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Does it take more than a static pilot guide to match the accuracy of dynamic navigation? A preliminary randomised study

KEYWORDS

accuracy, CBCT, dental implant, dynamic guided surgery, guided surgery, static guided surgery

ABSTRACT

Purpose: To compare the accuracy of static guided surgery using a pilot drill guide and dynamic guided surgery for dental implant placement.

Materials and methods: Partially edentulous adult patients requiring implant placement were randomly assigned to either the static guided surgery group using a pilot drill guide or the dynamic guided surgery group. Digital implant planning was conducted using intraoral scans and CBCT with planning software to determine the optimal prosthetic position. Postoperative CBCT scans were taken to compare with the plan and assess platform, apex, vertical and angular deviations from the planned implant positions.

Results: A total of 25 implants were placed. Mean deviations at the implant platform were 1.17 ± 0.75 mm for the static guided surgery group and 1.17 ± 0.71 mm for the dynamic guided surgery group, with no significant differences ($P = 0.983$). Apical deviations were 2.39 ± 1.22 mm for the static guided surgery group and 1.75 ± 0.59 mm for the dynamic guided surgery group, with no significant differences ($P = 0.112$). Vertical deviations were 0.79 ± 0.50 mm for the static guided surgery group and 0.61 ± 0.51 mm for the dynamic guided surgery group ($P = 0.403$). Significant differences were found in angular deviations, with the static guided surgery group showing 10.9 ± 5.63 degrees and the dynamic guided surgery group showing 4.72 ± 2.63 degrees ($P = 0.002$). Independent variables such as sex, age, implant location, arch and implant size did not significantly influence accuracy.

Conclusion: Both static and dynamic guided surgery offer comparable precision in implant placement, with dynamic guided surgery providing superior angular accuracy. Further studies with larger sample sizes are recommended to validate these findings.

Conflict-of-interest statement: *The authors declare there are no conflicts of interest relating to this study.*

Introduction

In the field of dental implantology, accurate implant positioning is a fundamental starting point to optimise aesthetic and functional outcomes. Malposition of dental implants not only affects the desired aesthetic results but also increases the likelihood of biological and/or biomechanical complications.¹

The implant position is determined exclusively by the specific demands of the prosthetic rehabilitation and respect for the neighbouring anatomical structures.²

Traditionally, surgeons relied on panoramic images and tactile experience; however, two-dimensional images do not provide sufficient detail about anatomical structures, and thus increase the risk of

iatrogenic damage.^{3,4} Additionally, they fail to offer the necessary spatial information to accurately position implants and meet the prosthetic requirements for effective rehabilitation.^{5,6} Preoperative implant planning was transformed in 1993 when SimPlant (Simplant Pro, Dentsply Sirona, Charlotte, NC, USA) enabled clinicians to combine axial, cross-sectional and panoramic views with virtual implant placement. Later, the software introduced 3D reformatting imaging capabilities.⁵ This paved the way for two prominent methodologies aimed at translating the virtual implant plan to actual surgical placement: static and dynamic navigation.^{6,7} While static guided surgery (SGS) employs rigid templates to translate virtual implant positions to the surgical site, dynamic guided surgery (DGS) operates by optically tracking the position of the surgical handpiece relative to the patient's CBCT in real time, with the data visualised on a monitor.⁸⁻¹⁰ This approach offers an immediate feedback mechanism, enabling the surgeon to make real-time adjustments. It is analogous to the Global Positioning System (GPS) in the transportation industry. Although SGS has exhibited widely adequate accuracy and predictability in replicating planned implant positions,^{11,12} it presents certain limitations, such as the necessity for wider mouth opening, issues with stabilisation in edentulous patients, hampered visibility of the surgical field, obstructed bone irrigation, time-consuming preoperative preparation, irreversibility of the printed guide^{13,14} and, most importantly, as there is no intraoperative real-time feedback, the fact that large errors can only be determined postoperatively.¹⁵⁻¹⁹

DGS does not share many of the limitations observed in SGS and has therefore emerged as a promising alternative, with its advantages of offering an unobstructed surgical field, maintaining bone irrigation and eliminating the need for excessive mouth opening being well-documented. Moreover, DGS can be considered a form of freehand surgery that harnesses the benefits of a guided implant system, providing real-time feedback and greater flexibility in clinical scenarios. Studies have demonstrated the comparable accuracy of both methods in replicating planned implant positions,²⁰⁻²² with DGS often exhibiting superior angular precision.^{22,23} These findings highlight the accuracy and reliability

of DGS in dental implantology, supporting its integration into mainstream clinical practice.^{24,25} One of the significant drawbacks of DGS, however, is the steep learning curve associated with mastering the technique.^{20,22,26,27} This can pose challenges for newcomers to the field or those unfamiliar with the technology. Additionally, despite the advancements in navigation technology that have been made over the past decade, there are no comparative studies evaluating DGS against alternative static guidance methods, such as pilot drill guides, as opposed to fully guided techniques. The objective of this preliminary study is to address this lack of comparative data by evaluating the accuracy of SGS and DGS techniques in implant placement and to establish a foundation for future, larger-scale investigations. The null hypothesis is that there is no significant difference between SGS and DGS in terms of the accuracy of implant placement. Conversely, the working hypothesis posits that DGS provides greater accuracy compared to SGS.

