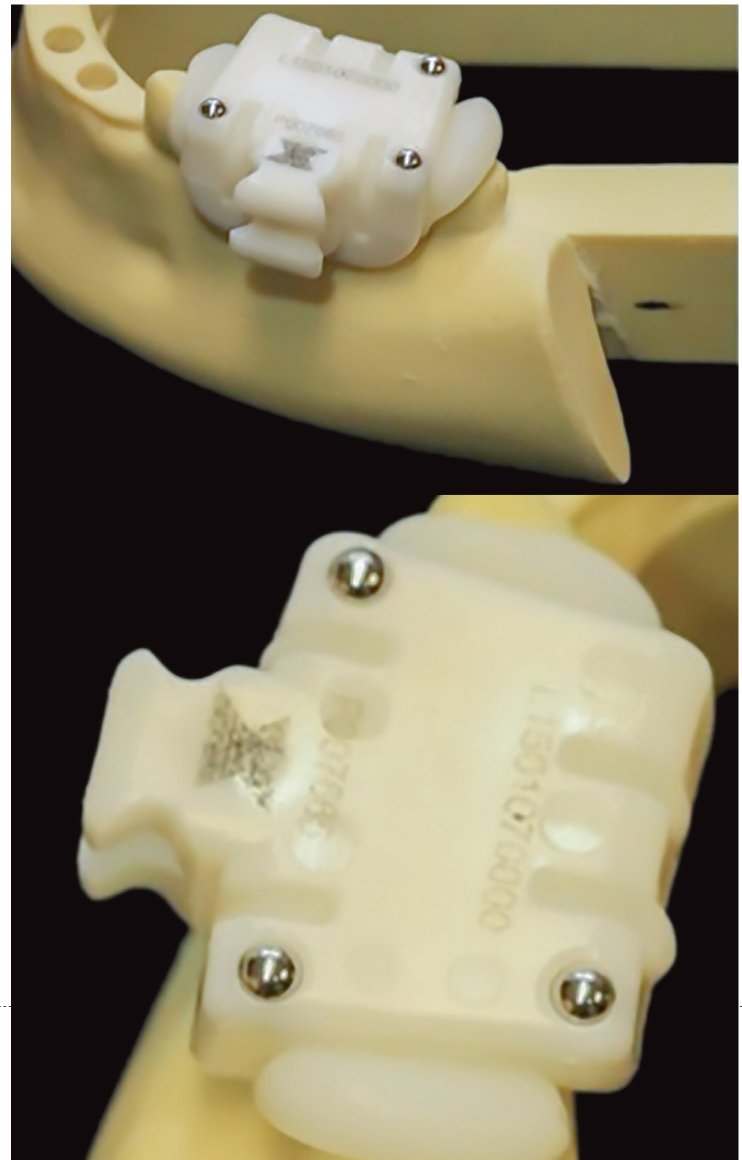


Figure 2:
Dentate Sawbones mandibular model.

Scanning Protocol

Prior to taking the CBCT, a prefabricated thermoplastic device (X-Clip®, X-Nav Technologies, LLC, Lansdale, Pa) with three radiographic markers, fiducials, is placed on the sawbones model in an area that the implants are not going to be placed. In the clinical situation one clip must be placed on each arch that implants are to be inserted. The clip is designed to rigidly hold the DRF during surgery (Fig 2). The clip, is heated to 140°F in a hot water bath. When the opaque-white thermoplastic material becomes translucent the clip is malleable enough to create an impression. After reaching the molding point, the clip is removed from the hot water, and applied to the teeth and quickly removed taking care not to distort the impression. The clip is placed in cold water (41°F) for 3 minutes becoming solid and stable. The clips are appropriately labeled and saved for CBCT

Figure 3:
Thermoplastic fiducial device (X-Clip) in place for CBCT.



acquisition and later simulated surgery. An i-CAT® (Imaging Sciences International, USA) is used to take a CBCT on each model, using a 0.3 voxel resolution for 8.4 seconds. Each model is scanned with the clip placed into its original position (Fig 3).

