Implant Placement Is More Accurate Using Dynamic Navigation

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Purpose: The purpose of this prospective study was to measure and compare the accuracy and precision of dynamic navigation with freehand (FH) implant fixture placement. The authors hypothesized that the evaluated dynamic navigation system would have high accuracy and precision and would be superior to FH methods.

Materials and Methods: The authors designed and implemented a prospective cohort study and enrolled patients who had implants placed from December 2014 through December 2016. The predictor variable was implant placement technique comparing fully guided (FG) and partially guided (PG) dynamic navigation with FH placement. The outcome variables were accuracy measured as deviation from the virtual plan, and precision was represented as the standard deviation of the measurements. Analysis of variance (ANOVA) was used to compare measurements. Virtual implant placement was compared with post-implant placement using mesh analysis. Deviations from the virtual plan were recorded for each implant for each surgeon. FH implant placement was evaluated by comparing a virtual plan with postoperative scans for patients who did not have the navigation system used for their implant placement. One-way ANOVA was performed to determine within-group and between-groups differences to determine whether there were meaningful differences among surgeons and methods (FG, PG, and FH) of placement.

Results: Prospective data from 478 patients involving 714 implants were evaluated. There were no demographic differences among surgeons. The sample size differed by the number of implants placed by each surgeon. Within each method group, the only difference among surgeons was angular deviation. All surgeons' data were combined. For FG navigation, the mean angular deviation was $2.97 \pm 2.09°$, the mean global platform position deviation was 1.16 ± 0.59 mm, and the mean global apical position deviation was 1.29 ± 0.65 mm. For PG navigation, the mean angular deviation was $3.43 \pm 2.33°$, the mean global platform position deviation was 1.31 ± 0.68 mm, and the mean global apical position deviation was 1.52 ± 0.78 mm. For FH placement, the mean angular deviation was $6.50 \pm 4.21°$, the mean global platform position deviation was 1.78 ± 0.77 mm, and the mean global apical position deviation was 2.27 ± 1.02 mm. Differences in measurements comparing FG and PG navigation with FH indicated significantly less deviation from the virtual plan ($P < .05$) using navigation.

Conclusions: Accuracy and precision for implant placement were achieved using dynamic navigation. The use of this type of method results in smaller deviations from the planned placement compared with FH approaches.

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When an implant is placed in the ideal position, the restoration process will have less need for complicated prosthetics. Deviations in implant position include, but are not limited to, angulation, platform position, apical implant position, and depth. Deviations from an ideal placement can result in additional cost and time using custom-fabricated parts and variations in restorative methods. Use of the freehand (FH) approach, in which the clinician placing the implants uses adjacent teeth or laboratory-fabricated stents to guide implant placement, can result in accurate implant placement.[1-4] However, the FH approach is less accurate compared with implant placement using navigation.[1-3] FH data have been reported using model surgery[5] and in clinical trials[6-8]; however, the clinical data lack a large sample.

The accuracy and precision of implant placement should be the same for every patient and for every clinician. The use of navigation has been shown to result in accurate implant placement.[6,9-34] For the clinician to use navigation on every patient receiving an implant, the navigated surgery method must provide the surgeon compelling reasons to adopt the technology and appreciate improvements in accuracy, precision, efficiency including time and cost, and ergonomics. Additional benefits can include improved methods for teaching novice surgeons.

Navigation methods for implant placement use a static or a dynamic system.[2,3] The static systems use a tooth-borne, mucosa-borne, or bone-borne guide with metal tubes, which allows the use of a coordinated surgical kit to place the implant into the planned positon. The plan cannot be easily changed. During implant placement, no changes can be made to implant angulation, size, or depth or implant selection. The implant choice cannot be easily changed. The cost of the guides varies according to manufacturers and requires time to fabricate the static guide. The software used to create a static guide can be difficult to learn, with the need for a third party to help design the case on the computer. The physical dimensions of the static guide can prevent its use in second molar regions or in patients with restricted opening. Because of these limitations, static guides are not used for every implant case but only for those with strict requirements.

