Implant Placement Accuracy Using Dynamic Navigation

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Purpose: *The aim of this prospective study was to determine platform and angle accuracy for dental implants using dynamic navigation, a form of computer-assisted surgery. Three hypotheses were considered: (1) the overall accuracy for implant placement relative to the virtual plan is similar to that of static tooth-borne computerized tomography (CT)–generated guides; (2) the dynamic system is more accurate than freehand methods; and (3) there is a learning curve associated with this method.* ***Materials and Methods:*** *This study involved three surgeons placing implants in the mandible and maxilla of patients using a dynamic navigation system (X-Guide, X-Nav Technologies). Virtual implants were placed into planned sites using the navigation system computer. Post–implant placement cone beam CT scans were taken on all patients. For each patient, this scan was mesh overlayed with the virtual plan and used to determine platform and angular deviations to the virtual plan. The primary outcome variables were platform and angular deviations comparing the actual placement to the virtual plan. Secondary analyses included determination of accuracy related to case experience and freehand placement of implants. Comparisons to published accuracy studies were made for implant placement using static guides.* ***Results:*** *Accuracy deviations from the virtual plan were similar to those reported for static tooth–based guides using literature references as the comparison. The accuracy of dynamic navigation was superior compared to freehand implant placement. The three surgeons had similar accuracies after their learning curve was achieved. Proficiency based on case series was achieved by the 20th surgical procedure.* ***Conclusion:*** *Dynamic navigation can achieve accuracy of implant placement similar to static guides and is an improvement over freehand implant placement. In addition, there was a learning curve to achieve proficiency.* Int J Oral Maxillofac Implants 2017;32:92–99. doi: 10.11607/jomi.5004

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Patients who undergo implant surgery are looking for a solution that will provide long-lasting function, meet their high esthetic demands, minimize complications, and optimize their time. Methods for placing implants include the freehand approach, limited guidance using laboratory-fabricated surgical guide stents made on models, and computer-aided design/computer-aided manufacturing (CAD/CAM)–generated static guide stents that are either tooth, mucosa, or bone supported.

Computer-Assisted Surgery

Computer-assisted surgery for dental implant placement includes static and dynamic systems. A static system uses computerized tomography (CT)–generated CAD/CAM stents, with metal tubes and a surgical system that uses coordinated instrumentation to place implants with the help of the guide stent. Implant position is dependent on the stent without the ability to change implant position. Static in this case is synonymous with a predetermined implant position without real-time visualization of the implant preparation site as the site is being developed. No intraoperative position changes can be made with a static system.

Dynamic navigation/guidance is the use of a system that allows the surgeon to visualize implant site development while the drills are in function. Deviations from the predetermined plan can be seen in "real time" and changes to the plan can be made at the time of surgery.[1] Surgeons are not forced to abandon a plan should they desire to make a change. Full guidance is possible, as real-time visualization and adjustment of position can be made at any time.[2]

Navigation is used for dental implant placement for several reasons: *(1)* to avoid important structures, such as the inferior alveolar nerve; *(2)* to minimize flap mobilization in order to achieve minimally invasive surgery; *(3)* to accurately place multiple implants with proper spacing and angulation; and *(4)* to place single implants in exact locations when access is minimal and when the esthetic needs are high. Navigation allows prosthetic/surgical collaboration with precise planning and accurate orchestration of the plan to achieve ideal patient-specific results.

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Currently available dynamic navigation systems for dental implant placement use optical technologies to track the patient and the handpiece, and to display them on a monitor.[3,4] The optical systems use either passive or active tracking arrays. Passive systems use tracking arrays that reflect light emitted from a light source back to stereo cameras. Active system arrays emit light that is then tracked by the stereo cameras. The drill and patient-mounted array must be within the line of sight of the overhead stereo cameras to be accurately tracked on the monitor.[5] Previous systems using jaw-mounted tracking systems have been shown to be effective at taking into consideration patient movements during surgery.[6–13]

Dynamic navigation systems for the placement of dental implants require some type of radiopaque markers, ie, fiducials, to be rigidly fixed on the patient jaw while the CT is taken. The space imaged by the preoperative CT scan is called the scan volume, and each point in the volume has a unique xyz coordinate. These fiducial markers are used to register the patient within the three-dimensional matrix of the CT and the operative field volume at the time of surgery. The operative field volume is the space around the surgical site in which tracking occurs. The patient tracking array is called the dynamic reference frame. This serves as the reference for all localizations. During the registration process, the xyz coordinates of the operative field volume and the CT scan volume are aligned.