Implant planning

Virtual implant planning is performed using the test device planning software (X-OS®, X-Nav Technologies, LLC, Lansdale, Pa). The presurgical dicom data sets are imported into the software. The software allows determination of arch form. Anatomic structures such as the inferior alveolar nerve can be appropriately mapped. Intraoral scans (stl files) are then imported and superimposed on the .dicom datasets for further visualization. Multiple views allow the ideal position to be seen and manipulated in three dimensions. The implant platform and apex position and angles are then planned. The software also allows for manipulation of implant platform and apical diameter to be manipulated as well as length. Six implants were planned in each of the four mandibular models, areas #22, 23, 24, 27, 29, and 30. Five implants in areas #6, 9, 13, 14, and 15 were planned in the four maxillary models.

Handpiece calibration

The surgical handpiece DRF is calibrated prior to surgical simulation. This calibration defines the geometry of the handpiece tracking array and the axis of the drill. The handpiece is positioned at a distance between 60 and 80cm below the camera/LED assembly. A precalibrated trackable disc is placed in the chuck of the handpiece. The disk is rotated at a low speed (approximately 15rpm) in front of the camera assembly. Software calibration is completed after approximately 500 estimates in 30 to 60 seconds (Fig 4).

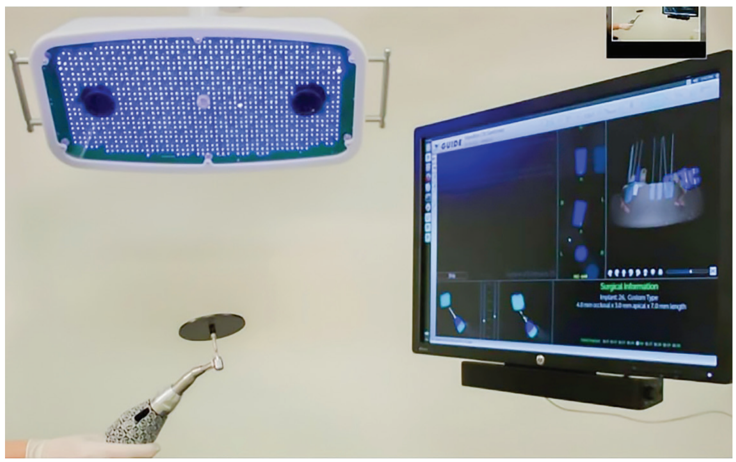


Figure 4:
Handpiece calibration with calibration disc in place.

Calibration of the X-Clip

The calibration of the patient DRF relates the geometry of the patient tracking assembly (Clip + patient tracking cylinder arm + patient tracking cylinder) to the fiducials in the CT volume. During the calibration process the software acquires approximately 500 estimates of the assembly geometry in 30 to 60 seconds. This provides a link between the pre-operative planning coordinate system and the tractable coordinate system. During surgery the system simultaneously triangulates each tracking array to determine their position and orientation in a common coordinate frame. In combination with the previously mentioned calibration, this real-time link allows the drills body and tip to be related to the pre-surgical CT coordinate system as the surgeon manipulates it in real-time. Two real-time windows allow the surgical team to get feedback from the system to visualize the entire surgical field and monitor the quality of the tracking in the surgical field volume (Fig 5).

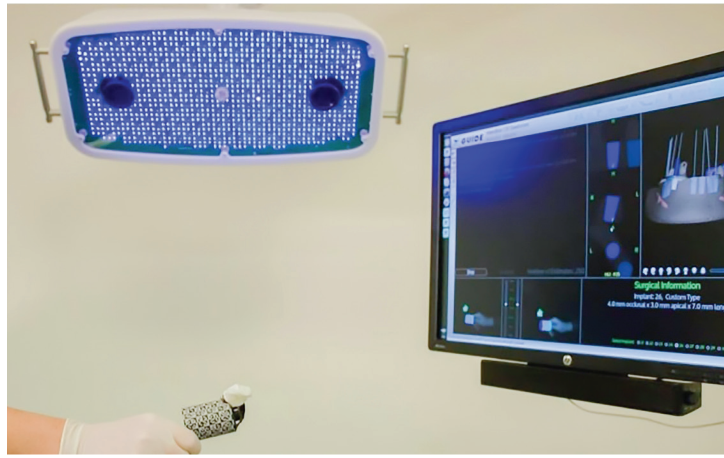


Figure 5:
Calibration of the patient tracking array with X-Clip attached.