If implant placement accuracy is superior when using navigation, then it is desirable to use navigation on every patient. Dynamic navigation systems have been developed to allow for efficient use of in-mouth fiducial registration during cone-beam computed tomographic (CBCT) scanning, software for virtual implant planning, and a user-friendly setup to allow for efficient time management when placing the implants using dynamic navigation. This type of workflow can result in the use of navigation for every patient who will receive a dental implant. If necessary, changes to the plan can be made at the time of surgery, including implant size, length, width, shape, and changes in positioning as required clinically to achieve an accurate implant position. Dynamic navigation is a real-time coordination of the surgeon's hands and eyes by 3-dimensional (3D) visualization of the preparation with high magnification.

Accuracy and precision must be established with all navigation systems. This article reports on the accuracy and precision of implant placement for multiple surgeons and for 714 implants placed in more than 478 patients.

This study tested the hypothesis that the evaluated dynamic navigation system would have high accuracy and precision and would be superior to FH implant placement methods.

Materials and Methods

This protocol was approved and administered under institutional review board (IRB) protocol number 2014-10-15 of BioMed (San Diego, CA).

TRIAL DESIGN

The study is a prospective evaluation of the accuracy and precision for placing implants. Four surgeons contributed patient data to this study. The surgeons agreed to follow the manufacturer's protocol with IRB consent by each patient.

PARTICIPANTS

Patients were consecutively included in this study within each surgeon's private practice. Patients were excluded from the study if they refused to sign a consent form. There was a difference in the number of included patients for each surgeon, reflecting the number of implants placed by each surgeon within the private practice. The total number of patients was grouped together for analysis. The demographic data comparing each surgeon were compared to ensure similar group demographics for the combined analyses (Table 1).

Each surgeon received 1 full day of training, which included simulation. At the conclusion of the training, they must have achieved proficiency as measured by angular deviation using the navigation screen's live feedback on bur angulation compared with the virtual plan. The second day of training included over-the-shoulder training to further decrease their learning curve.

PATIENT RECRUITMENT

All patients who required at least 1 implant and had sufficient teeth for clip registration were consecutively

Table 1. DEMOGRAPHIC VARIABLES OF PATIENTS TREATED BY EACH SURGEON

Surgeon	Patients, n	Men, n (%)	Age (yr), Average (Range)	Implants, n
1	263	135 (51.3)	59 (21-87)	407
2	128	58 (45.3)	61 (21-89)	188
3	37	18 (48.6)	52 (21-73)	45
4	50	31 (62.0)	58 (22-77)	74
Total	478	242 (50.6)	59 (21-89)	714

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enrolled in this IRB-approved protocol. Patients had to be older than 21 years and able to understand and sign a consent form. Inclusion criteria included the presence of at least 3 adjacent teeth in the arch to hold the clip, which contained the fiducials necessary to register the jaw to the navigation computer system. Exclusion criteria included those who refused to sign a consent form for prospective data evaluation, those who could not accept the normal risks associated with dental implants, or those whose remaining teeth could not support the patient tracking array. This could be the result of provisional restorations, tooth shape with a minimal retention form to stabilize the clip, or unstable teeth secondary to bone loss.

SCANNING PROTOCOL FOR DENTATE PATIENTS

To register the jaw into the navigation computer, a clip with 3 metallic fiducial markers was adapted onto the patient's teeth after heating in a water bath. The clip was placed in the same jaw as the planned implant, on the opposite side of the arch, avoiding the surgical site. The CBCT scan was obtained and the digital information was transferred to the navigation system's computer. Using the supplied software, nerve mapping was performed for mandibular posterior implants and virtual teeth were placed. If available, intraoral or laboratory laser scans as stereolithographic files were superimposed on the patient's jaw image using the planning software to guide implant placement. Virtual implants were placed and oriented in a position that allowed for the planned restorative care. The planned implant's platform diameter, apical diameter, length, and shape were entered in generic fashion into the software so the planned implant's geometry was identical to the implant to be placed in the patient. This system does not contain an implant library. Therefore, the implant's dimensions are used to plan the case.