Accuracy Considerations

CT-generated guide stents result in more accurate implant placement and depth control compared to the freehand procedure or model-based nonrestricted guides.[14–17] CT-generated guide stents do have measurable error when comparing the virtual plan to the implant placement position. Mucosa-supported guides have been reported in clinical studies, with mean deviations ranging from 1.6 mm at the implant apex to 1.4 mm at the shoulder and angulation deviations ranging from 2.5 to 4.75 degrees from the virtual plan. More than half of the implants placed with static guides are placed more superficially than planned.[18,19] In two meta-analyses,[20,21] with static guides there was a mean deviation of 1.04 mm (up to 4.5 mm) at the entry point and 1.4 mm (up to 3.75 mm) at the implant's apex. Analyses using freehand methods were model based.[20,21] CT-generated static guided methods had less deviation from the virtual plan compared to model-based freehand methods.[21–28]

There is also a difference in accuracy between clinicians. Some clinicians are more accurate with CT guided implant placement than others regarding the positions of the apex, depth, and angle. In a study in which inexperienced surgeons were supervised by experienced surgeons, no significant difference in implant placement accuracy when using CT-generated stents was found between inexperienced and experienced surgeons.[29]

Navigation System Accuracy

Several studies on models[30–34] indicate that dynamic navigation systems have a mean entry deviation approximating 0.4 mm and mean angular deviation error approximating 4 degrees. These studies, simulating dynamic navigation, indicate very accurate implant placement. Clinical reports are limited, but implant integration rates are similar to those of conventional drilling methods.[35–37]

Dynamic navigation is relatively new to dental implant placement. Whether there is a true learning curve for the clinician to achieve proficiency needs to be determined. This study compares clinical accuracy data to test the following hypotheses:

1. The accuracy of the evaluated dynamic navigation system is similar to the accuracy reported for static CT-generated guides.
2. The accuracy of the evaluated dynamic navigation system is similar to that of freehand implant placement.
3. After 20 cases there are minimal accuracy differences between surgeons.

MATERIALS AND METHODS

The protocol was approved and administered under IRB Protocol 2014-10-15 BioMed IRB, San Diego, California.

Three surgeons' experiences were included in this study. Surgeon 2 had prior experience with another dynamic navigation system prior to the system used in this study. The other two surgeons had no prior dynamic navigation experience.

All patients who required at least one implant and had sufficient teeth for clip registration were consecutively enrolled in this study. Patients had to be over 21 years of age and able to understand and sign a consent form. Other inclusion criteria were the presence of at least three adjacent teeth in the arch to hold the clip. Exclusion criteria were patients who refused to sign a consent form for prospective data evaluation or those who could not accept the normal risks associated with dental implants (Table 1).

Patients were consecutively enrolled in this study within each surgeon's private practice. The difference in the number of patients for each surgeon reflected the number of implants placed by each surgeon within their private practice. All patients were grouped

Table 1 Demographic Variables of Patients Treated with Dynamic Guided Method

Surgeon	No. of patients	No. of males (%)	Average age, y (range)
1	36	14 (38.9%)	60 (27–89)
2	49	21 (42.8%)	58 (21–78)
3	15	4 (16.0%)	54 (29–72)
Total	100	39 (39.0%)	58 (21–89)

together to provide a sufficient sample size for analysis. The demographic data for each surgeon were compared to ensure similar group demographics for the combined analyses.