Next the length of the drill bit is determined. The appropriate drill bit is inserted into the calibrated handpiece and moved in front of the cameras. The tip of the drill bit is then placed on the Go-Plate®, (X-Nav Technologies, LLC, Lansdale, Pa) with the drill bits long axis being oriented at 90 degrees to the plan of the Go-Plate. In approximately 4 seconds the drill bit length and all data displayed on the computer screen is now adjusted to the length of the drill bit (Fig 6).

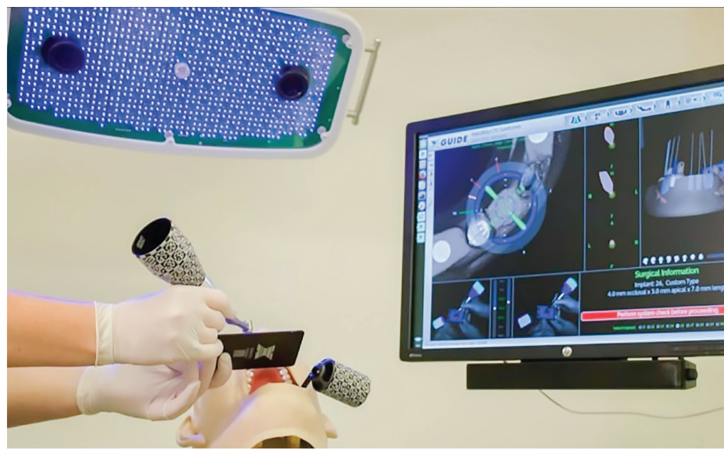


Figure 6:
Measuring the drill length using the Go-Plate. Patient dynamic reference frame attached to patient via X-Clip assembly.

Finally, the calibration of all the devices in verified. The calibrated handpiece with the measured drill bit it touched to each of the fiducials on the X-Clip in front of the cameras. The navigation system will display the system accuracy in microns. The system is considered accurate at 200 microns.

Operative Procedures

The dental students were instructed in virtual implant planning and placement by an experienced implant surgeon prior to the simulated surgical procedures. All implants were planned using the navigation software. The implants were first placed freehand based upon the virtual plan, mandible followed by maxilla. The implants were then placed using the dynamic navigation system.

Free-hand surgery

First, the model was evaluated by the student and the implant site was identified and compared to the image on the computer planning screen. Drilling was initiated with the pilot drill to a depth of 7mm. The osteotomy position and angle was verified using a direction indicator pin which was inserted into the osteotomy. Once ideal position and angle were determined the drilling sequence outline by the manufacturer was completed for a 4.0 X 13mm parallel wall implant (Certain Prevail®, Zimmer Biomet, Inc., USA). A surgical analog was used to visualize position, angle and depth before the implant was hand delivered.

Dynamically guided surgery

After calibration, the students placed the patient tracking array assembly on the models in the same position that it was when the CBCT was taken. They then performed a system check to verify that the calibrated instruments were properly registered to the model. The drill length was measured and the drill tip touched to a known point on the model. The image on the monitor was noted to be identical as that seen in the mouth. Once ideal position and angle were determined the drilling sequence outline by the manufacturer was completed for a 4.0 X 13mm parallel wall implant (Certain Prevail®, Zimmer Biomet, Inc., USA) using the X-Guide to deliver the implant to depth.

Data analysis

An engineer who was not involved in the placement of the implants performed all the data analysis.