SURGICAL PROCEDURES

The handpiece and patient tracking array were calibrated before each surgery. After staff calibrated the handpiece and tracking array, the surgeon performed the surgery. Each drill length was calibrated as it was used by the surgeon in the normal sequence of implant site preparation. System checks were performed to ensure accuracy of tracking, and the implant was guided into final position using the navigation screen.

The surgeon used the navigation screen to guide the position and angulation of the implant preparation (Fig 1). This is a real-time coordination of the surgeon's hands and eyes by 3D visualization of the preparation and important adjacent anatomy. If necessary, then changes in the plan were made at the time of surgery, including implant size, length, width, shape, and positioning as required clinically to achieve an accurate implant position.

A post-implant placement CBCT scan was taken. The plan and postoperative CBCT scans were uploaded for analysis by an individual not involved in patient treatment. Data were entered into a spreadsheet with no patient identifiers except for case number.

Fully guided (FG) describes the use of the navigation system to place the implant at its final depth. Partially guided (PG) describes when the preparation site is performed using the navigation system; however, the final seating of at least 50% of the implant's length is by hand. This is performed when the torque generated by the implant exceeds the torque available from the implant drill system or when the surgeon judges that direct visualization of the implant's depth is needed during seating.

FH placement occurred for several reasons. During the initial phase of this prospective study, the use of the navigation system was not used to complete an early data analysis to confirm that the accuracy of the system was appropriate for continued use of the system. During this short period, patients had a virtual plan in place, but the implants were placed by FH. The early data were found to be accurate so the study was continued using the navigation system. Another reason for FH placement was when the patient tracking array was not stable because of a lack of tooth contour definition. Another reason was the placement of provisional restorations or changes in restorations that were previously in place when the patient

FIGURE 1. The dynamic system in use. The light source above the patient reaches the patient tracking array and the array on the handpiece. The light is reflected from the arrays to 2 high-definition cameras (*arrows*). The captured reflected light is transmitted to the system-specific navigation computer to create the dynamic real-time representation.

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tracking array was used for scanning. At the time of surgery, the clips did not fit because of the new restorations.

FH data included those implants that were not delivered with the guidance system or when the guidance system was not used to prepare the osteotomy.

MESH ANALYSIS ACCURACY

Mesh analysis has been used to measure various objects.[35-40] For this study, a variant of the analysis was used.[41]

The mesh registration accuracy was assessed before its use in this study and was used in the submission to the Food and Drug Administration for the dynamic navigation system used in this study. Each of 20 sawbones models had 3 ball bearings inserted into jaw sawbones models. The sawbones were scanned by CBCT with a patient tracking array in place on the sawbones model. An implant was placed according to a virtual plan using the sawbones models. A second post-implant insertion CBCT scan was obtained.

The accuracy test was performed with registration of an iso-surface mesh extracted from the initial CBCT scan and registered to the secondary CBCT scan, finding a "best fit" transform that related the vertices of the mesh in the primary scan to those in the secondary scan with minimal cumulative displacement between the vertices. The computed mesh-to-mesh transform provided a mapping from one CBCT coordinate system to the other because the mesh vertices are defined within the CBCT coordinates.

To verify the transform was accurate, a second set of iso-surfaces was extracted from the initial and secondary CBCT scans. These iso-surfaces displayed only the metal inserted into the sawbones model. Automated analysis method was used to determine deviations in measurements. The errors were determined. The mean ball bearing displacement was 169 μm. The mean angular error was 0.375°. Based on this error analysis, this method was chosen to assess accuracy.

ACCURACY ANALYSIS PROCESS

The pre- and postoperative CBCT scans and the virtual plan file from the navigation system were uploaded to a computer for analysis. These 3 files were meshed in MeshLab (http://www.meshlab.net/). A virtual implant with the same dimensions as the plan was placed on the postoperative CBCT image, where the actual implant was delivered during surgery. This was accomplished because the implant was radiopaque. The virtual plan was superimposed onto the postoperative CBCT image. A mathematical algorithm was used 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 in 3 dimensions.