The study was initiated to use the navigation system on all patients. However, after the initial 100 patients were recruited, the FDA (Federal Drug Administration) instructed the IRB to halt the use of the dynamic navigation system until the data were reviewed. There were 20 patients who had had cone beam CT (CBCT) scans taken with clips, but because of the FDA suggestion to halt the use of the dynamic navigation system, these implants were placed freehand. The virtual plan was used as a descriptive view, with no stents used. This provided a consecutive series of patients with a virtual plan in place, with pre- and postoperative CBCT scans, to be utilized to generate freehand implant placement data by the three experienced surgeons involved in this study. The consecutive nature of this group and the original intention of use of the dynamic navigation system reduced the risk of selection bias.

Scanning Protocol for Dentate Patients

Prior to acquisition of the CBCT scan, a small thermoplastic device with three radiopaque fiducials (X-Clip, X-Nav Technologies) was placed on the teeth of the arch that was planned to receive the dental implants. After the clip was adapted to the teeth on the same arch as planned implant placement, a CBCT was taken at 0.3-voxel resolution. The patient-specific clip is designed to hold the array on the patient during surgery. The clip device was removed after the CBCT, appropriately labeled, and stored for later use during implant surgery.

Implant Planning

The DICOM (Digital Imaging and Communications in Medicine) data set from the CBCT was uploaded to the dynamic navigation system (X-Guide, X-Nav Technologies) and entered into its planning system. A virtual implant was positioned using the navigation system software. The software allows for nerve mapping and implant-dimension manipulation, with multiple views to orient the virtual implant into the bone. Files from intraoral scanners or laboratory-based scanners can be superimposed on the DICOM images for fine detail during treatment planning.

Surgery Procedures

Calibration of the surgical handpiece and the patient tracking array was performed prior to surgery. The handpiece calibration determined the relationship between the geometry of the handpiece tracking array and the axis of the drill. The patient tracking array calibration related the geometry of the patient tracking array to the CT fiducials, hence providing a link between the preoperative planning coordinate system and the tracking coordinate system. The stereo tracking system simultaneously triangulated each tracking array to determine their precise position and orientation in a common coordinate frame. In combination with the aforementioned calibrations, this real-time link allowed the drill's body and tip to be related to the patient's preoperative CT coordinate system as it was dynamically manipulated by the surgeon.

The surgeon anesthetized the patient, and the soft tissue reflection was performed as indicated for the specific procedure. The patient tracking array included the clip with the connected tracking cylinder. It was placed onto the teeth in the same location as during CBCT acquisition. The tracking software algorithm triangulated the two arrays continuously. Two live video windows allowed the surgical team to get virtual feedback from the navigation system to visualize site preparation and monitor the quality of tracking in the surgical field volume (Fig 1).

The length of each drill was calibrated as it was used. The drills were used in their normal sequence to prepare the implant site. The implant was placed under guidance. (Freehand refers to implant placement without dynamic guidance.)

A post–implant placement CBCT scan was taken at 0.3 voxels. The plan and CBCT scans were uploaded for analysis by individuals not involved in patient treatment. Data were then entered on a spreadsheet with no patient identifiers except for case number.

Accuracy Analysis Process

Three files were necessary to complete the data analysis: the presurgical CBCT scan, postsurgical CBCT scan, and surgical plan file from the navigation system.

The two CBCT scans were imported separately into the navigation software (X-Guide). The scans were meshed using MeshLab software. Then, using the postsurgical CT scan as a guide, a virtual implant with the same dimensions as the plan was placed where the actual implant was delivered during surgery. This was possible because the implant is radiopaque, so it is clearly distinguishable. The plan file created by the surgeon was copied into the presurgical case file to mimic the surgical procedure. Finally, a mathematical algorithm was implemented on the presurgical case with the plan, the postsurgical case with the virtual implant overlaid on the actual implant, and the meshed CBCT scans to calculate angular and positional deviations between the planned and actual implant positions.