The implant accuracy analysis was done using a CBCT dataset mesh overlay technique. The preoperative virtual plan was superimposed on the post-operative CBCT. This was then used to quantify the deviations from the plan. The process began with a trained engineer identifying the precise location of the implant in the post-op CBCT using the X-Guide planning software. The pre and post-operative CBCTs were than registered by aligning the Sawbones structures in the scans via a rigid transformation. Conventional iso-surface thresholding techniques were used to generate polygonal meshes representing the outer Sawbones surfaces from the pre and post-operative CBCT scan and register to two scans. The meshes were than aligned with the open source MeshLab software suite. The rigid transform defined by the MeshLab registration was used to project the virtual pre-op plan onto the postoperative CBCT scan. The position and orientation was than compared to the post-op result. The following variables were analyzed and compared:

- Depth deviation (mm): difference in depth along the implant long axis.
- Lateral deviation (mm): a two-dimensional measure of the difference in mesial/distal (yaxis) and buccal/lingual (x-axis) placement of the implant (disregarding depth deviation).
- Global deviation (mm): overall 3D distance taking depth and lateral deviation into consideration).
- Angular deviation (degree): largest angle in three-dimensional space between center axes.

Statistical Methods

Two and three-factor analyses of variance without replication and using type III sum of squares were performed to determine whether differences in jaw, student, or surgical method (e.g., freehand) had statistically significant impacts on any given accuracy measure. We used an alpha level of 0.001 for all statistical tests.

RESULTS

Results were categorized and tabulated by case type, i.e., freehand vs. guided and by surgical jaw, i.e., mandible or maxilla. The surgical sites (tooth numbers) are listed for each category in Table 1. In total there were four maxillary and four mandibular models. Two freehand and two guided per student. There were six implants in each mandibular model and five implants in each maxillary model. The actual deviation measurement cannot be assumed to be completely uncorrelated when their source implants share a common model. In this paper, however, when computing means and standard deviations each implant was treated with equal weight. Table 2 shows the deviations of the planned implants from the post-operative position. Means, standard deviations (SD) and maximal values were computed for each measure described in the analysis section and reported for each category and overall. Freehand implants overall had angular deviations of 9.54 degrees ± 5.58 and Global Apical 2.01mm ± 1.07. Guided implants had overall angular deviations of 0.99 degrees ± 0.60 and Global Apical of 0.35mm ± 0.17. There was a statistically significant difference in all measures between the free-hand and the guided implants ($p < 0.001$) disproving the null hypothesis. For example, for Global Apical, there was a statistically significant main effect for surgical method, $F(1, 36)$ =

99.20, p < 0.001. There was no statistically significant main effect for jaw, F (1, 36) = 4.53, p = 0.04. And, there was no statistically significant main effect for student, F (1, 36) = 1.70, p = 0.20. The choice of jaw did not have a statistically significant impact on all accuracy measures, except for Apical Depth deviation, within the guided method (p > 0.001). Within the freehand method, the choice of jaw did not have a statistically significant impact (p > 0.001) on all accuracy measures, except for Angular deviation.

Table 1:
Number of models and Implant sites broken out by guidance type.

	FREEHAND		GUIDED	
	MAXILLA	MANDIBLE	MAXILLA	MANDIBLE
Number of Models	2	2	2	2
Tooth Number (count)	13 (2)	31 (2)	13 (2)	31 (2)
	21 (2)	32 (2)	21 (2)	32 (2)
	25 (2)	33 (2)	25 (2)	33 (2)
	26 (2)	43 (2)	26 (2)	43 (2)
	27 (2)	45 (2)	27 (2)	45 (2)
		46 (2)		46 (2)

Table 2:
X-Guide deviations broken out by surgical jaw and guidance method. Values are Mean ± SD (max) deviation (max value) – Angular deviations is expressed in degrees and others in mm.