Materials and methods

Study design

Patients at the Universitat Internacional de Catalunya (UIC), Barcelona, Spain, requiring implant rehabilitation were considered for a prospective, single-blinded, randomised clinical trial that adhered to the Helsinki Declaration and was approved by the institution's Ethics Committee (Sant Cugat del Vallés, Barcelona, Spain; code: CIR-ECL-2018-09). The trial was registered at ClinicalTrials.gov with the number NCT06417788. The eligibility criteria included being aged 18 years or older, type 1 or 2 according to the American Society of Anesthesiologists' classification, full mouth plaque scores up to 25%,²⁸ partial edentulism with at least one missing tooth, and bone crest of at least 10.0 mm in length and 7.0 mm in width. The exclusion criteria included medical conditions contraindicating surgery, untreated periodontal disease or caries, the need for bone augmentation, acute local infections, and a history of head/neck radiation. In line with the CONSORT statement,²⁹ patients were randomly assigned

using software (<https://www.randomizer.org/>) to either DGS using Navident (ClaroNav, Toronto, Canada) (test group) or SGS with a stereolithographic template (control group). A total of 10 patients and 25 implants were enrolled in the study, which was designed as a preliminary investigation. No formal power analysis was conducted; the sample size was determined based on convenience, resource availability and ethical considerations.

CBCT data acquisition

CBCT scans (i-Cat; Imaging Sciences International, Hatfield, PA, USA) were taken of each patient. To standardise data collection, the diameter and height of the exposure volume were set to 102.0 mm. The voxel size was $0.2 \times 0.2 \times 0.2$ mm. The manufacturer's recommendations were followed when configuring the settings (80 kV and 5 mA). Additionally, the Frankfort plane was used for cranial reference, and an occlusal rim was employed to avoid occlusion during the acquisition phase.

Implant planning

The SGS planning process began by taking a conventional intraoral scan using the TRIOS system (3Shape, Copenhagen, Denmark). This scan was uploaded to exoplan, the implant planning and surgical guide design software (exocad, Darmstadt, Germany), to design a digital crown representing the desired prosthetic outcome.

The crown design included a drill hole positioned on the central occlusal surface to reflect the correct position and axis for a screw-retained restoration. This predetermined pilot drill hole served as the reference to position the virtual implant in a precise axis and position in the CBCT scan, ensuring that the implant placement would align with the prosthetic plan.

The crown design file, containing the pilot drill hole, was then uploaded to digital planning software (Blue Sky 4, Grayslake, IL, USA). Using this information, a tooth-retained, sleeve-free pilot drill guide was created, designed like a nightguard for stability by extending over as many teeth as possible while avoiding gingival coverage to allow flap elevation during surgery (Fig 1). The hole was wide

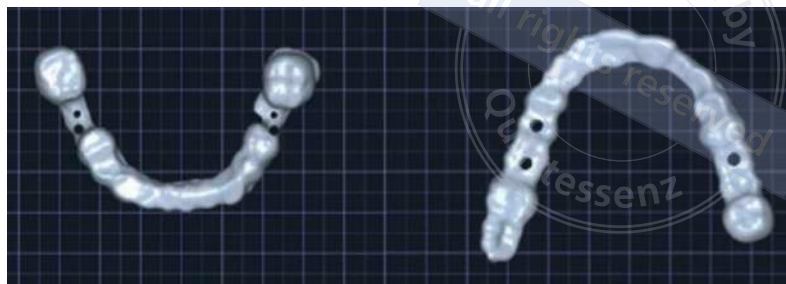


Fig 1 Static stereolithographic pilot drill guide design.

enough to fit only the pilot drill, rendering the use of a specific guided surgical kit unnecessary as this was not a fully guided approach. Finally, a stereolithographic template was printed using a Form 2 3D printer (Formlabs, Somerville, MA, USA).