The following deviations from the virtual plan were calculated:

- Angular deviation (degrees): Largest angle in 3D space between the center axes of the planned and placed implants.
- Global deviation (mm): Overall deviation of the planned and placed implant (takes angle, depth, and position into consideration).
- Depth deviation (mm): Difference in depth (z-axis) of the implant between the planned and placed implants.
- Lateral deviation (mm): Difference in mesiodistal (y-axis) and buccolingual (x-axis) placement of the implant between the planned and placed implants.

A repeated-measures analysis of variance was performed to determine whether there was a statistically significant difference between surgeons.

In the 20 patients who had clips placed onto their teeth and a virtual navigation plan made but had their implants placed freehand because of the aforementioned regulatory restraints, routine preoperative and immediate postoperative CBCT scans were mesh analyzed to provide freehand data.

The accuracy of the two approaches was compared by repeated-measure analysis of variance (ANOVA). Proficiency was determined for each surgeon by evaluating a consecutive series of 10 cases. The combined cases were used to evaluate general proficiency. ANOVAs were performed to assess whether there was a statistically significant difference between surgeons and whether there was a learning curve.

Fig 1 The dynamic system in use. Note the blue light source above the patient. The blue light is reflected from the arrays—one attached to the patient via the clip attached to the patient's teeth, and one array on the handpiece. The two cameras pick up the reflected light, and the computer creates the dynamic real-time representation.

RESULTS

Table 1 shows the demographic summary for the guided methods. Surgeon 3 had a larger proportion of female patients.

Table 2 shows the deviations from the virtual plan for multiple measures (Fig 2). Surgeon 2 showed minimal deviation with a flat learning curve. Surgeons 1 and 3 demonstrated more deviation for the first 10 and second 10 cases, and then their learning curves flattened. The deviations from the plan for the freehand method are listed in Table 3.

The repeated-measure ANOVA showed a significant difference in accuracy between case experiences (0–30 surgeries, and 0–20 vs 21–40) for both platform deviation (P = .001, P = .025) and apical deviation (P = .008, P = .005). It showed no difference in accuracy between case experiences for angular deviation (P = .548, P = .131). There was no significant difference in accuracy between surgeons for any of the three deviations (P = .619, P = .274, P = .176).

Two additional repeated-measure ANOVA tests were performed to assess the differences between guided and freehand cases for two surgeons. In the first test, the first 10 surgeries were compared to freehand cases (n = 20). It showed a significant difference in accuracy for global platform deviation ($P < .05$) and global apical deviation ($P < .05$). There was no apparent difference for angular deviation (P = .90). In the second test, surgeries 21–30 were compared to freehand. A significant difference was found in accuracy between guided and freehand surgeries for all three deviations ($P < .05$). There was no significant difference in accuracy between surgeons for either test.

Two meta-analyses[20,21] were used to compare the accuracy in this study to those that used static tooth-borne guides (Table 4). The dynamic navigation measures were similar to those reported for static guides.

Table 2 Summary of Guided Surgical Data, Mean (SD)