		ANGULAR DEVIATION	ENTRY DEVIATIONS			APEX DEVIATIONS		
			GLOBAL	DEPTH	LATERAL	GLOBAL	DEPTH	LATERAL
Freehand	Maxilla	12,9 ± 3,38 (25,56)	3,43 ± 0,48 (4,67)	2,49 ± 0,79 (3,47)	1,41 ± 0,79 (3,07)	2,41 ± 1,23 (4,61)	2,80 ± 0,65 (3,82)	1,87 ± 1,11 (3,65)
	Mandible	6,74 ± 2,53 (10,52)	3,18 ± 0,70 (4,01)	3,06 ± 0,79 (4,59)	0,67 ± 0,50 (1,58)	1,68 ± 0,79 (3,16)	3,14 ± 0,77 (4,63)	0,75 ± 0,50 (1,94)
Freehand Combined		9,54 ± 5,58 (25,56)	3,31 ± 0,62 (4,67)	2,80 ± 0,84 (4,59)	1,01 ± 0,75 (3,07)	2,01 ± 1,07 (4,61)	2,98 ± 0,74 (4,63)	1,26 ± 1,00 (3,65)
Guided	Maxilla	0,78 ± 0,35 (1,14)	0,60 ± 0,18 (1,02)	0,45 ± 0,20 (0,81)	0,19 ± 0,11 (0,36)	0,35 ± 0,13 (0,49)	0,34 ± 0,25 (0,81)	0,24 ± 0,14 (0,55)
	Mandible	1,16 ± 0,71 (2,97)	0,92 ± 0,30 (1,44)	0,88 ± 0,29 (1,24)	0,67 ± 0,11 (1,58)	0,36 ± 0,20 (0,90)	0,89 ± 0,29 (1,42)	0,21 ± 0,15 (0,52)
Guided Combined		0,99 ± 0,61 (2,97)	0,77 ± 0,30 (1,44)	0,68 ± 0,33 (1,24)	1,01 ± 0,75 (1,58)	0,35 ± 0,17 (0,49)	0,64 ± 0,39 (1,42)	0,22 ± 0,14 (0,55)

Figure 7 illustrates all measures of angular deviations from the plan of the mandibular and maxillary implant for both free-hand and guided placement. Figure 8 illustrates all measure for the mandibular platform non-depth deviations vs. the apical non-depth deviations for both free-hand and guided implants. Figure 9 illustrates all measures for maxillary platform non-depth deviations vs. the apical non-depth deviations for both free-hand and guided implants.

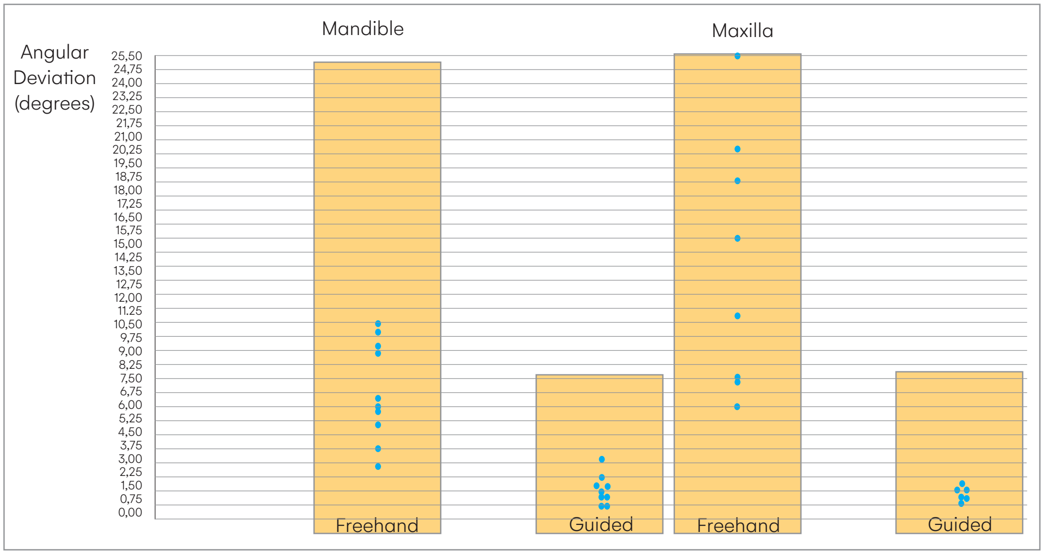


Figure 7:
Angular deviations from plan of mandibular and maxillary free-hand and guided implants.