Table 2. SUMMARY OF FULLY GUIDED, PARTIALLY GUIDED, AND FREEHAND METHOD SURGICAL MEASUREMENTS

Surgeon	Angular Deviation (°)	Global Platform (mm)	Platform Depth Deviation (mm)	Platform Lateral Deviation (mm)	Global Apical (mm)	Apical Depth Deviation (mm)	Apical Lateral Deviation (mm)	Implants, n
Fully guided								
1	2.43 (1.36)	1.00 (0.49)	0.74 (0.55)	0.57 (0.30)	1.13 (0.53)	0.73 (0.54)	0.76 (0.37)	85
2	3.14 (2.54)	1.31 (0.56)	0.81 (0.58)	0.94 (0.42)	1.38 (0.63)	0.82 (0.59)	0.98 (0.57)	77
3	2.46 (1.05)	1.07 (0.61)	0.93 (0.71)	0.43 (0.17)	1.16 (0.64)	0.91 (0.71)	0.61 (0.31)	10
4	3.76 (2.23)	1.22 (0.70)	0.76 (0.68)	0.82 (0.52)	1.45 (0.81)	0.77 (0.70)	1.08 (0.73)	47
Total	2.97 (2.09)	1.16 (0.59)	0.76 (0.60)	0.74 (0.43)	1.29 (0.65)	0.78 (0.60)	0.90 (0.55)	219
Partially guided								
1	2.86 (1.78)	1.20 (0.64)	0.85 (0.70)	0.70 (0.40)	1.39 (0.69)	0.86 (0.71)	0.95 (0.53)	255
2	4.86 (2.88)	1.55 (0.73)	0.89 (0.84)	1.08 (0.52)	1.77 (0.92)	0.88 (0.82)	1.34 (0.85)	78
3	4.81 (2.78)	1.70 (0.68)	1.38 (0.74)	0.87 (0.40)	2.01 (0.75)	1.48 (0.71)	1.31 (0.65)	24
4	3.41 (2.43)	1.27 (0.58)	0.82 (0.51)	0.88 (0.55)	1.51 (0.76)	0.84 (0.52)	1.20 (0.71)	16
Total	3.43 (2.33)	1.31 (0.68)	0.89 (0.73)	0.80 (0.49)	1.52 (0.78)	0.90 (0.74)	1.01 (0.65)	373
Freehand								
1	6.10 (4.14)	1.86 (0.76)	1.25 (0.73)	1.24 (0.70)	2.34 (1.04)	1.17 (0.75)	1.90 (0.95)	67
2	7.74 (4.71)	1.86 (0.84)	1.12 (0.99)	1.21 (0.69)	2.44 (1.04)	1.17 (0.99)	1.97 (1.17)	33
3	5.79 (3.45)	1.63 (0.41)	0.72 (0.73)	1.26 (0.47)	1.90 (0.80)	0.72 (0.67)	1.65 (0.76)	11
4	5.96 (4.21)	1.24 (0.71)	0.77 (0.79)	0.78 (0.52)	1.68 (0.57)	0.84 (0.75)	1.30 (0.52)	11
Total	6.50 (4.21)	1.78 (0.77)	1.12 (0.83)	1.19 (0.68)	2.27 (1.02)	1.10 (0.82)	1.84 (1.05)	122

Note: Data are presented as mean (standard deviation).

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The following deviations (mean ± standard deviation) from the virtual plan were calculated[1] and are presented in Table 2:

- Angular deviation (°): largest angle in 3D space between the center axes of the planned and placed implants
- Global platform deviation (mm): overall deviation of the planned from the placed implant (takes angle, depth, and position into consideration)
- Global apical deviation (mm): overall deviation of the planned from the placed implant (takes angle, depth, and position into consideration)
- Depth deviation (mm): difference in depth (*z*-axis) of the planned from the placed implant (absolute values were used)
- Lateral platform deviation (mm): difference in lateral entry position of the planned from the placed implant
- Lateral apical deviation (mm): difference in the lateral apical position of the planned from the placed implant

STATISTICAL METHODS

One-way analysis of variance (ANOVA) with post hoc Tukey honest significant difference tests was performed to determine whether there was a statistically relevant difference among methods (FG, PG, and FH) of placement. ANOVA was performed on the entire dataset to determine whether the surgery method had a meaningful effect on the accuracy measurement. A χ^2 test of independence was used to determine differences in the patient population among surgeons.