	Angular deviation (deg)	Global platform (mm)	Platform depth deviation (mm)	Platform lateral deviation (mm)	Global apical (mm)	Apical depth deviation (mm)	Apical lateral deviation (mm)
Cases 1–10							
Surgeon 1	4.05 (3.65)	1.10 (0.29)	0.72 (0.42)	0.75 (0.16)	1.48 (0.60)	0.74 (0.41)	1.15 (0.71)
Surgeon 2	2.67 (1.59)	1.55 (0.53)	0.93 (0.64)	1.05 (0.54)	1.63 (0.69)	1.09 (0.88)	1.05 (0.25)
Surgeon 3	5.10 (2.99)	1.91 (0.65)	1.66 (0.69)	0.88 (0.25)	2.24 (0.78)	1.79 (0.70)	1.29 (0.54)
Total	3.94 (3.04)	1.52 (0.61)	1.10 (0.72)	0.89 (0.38)	1.78 (0.77)	1.21 (0.82)	1.16 (0.54)
Cases 11–20							
Surgeon 1	5.14 (3.53)	1.68 (0.52)	1.08 (0.63)	1.12 (0.50)	2.01 (0.79)	1.05 (0.64)	1.45 (1.03)
Surgeon 2	3.39 (1.87)	1.45 (0.57)	1.10 (0.76)	0.75 (0.29)	1.64 (0.61)	1.12 (0.77)	1.14 (0.50)
Surgeon 3	2.74 (1.63)	1.27 (0.76)	1.10 (0.72)	0.57 (0.37)	1.51 (0.80)	1.08 (0.72)	0.96 (0.56)
Total	3.76 (2.69)	1.47 (0.65)	1.09 (0.71)	0.81 (0.46)	1.72 (0.77)	1.08 (0.71)	1.18 (0.76)
Cases 21–30							
Surgeon 1	3.16 (2.15)	1.39 (0.39)	0.94 (0.38)	0.97 (0.33)	1.34 (0.41)	0.91 (0.42)	0.92 (0.35)
Surgeon 2	3.33 (2.11)	1.04 (0.61)	0.84 (0.62)	0.55 (0.25)	1.30 (0.74)	0.85 (0.61)	0.87 (0.60)
Surgeon 3	–	–	–	–	–	–	–
Total	3.15 (2.12)	1.20 (0.53)	0.89 (0.50)	0.74 (0.36)	1.31 (0.58)	0.88 (0.51)	0.88 (0.48)
Cases 1–30							
Surgeon 1	4.11 (3.28)	1.39 (0.47)	0.91 (0.51)	0.95 (0.39)	1.61 (0.69)	0.90 (0.52)	1.17 (0.78)
Surgeon 2	3.13 (1.89)	1.35 (0.61)	0.96 (0.68)	0.78 (0.44)	1.52 (0.70)	1.02 (0.77)	1.02 (0.49)
Surgeon 3	–	–	–	–	–	–	–
Total	3.62 (2.73)	1.37 (0.55)	0.93 (0.60)	0.87 (0.42)	1.56 (0.69)	0.96 (0.66)	1.09 (0.66)

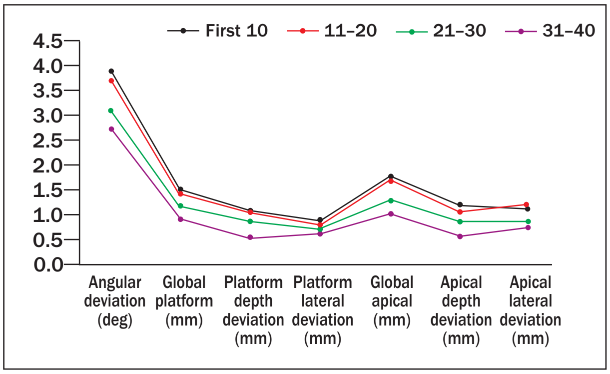

Fig 2 Changes in deviation from virtual plan per 10 surgeries.

Table 3 Summary of Freehand Surgical Data, Mean (SD)

	Angular deviation (deg)	Global platform (mm)	Platform depth deviation (mm)	Platform lateral deviation (mm)	Global apical (mm)	Apical depth deviation (mm)	Apical lateral deviation (mm)
Surgeon 1	8.13 (5.70)	1.59 (0.43)	0.86 (0.62)	1.08 (0.64)	2.38 (0.99)	0.83 (0.54)	2.11 (1.11)
Surgeon 2	6.88 (2.78)	1.82 (0.40)	1.14 (0.59)	1.27 (0.47)	2.73 (0.46)	1.08 (0.53)	2.39 (0.70)
Total	7.69 (4.92)	1.67 (0.43)	0.96 (0.62)	1.15 (0.59)	2.51 (0.86)	0.92 (0.55)	2.21 (0.99)

Table 4 Literature-Based Accuracy of Static Guides in Clinical Cases (Meta-Analyses)

Authors	Entry point mean error, mm (range)	Apex mean error, mm (range)	Angular error, deg (range)
Jung et al[21]	1.45 (0.8–4.5)	2.99 (2.23–3.75)	4.0
Tahmaseb et al[20]	1.04 (0.8–1.2)	1.38 (1.2–1.7)	4.06 (3.5–4.6)

DISCUSSION

A method is needed to perfect implant placement for all cases. This method should be accurate, have a practical workflow for the surgeon, and have a reasonable learning curve to allow for proficiency to be achieved.