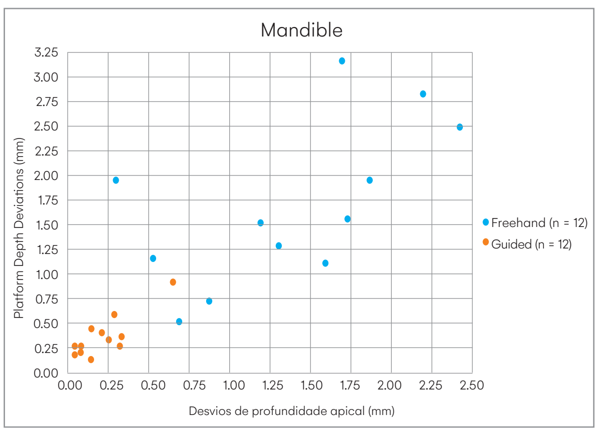


Figure 8:
Mandibular Platform non-depth deviations vs. Apical non-depth deviation (mm), Free-hand vs. Guided.

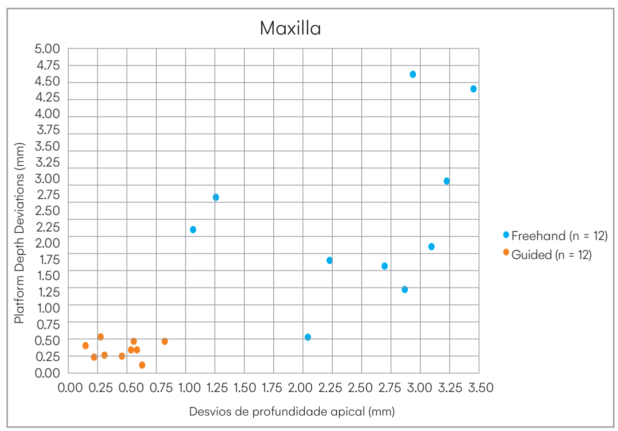


Figure 9:
Maxillary Platform non-depth deviations vs. Apical non-depth deviation (mm), Freehand vs. Guided.

DISCUSSION

Numerous studies have shown guided surgery improves the accuracy of implant placement.[5-18] Very few clinical trials have compared the accuracy of guided surgery to free-hand surgery. Vercruyssen et al.[16] compared three-dimensional (global) static guidance to free-hand to conventional laboratory fabricated templates. Their findings: Static guidance: deviation from plan global entry 1.4mm range (0.3 - 3.7), global apex 1.6mm (0.2 - 3.7) and angular 3.0 degrees (0.2 - 16) compared with non-guided global entry 2.8mm (0.3 - 8.3), global apex 3.1mm (0.3 - 7.5) and angular 9.1 degrees, range 0.6 - 27.8).[16] They concluded guided surgery was significantly more accurate than non-guided. In the only other clinical trial comparing guided to free-hand Block et al.[17] compared the present dynamic guidance system (X-Guide) to freehand and found similar results with significant improvements in all measured variables. Their findings: Dynamic guidance: deviation from plan mean global entry 1.37mm (0.55) SD apex 1.56 mm (0.69) and angular deviation 3.62 degrees (2.73). For freehand: global entry 1.67mm (0.43), global apex 2.51 (0.86) and angular 7.69 degrees (4.92)[17]. Farley et al. did a split mouth comparison of static guides and conventional laboratory fabricated guides and found CAD/CAM guide were more consistent in the level of accuracy.[14] The authors speculate on the variables that possibly cause the deviations from the plan including movement of the static guide after seating, poor fit between drills and metal tubes in static guides and wear of the instruments with use over time. Dynamic guide deviation can result from movement on the patient tracking array after seating. Of importance is that these results are consistent with larger meta analyses involving the accuracy of guided surgery.[7,18]

Model based studies are useful because they remove some to the variables associated with clinical trials. The difference in bone density is one of those variables. Not only does bone density effect the preparation of the osteotomy it also effects the ability to visualize structures while planning. When performing model based studies this important variable can be controlled.[19] As with clinical trials the number of model based studies that measure both guided surgery and freehand are limited.[20-22] Brief showed mean ± SD (max) freehand angular deviations of 4.59 degrees ± 2.85 (10.66).[20] Hoffman showed angular freehand deviations of 11.2 degrees ± 5.60(25.3)[23] and Nickenig showed angular freehand deviations of 9.80 ± 4.25 (17.0). In a previous paper Emery et al. presented a meta analysis of these papers and the combined free-hand angular deviations were 10.40 ± 5.41 (25.30).[19] The results of our combined free-hand angular deviation in this study was 9.54 ± 5.58 (25.56). The only other three dimensional (global) free-hand deviations reported was Brief for the apex 1.89mm ± 0.8 (2.95). We have reported global apical freehand deviations of 2.01 ±1.07 (4.61). Although no statistical inference can be made, our results appear consistent with the published free-hand data. This is particularly interesting as this study was evaluating novice surgeons and the other studies had experienced surgeons.