Results

PATIENT SAMPLE

Table 1 presents the demographic summary for the guided methods. A χ^2 test of independence was performed to examine the demographics of patients among surgeons. There were no significant differences among surgeons ($\chi^2_3 = 4.41437$; $P = .2464$).

BETWEEN-SURGEONS ANALYSIS

One-way ANOVA was conducted to compare surgeons within each method. For FH cases, the surgeons did not show statistically significant ($P > .05$) differences across all accuracy measurements. For PG cases, the surgeons showed statistically significant ($P < .05$) differences for all accuracy measurements. For FG cases, the surgeons showed statistically significant ($P < .05$) differences for all measurements except apical depth deviation and platform depth deviation.

WITHIN-SURGEON ANALYSIS

One-way ANOVA was conducted to compare differences in accuracy measurements across methods for each surgeon. Surgeons 1 and 3 each showed

Table 3. SIGNIFICANCE LEVELS COMPARING GUIDANCE METHODS

	Angular Deviation	Global Platform Deviation	Platform Depth Deviation	Platform Lateral Deviation	Global Apical Deviation	Apical Depth Deviation	Apical Lateral Deviation
FH vs PG vs FG	<.05	<.05	<.05	<.05	<.05	<.05	<.05
FG vs FH	<.05	<.05	<.05	<.05	<.05	<.05	<.05
PG vs FH	<.05	<.05	<.05	<.05	<.05	<.05	<.05
FG vs PG	<.05	<.05	<.05	NS	<.05	<.05	<.05

Note: Data are presented as *P* values (significant at *P* > .05).
Abbreviations: FG, fully guided; FH, freehand; NS, not significant; PG, partially guided.

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statistically relevant differences across the 3 methods in all accuracy measurements. Surgeon 2 showed statistically relevant differences across the 3 methods in all accuracy measurements except platform depth deviation and apical depth deviation. Surgeon 4 showed a statistically relevant difference across the 3 methods for only 1 accuracy measurement (angular deviation). Table 2 presents the average deviations from the virtual plan for each surgeon. For most accuracy measurements, each surgeon had better average accuracy and precision using guided methods than the FH method.

ANOVA results are listed in Table 3. When all 3 methods were evaluated together, differences in surgery methods were statistically significant (*P* < .05) for all measurements. When comparing FG navigation with FH methods, all measurements were significantly different (*P* < .05). When comparing PG navigation with the FH method, all measurements were significantly different (*P* < .05). When comparing FG navigation with PG navigation, there were meaningful differences for 6 of 7 measurements. The differences between angular deviation and platform lateral deviation were not relevant. The remaining 6 measurements were substantially different.

One-way ANOVA applied to the dataset showed statistically significant (*P* < .05) differences among the 3 guidance methods on all accuracy measurements. All combinations of comparisons among the guidance methods are presented in Table 3.

Table 4 presents the 95% confidence intervals broken down by surgeon and guidance method for angular deviation. The confidence interval shifts among guidance methods for each surgeon across all accuracy measurements.

Table 5 presents the 95% confidence intervals broken down by guidance method and accuracy measurement. For each accuracy measurement, the confidence interval shifts among guidance methods. For each accuracy measurement, the means and standard deviations are smaller for guided (FG and PG) methods than for the FH method.

Figure 2 graphically shows that the FG and PG methods were more accurate than the FH methods. Figure 3 shows the mesh analysis.

Discussion

Accuracy of implant placement is essential to allow for efficient and routine care of patients. If an implant is not accurately placed, then it still might be restorable but requires additional prosthetic manipulation through the use of custom abutments, angled screws, deeper cement margins, increased chair time, and additional costs for the dentist and patient.