The evaluated dynamic guided system is at least as accurate as static guides and is much improved over freehand implant placement. Even with the aid of a laboratory-fabricated guide, which is not true guidance, the error with the freehand approach is greater in all measured parameters.[16] The freehand data collected in this report may be among the first to document freehand implant placement accuracy. Experienced surgeons can place implants freehand within a sphere of accuracy, but using navigation methods is clearly superior.

A guided system must be easily available and cost effective for guided surgery to be performed on every patient receiving dental implants. As dynamic navigation becomes more available and the evidence base confirms its accuracy, surgeons will need to accept the learning curve.

Navigation surgery is known to have a learning curve associated with it. The learning curve of cardiothoracic and vascular surgical procedures has been summarized in a total of 48 studies, as Arora et al reported in their systematic review. [38] Based on operating time, the learning curve for coronary artery bypass surgery ranged between 15 and 100 cases; for endoscopic vessel harvesting and other cardiac vessel surgery, between 7 and 35 cases; for valvular surgery, which included repair and replacement, between 20 and 135 cases; for video-assisted thoracoscopic surgery, between 15 and 35 cases; for vascular neurosurgical procedures, between 100 and 500 cases, based on complications; for endovascular vessel repairs, between 5 and 40 cases; and for ablation procedures, between 25 and 60 cases. The authors concluded that the learning curves for cardiothoracic and vascular procedures varied depending on the procedure and the level of experience of the clinician.

Simulation of dynamic navigation has been used to decrease the learning curve for clinicians performing colonoscopy. Simulators improved training of novice endoscopists.[39] In a study involving colonoscopy procedures, the mean cecal intubation time decreased from a baseline of 9.50 minutes to 2.20 minutes at completion of the training. Colonic insertion depth improved from 29.4 cm to 63.7 cm. The learning effect of simulator training ceased after 60 colonoscopies. This study demonstrates the rationale for intensive simulator training in the early learning curve of novices performing colonoscopy. It is recommended that all clinicians using a dynamic navigation system have training on manikins, mentoring with over-the-shoulder observation, and if possible, hands-on mentoring when performing the initial case surgeries. The study showed that mentoring and over-the-shouder training increased efficiency.

When an implant is placed in an ideal location and angulation, the planned prosthetic restoration should be optimal. As implant placement deviations increase, the prosthetic methods become more complicated and can compromise the final result. This study showed an improvement in placement accuracy with dynamic guidance compared to freehand approaches.

Patients benefit from any guide method that optimizes implant positioning. This is a primary reason to use computer-assisted surgical navigation, either static or dynamic. The literature supports the improved accuracy of computer-assisted surgery over freehand methods.[16,17] Additional advantages using guidance are multiple. The size of incisions can be minimized, as tissue reflection is only needed to preserve attached tissue and/or modify its position. Tissue reflection is not necessary for bone visualization. Both systems allow for provisional restorations to be fabricated prior to surgery. Using static guides, provisionals can be fabricated using lab analog mounts in the static guide itself. With dynamic guidance, the provisionals can be made using the dynamic system to place implant analogs in a model for provisional fabrication. Fabricating the provisional prior to surgical placement allows the immediate restoration of implants.