On the other hand, in the DGS system, stereolithographic (STL) files from the TRIOS intraoral scanner and DICOM files were imported into Navident planning software (version 2.1). After synchronising these files, a digital crown was created directly within the Navident software library, adjusting the size, shape and position to achieve the optimal prosthetic outcome. The implant was then situated virtually based on the position of the adjusted crown. The implant chosen from the library was one that had a similar macrodesign to the IS-III Active implant (NeoBiotech, Seoul, South Korea) with a diameter of either 3.5 or 4.0 mm and a length of either 8.5 or 10.0 mm. Digital planning was performed simultaneously by two experienced operators (JMG and ABB), and any discrepancies that arose were solved through discussion.

In both groups, the position of the virtual implant was determined based on the following:

- Meso-distal position: The implant was placed at least 1.5 mm away from the neighbouring teeth or at least 3.0 mm away if there was a neighbouring implant. The angulation allowed the implant to have an emergence at the central part of the occlusal virtual crown.
- Bucco-palatal/lingual position: The implant was placed within the alveolar bone, with at least 1.5 mm buccal and palatal bone thickness and with an angulation emerging at the central fossae part of the virtual crown.
- Vertical (apico-coronal) position: The implant platform was positioned between 3.0 and

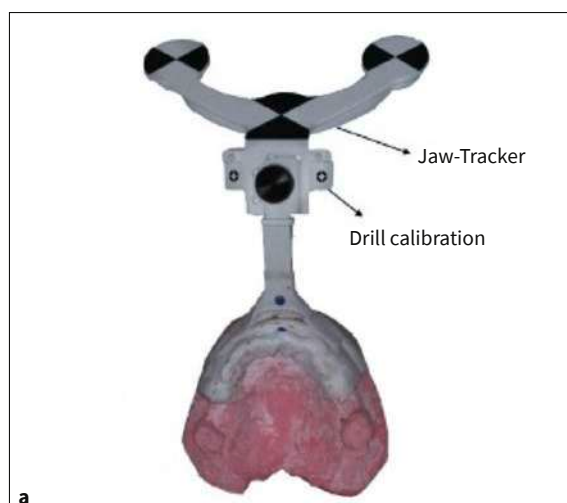


Fig 2a and b The Jaw-Tracker is secured by the guide and positioned within the view of the camera for tracking. The drill calibration module calibrates the drill length before each use, where the drill is placed within the designated circle for calibration, and must also remain within the view of the camera (a). The DrillTag, attached to the handpiece, must stay within the view of the camera to enable accurate tracking (b).

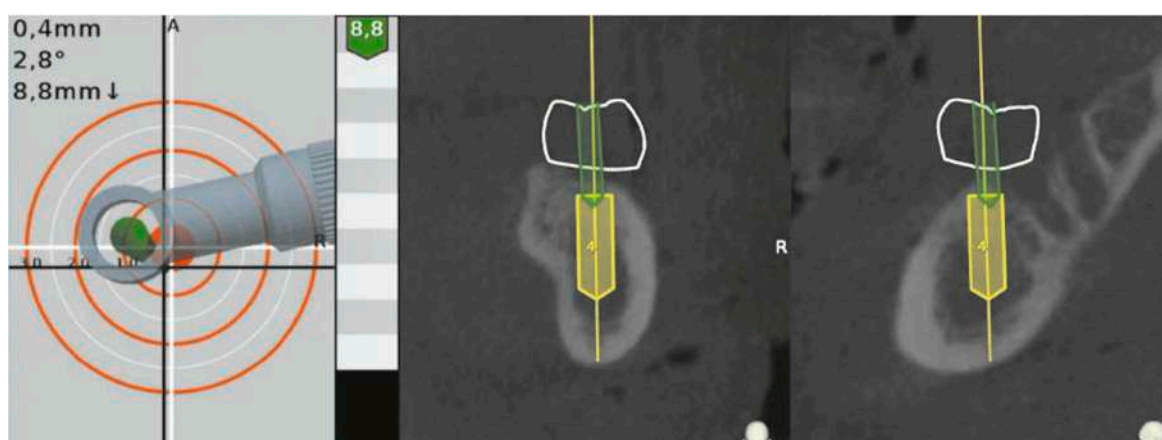


Fig 3 Real-time guidance showing the actual drilling (in green) and the planned implant position (in yellow). Any discrepancies are displayed immediately.

4.0 mm below the zenith of the virtual crown and 0.5 to 1.0 mm subcrestal to the alveolar process.

Surgical procedure

All surgical procedures were performed by a third-year resident (ABB) of the international Master in Oral Surgery programme at the UIC, with extensive experience in conventional implant dentistry and no prior hands-on experience with either SGS or DGS.