Advances in dynamic navigated surgery have allowed an understanding of the various levels of guidance (FG, PG, and FH). Often these levels of guidance are driven by the clinical situation at the time of surgery,

Table 4. 95% CONFIDENCE INTERVALS FOR SURGEON TO METHOD FOR VARIABLE ANGULAR DEVIATION

				95% CI	
Surgeon	Method	Estimated Marginal Mean	SE	Lower Bound	Upper Bound
1	FH	6.102	0.317	6.851	8.624
	FG	2.431	0.281	1.878	2.983
	PG	2.861	0.162	2.542	3.180
2	FH	7.738	0.452	6.851	8.624
	FG	3.145	0.296	2.564	3.725
	PG	4.864	0.294	4.287	5.441
3	FH	5.790	0.782	4.254	7.326
	FG	2.456	0.820	0.846	4.066
	PG	4.810	0.529	3.770	5.849
4	FH	5.960	0.782	4.424	7.326
	FG	3.762	0.378	3.019	4.505
	PG	3.407	0.648	2.134	4.681

Abbreviations: CI, confidence interval; FG, fully guided; FH, freehand; PG, partially guided; SE, standard error.

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Table 5. 95% CONFIDENCE INTERVALS OF ACCURACY MEASUREMENTS ACROSS METHODS

Accuracy Measurement	Method	Mean	SE	95% CI Lower Bound	95% CI Upper Bound
Angular deviation (°)	FH	6.398	0.309	5.791	7.004
	FG	2.948	0.248	2.462	3.435
	PG	3.986	0.225	3.543	4.428
Global platform (mm)	FH	1.647	0.078	1.493	1.801
	FG	1.150	0.063	1.027	1.273
	PG	1.431	0.057	1.318	1.543
Platform lateral deviation (mm)	FH	1.122	0.057	1.011	1.234
	FG	0.686	0.046	0.597	0.776
	PG	0.883	0.042	0.802	0.965
Apical lateral deviation (mm)	FH	1.704	0.083	1.541	1.866
	FG	0.859	0.066	0.729	0.989
	PG	1.201	0.060	1.082	1.320
Global apical (mm)	FH	2.093	0.092	1.912	2.273
	FG	1.280	0.074	1.135	1.425
	PG	1.684	0.067	1.553	1.816
Apical depth deviation (mm)	FH	0.974	0.084	0.808	1.139
	FG	0.810	0.068	0.677	0.943
	PG	1.015	0.062	0.894	1.136
Platform depth deviation (mm)	FH	0.965	0.084	0.799	1.130
	FG	0.809	0.067	0.677	0.942
	PG	0.986	0.061	0.865	1.106

Abbreviations: CI, confidence interval; FG, fully guided; FH, freehand; PG, partially guided; SE, standard error.

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including limited mouth opening or clip stability. The present findings are similar to those of other large trials, confirming that navigated guidance increases accuracy and precision for implant placement.[2]

As presented in Table 2, FG implant placement had the least deviation from the virtual plan compared with the other 2 methods. In a situation in which the implant site was prepared but the implant was placed with more than half its length placed without navigation guidance (PG), accuracy decreased. This is most likely the result of the implant following the course of least resistance within the bone because of the

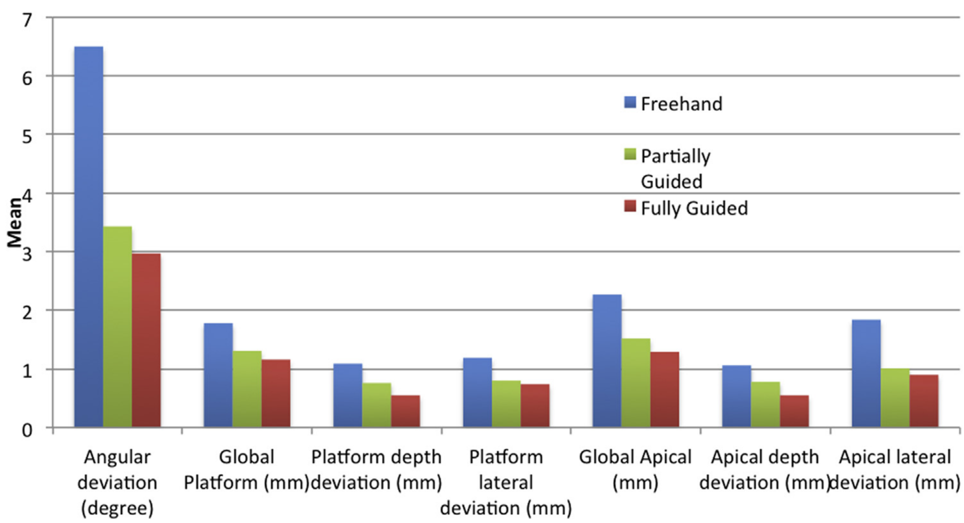

FIGURE 2. Mean accuracy values by surgery method.