When comparing the outcome of static guided model based studies the meta analysis of Tahmaseb et al.[18] provides angular and global apical deviations based upon the literature through 2007. They reported mean ± SD for static angular deviations of 1.44 degrees ± 3.36 and global apical deviation of 0.73 ± 2.02mm7. In this study mean ± SD (max) static angular deviations of 0.99 ± 0.61 (2.97) and global apical deviation of 0.35mm ± 0.17 (1.58). Somogyi-Ganss studied three different static systems as well as an investigation dynamic system.[24] The results of the static systems reviewed in their study were consistent with the result of previous model based studies regarding the accuracy of static guides.

Model study based literature reviewing the accuracy of dynamically guided systems is extremely limited as there have been few systems available until recently. Presently in the United States there are only two dynamically guided systems available and one investigational system. Brief et al. investigated the accuracy of the IGI System (Image Navigation Ltd., N.Y., N.Y) and a system available in the EU Robodent (RoboDent GmbH, Bavaria, Germany).[20] In their model based studies evaluating the accuracy of bore holes they found mean ± SD (max) static angular deviations of 2.12 degrees ± 0.78 (3.64) for RoboDent and of 4.21 degrees ± 4.76 (20.43) for IGI. Global apical was found to be 0.60mm ± 0.20 (0.92) for RoboDent and of 0.94mm ± 0.40 (1.88) for IGI. Somogyi-Ganss in their model based study of NaviDent reported angular deviations of 2.99 degrees ± 1.68 (11.94) and Global apical was found to be 1.71mm ± 0.61 (3.92). Emery et al. in a model based study of a single experienced surgeon reported angular deviations of 1.09 degrees ± 0.55 (2.47) and Global apical was found to be 0.48 ± 0.21 (1.01) 19. In this study of novice surgeons the mean combined angular deviations of 0.99 degrees ± 0.61 (2.97) and Global apical was found to be 0.35 ± 0.17 (0.49). Once again this study supports the literature based data that dynamically guided surgery is more accurate than free-hand.

A meta analysis of studies of medical clinicians learning to perform a colonoscopy has shown simulation using dynamic navigation can decrease their learning curve and allow for more objective assessment of a clinician's competence then the standard threshold numbers presently used to determine competence.[25] Block et al reported a learning curve associated with the use of the XGuide.[17] For three experienced surgeons they become clinically proficient after the 20th implant was performed. Casap evaluated the use of dynamically guided surgery as an adjunct to the instruction of fourth year dental students. In their study each student placed 6 implants into the posterior mandible, two premolars and one molar on each side. The accuracy of marking the initial site, then 2mm and 3mm bore holes were placed and evaluated. The students only navigated three implants. They found that in all these tasks, the navigation group performed somewhat better (but with-out statistical significance) with the navigation system.[3] The students were slower when they used the navigated system. In the present study the students became more accurate and precise than free-hand after consecutively placing 11 dynamically guided implants. The high level of accuracy and precision of the students in a simulated clinical situation may reflect the improvement in the hardware and software of the newer dynamic navigation system. However, the consecutive sequence of placement, first freehand followed by dynamic may have compromised the results. Further study with larger number of students and randomization of the order of placement are indicated.

CONCLUSION

There is no significant difference ($P<0.05$) between the maxilla and mandible within surgical techniques. Implants placed using dynamic image navigation are significantly ($P<0.001$) more accurate when compared with the freehanded technique disproving the null hypothesis. When comparing the accuracy of model based dynamic guided system to the literature related to model based static guides the evaluated system is similar. Dynamic navigation holds promise in the train and evaluation of novice dental surgeons. Further studies with larger samples sizes and randomization are indicated.

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