Dynamic navigation has a number of inherent advantages over static navigation. Dynamic navigation allows real-time modifications of the surgical plan as needed when clinically indicated. Dynamic navigation allows for direct visualization of the surgical field at all times. There is no static guide interfering with visualization of the drill site. Dynamic navigation can be used on patients with limited mouth opening and in the posterior area of the mouth such as the second molar sites. Prolongation of tubes in static guides and drill stack heights are a significant limitation of static guides. Tight single-tooth situations can be fully guided using dynamic guidance, as the dynamic guide is not restricted by drill tube size, eg, in the anterior mandibular incisor sites. Dynamic navigation systems are completely "open" and do not require special instrumentation. Even nonproprietary statically guided implant systems require that very specific drills be used in a predetermined fashion. Implant size is not limited with dynamically guided systems as they are with static guides. As the size of implants increases, the size of drill guide rings must be increased in static guides and this limits the ability to place larger-sized implants. Dynamically guided implant systems are convenient for the patient and the doctor. The patient can have the

CT taken, the implant position planned, and the implant placed under computer-assisted guidance on the same day. There is no need to fabricate a guide in a laboratory or wait for a guide to be printed on a 3D printer. Finally, dynamic guidance allows for improved surgeon ergonomics during surgery. The surgeon visualizes the surgical field during the drilling procedure while looking at a computer monitor and does not need to bend over or twist to place the implant.

What are the common reasons for error when placing dental implants? The presence of asymmetric density in bone can result in deviation of the implant position. Dense bone will deflect drills when osteotomies are created and implants are delivered. For example, this occurs when placing an implant immediately into a mandibular molar extraction site, placing an implant after removing an anterior incisor, or placing an implant early after grafting lost facial cortical bone, with the lateral portion of the graft being softer than the lingual or palatal bone. When the surgeon recognizes these phenomena, the position of the implant drills can be compensated. This problem is present with or without the use of guided surgery; however, the use of dynamic navigation allows the deflection to be visualized on the monitor.

A surgeon will have either right- or left-handed dominance. The position of the arrays will be affected by the surgeon's dominant hand. For a left-handed surgeon, placement of the arrays on the right side of the arch allows for less interference with the direct line of sight to the patient-mounted arrays. The position of the patient reclined or sitting will affect the ability of the cameras to track the drill array, which in general should be parallel to the overhead camera. Each surgeon will need to practice different positions with the camera behind, over, or in front of the patient and get comfortable.

Working at high magnification allows the surgeon to acquire new skills. The surgeon has the ability to visualize within a "sphere of accuracy." The sphere of accuracy is affected by the surgeon's ability to hold the instrumentation, the rigidity of the instrumentation, the resolution of the CT, and the inaccuracy of the tracking system itself. The dynamic system presented in this article has a visualization tool that shows a 1-mm sphere of accuracy. The surgeon has the ability to see the laxity in the chuck of drill head. Additionally, when drilling components are stacked, eg, when drill extensions are used, the inaccuracy compounded by these components can be visualized.

The human hand has an inherent level of tremor, and our ability to hold an instrument still with 6 degrees of freedom will vary with our surgical skills. All dentists are taught to use a finger rest. Using a finger rest immediately reduces the degrees of freedom. Using a double finger rest during dynamic navigation helps increase stability, which leads to higher accuracy while tracking and gives the surgeon the ability to control the head position to improve tracking.

The system also requires a new cognitive approach for the surgeon. The surgeon must learn to trust the navigation system and his/her own presurgical planning. This will require a slower approach in the early stages as the surgeon confirms implant positioning after each drill is used.

With more experience using this system, the surgeon will gain proficiency and will use the plan with less trepidation. The use of either a static CAD/CAM guide or a dynamic guidance system improves the surgeon's ability to place implants in the planned position in all measured dimensions over freehand or conventional lab-fabricated guided surgery. The dynamic system evaluated in this study is as accurate in the clinical application as static guides reported in the literature.

CONCLUSIONS

As noted in the results section, the following conclusions can be made: *(1)* the accuracy of the evaluated dynamic navigation system was similar to the accuracy reported for static CT-generated guides; *(2)* the accuracy of the evaluated dynamic navigation system was significantly improved when compared to freehand implant placement; and *(3)* after 20 cases, there were minimal accuracy differences between surgeons.

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