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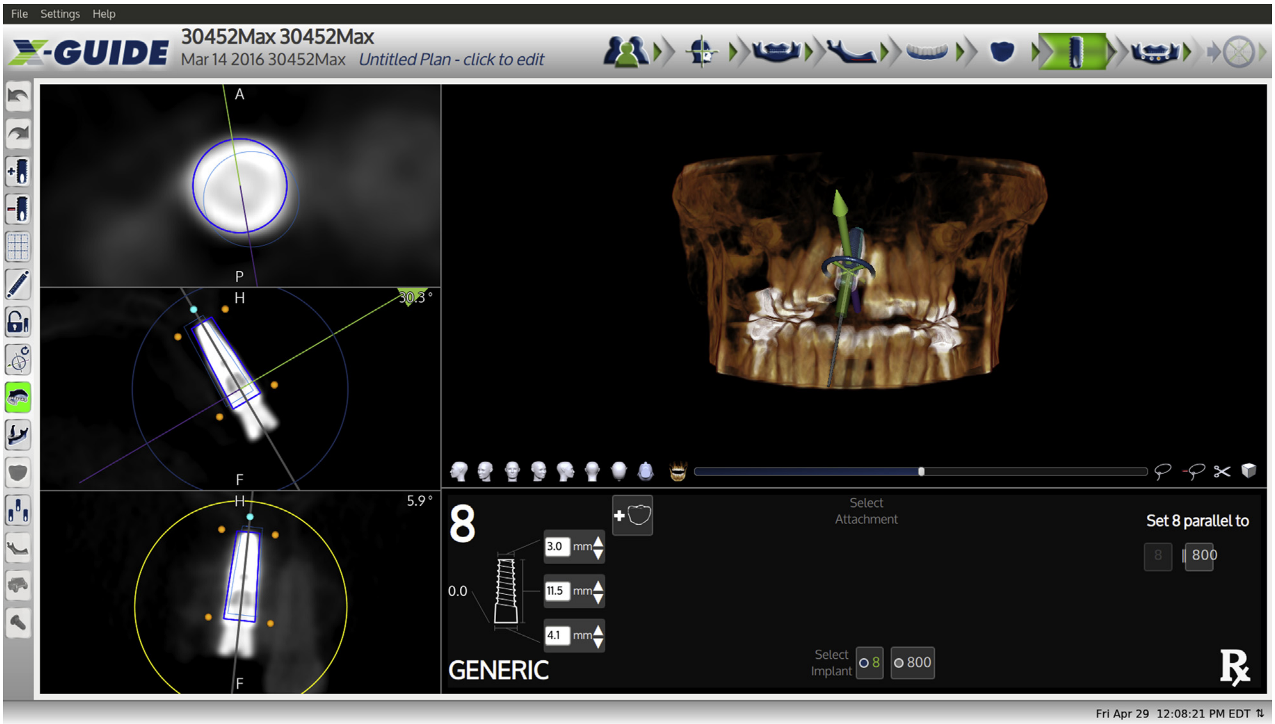

FIGURE 3. An example of a mesh used to determine accuracy. The *blue area* is the virtual plan and the implant image is the position of the implant taken from the cone-beam computed tomogram immediately after placement.

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presence of dense bone. FH placement was less accurate compared with guided methods.

When a laboratory-fabricated or static guide is used to place the implants, the presence of the guide can limit visualization of the implant's crestal depth location. Using the dynamic navigation system, the surgeons can always see the implant's location on the screen or in the mouth, without prosthetic interference. It is easier to fully guide the fixtures without such interference.

Precision describes the tightness of the pattern of placement. For implants, each placement should have the same precision with minimal deviation across patients. Routine precise implant placement should be the goal for all implant placements and not the standard of only a few. Clinicians should be aware of advances that allow for accuracy and precision within an efficient workflow in the practice setting. If there are methods that definitively improve the accuracy and precision of implant placement, then all patients should benefit from this method. Navigation does improve the accuracy and precision of implant placement and should be widely used. This method should have a practical workflow and a reasonable learning curve to allow for proficiency to be achieved by the clinician performing the surgery. There is a learning curve with dynamic navigation.[1] With static guides, the learning curve was decreased when the inexperienced surgeon learned from observing an experienced surgeon.[26] Cardiothoracic surgeons have been shown to have learning curves specific to their procedure.[42] The learning curve for colonoscopy has been shortened using simulation in their training.[43] The investigating surgeons believed their efficiency and ergonomics were improved using the device once proficiency was reached.

The evaluated dynamic guided system is at least as accurate as static guides and is an improvement over FH implant placement. Even with the aid of a laboratory-fabricated guide, which is not true guidance, the error with the FH approach is greater.[1-4] It is difficult to find data on the accuracy of implants placed with the diverse laboratory-fabricated guides used by clinicians, which range from vacuum forms to solid guides. Most of these laboratory fabricated guides are not designed with the underlying bone visualized.

Although experienced surgeons can place implants FH within a sphere of accuracy, in this report involving 4 experienced surgeons, the angular deviation was the variable most controlled by navigation. The difference was important. The data presented in Tables 4 and 5 show the binary limits of the ranges among the 4 surgeons for each method. It is obvious that the guided methods were more accurate with greater precision according to the confidence intervals compared with FH placement.

Global positions are 3D measurements affected by depth. Final depth positions are difficult to visualize before surgery. Thin labial bone and soft tissue margins might be impossible to visualize on CBCT. The inability to visualize depth during planning can result in less precision. The final decision regarding depth is often made during surgery. The tested dynamic navigation system has a software tool that allows the surgeon to easily adjust the plan depth during surgery. Thus, depth might be the least affected variable when any form of guidance is used. In this study, depth was the most accurate measurement and the least precise. The ability to change final depth position at the time of surgery is an important benefit of dynamic navigated surgery that is easy to overlook.

As presented in Table 2, the insertion point as reflected in the lateral platform deviation was similar comparing navigation with FH as categorized in this trial. Depth placement also was similar in reflecting expected visual aspects of placing the implant at the level of the crestal bone or a specific subcrestal amount depending on clinician preference. These values were clinically close; however, the differences in precision of the measurement did result in important differences.

The hypothesis that dynamic navigation would be an improvement in accuracy and precision compared with FH methods was tested and confirmed.

Using dynamic navigation does have additional benefits for the patient. There is a paralleling tool to aid the clinician in virtual implant placement. Incisions can be limited and flap reflection can be decreased because there is less need for broad bone exposure. A unique advantage using dynamic navigation is the ability to modify the surgical plan in real time. In this study, the final position and implant size actually placed were used in the mesh analysis.

Because of the shorter surgical instrumentation, this dynamic system can be used in second molar regions and in patients who have restricted opening. With navigation, one can expect fewer complications involving the inferior alveolar nerve or implant impingement on adjacent tooth roots. There is no specific drill system or surgical instrument needed for dynamic navigation systems in contrast to static navigation with their cylinders within the guides. Because the surgeon visualizes the surgery on a monitor, the surgeon can maintain excellent posture, decreasing clinician morbidity.

A clinician placing implants must be concerned with perfecting implant position. This study clearly indicates that navigation methods provide a statistically relevant improvement over FH methods. Clinicians placing implants must consider routinely improving their precision and accuracy and not just for a "special" case. Implants that are not parallel complicate restorative care. When adjacent implants are not properly spaced, the subsequent problems with maintenance and esthetics can affect long-term results. Axial alignment of implants to optimize occlusal force distribution should result in less screw breakage and other prosthetic complications.

Dynamic navigation will improve accuracy and precision of implant placement. Angulation deviation was the most important measurement improved using dynamic navigation.

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