Patients began a 7-day course of amoxicillin (500 mg every 8 hours) or clindamycin (300 mg every 8 hours for those allergic to penicillin) the day before their surgery. A self-tapping Active implant (Neo Biotech) either 3.5 or 4.0 mm in diameter and between 8.0 and 12.0 mm in length was used in all cases. Each surgical procedure started with rinsing with 0.12% chlorhexidine mouthrinse, followed

by an injection of 2% lidocaine hydrochloride with 1:100,000 adrenaline (Septodont, Louisville, KY, USA). In both groups, surgeries involved creating a full-thickness flap through a crestal incision with intrasulcular incisions around adjacent teeth if present.

After this, each group followed its respective guidance protocol. In the test group, the Head-Tracker and Jaw-Tracker (Navident) (Fig 2) were positioned extraorally, corresponding to the patient's maxilla or mandible, respectively, depending on the implant location. The printed QR codes for these tags, along with the tracer tool and the DrillTag, were then identified by placing them within the view of the camera. The tracer tool then matched radiographic landmarks (usually between three and six) from the scan to real points in the patient's mouth, like the canines and/or the gingival zenith. After

that, the calibrator was used to set the handpiece axis and each drill. Finally, the computer displayed the planned implant positions on the CBCT scan. It showed the bone drilling and implant insertion in real time, highlighting any deviations from the plan as they occurred (Fig 3). The dynamic guided implant placement workflow is described in Fig 4.

In the control group, only the starting helicoidal drill (pilot drill) was used through the guide, whereas all the subsequent drills were used completely free-hand. Nevertheless, the guide was employed in between each drill, and the corresponding guide pin was fitted through it with the intention to assess whether the drilling was satisfying the planned angulation and position.

After implant insertion, a healing abutment was placed, and the flap was sutured with interrupted monofilament 5/0 sutures. The implant placement sequence is described in Fig 5.

Postsurgical procedure

The evaluation process involved importing both scans directly into EvalNav without any manipulation in external software. The software includes built-in tools for focusing on areas of interest. Specifically, non-essential structures in the CBCT image were automatically excluded using the software's internal 3D sculpting functions to isolate the implant region and facilitate accurate alignment. The planned and postoperative scans were then matched manually by referencing key anatomical points, such as the mental foramen and greater palatine foramen. Automated alignment was applied afterwards to enhance precision and ensure the closest possible match between the scans. While much of the process was automated, manual intervention was employed when alignment was deemed imperfect to ensure accuracy. To determine the quality of alignment, three techniques were employed:

1. Checkerboard overlay: Alternates between pre- and postsurgical images, highlighting misalignments through visible shifts in anatomical structures.
2. Magenta/green blend: Misalignments appear as colour contrasts, whereas proper alignment appears grey.

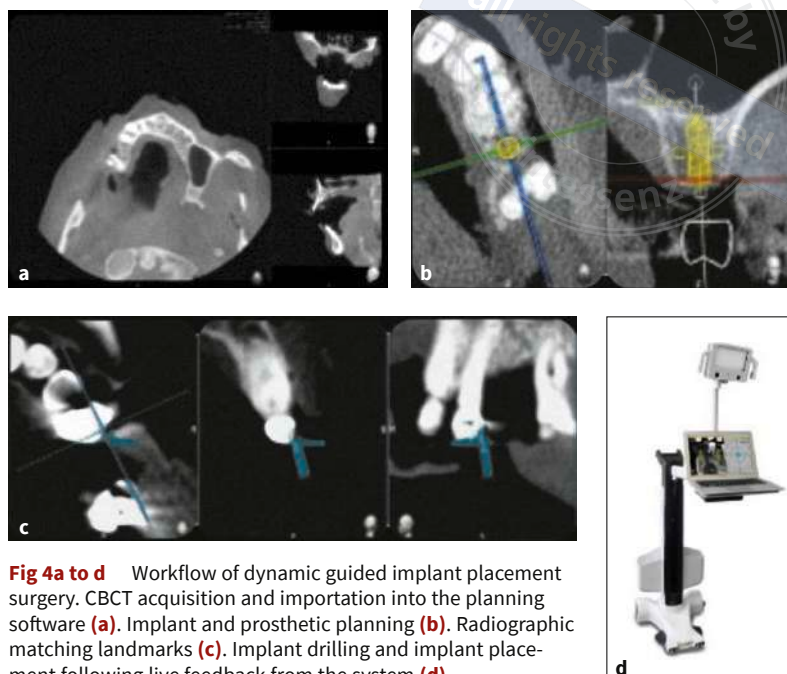


Fig 4a to d Workflow of dynamic guided implant placement surgery. CBCT acquisition and importation into the planning software (a). Implant and prosthetic planning (b). Radiographic matching landmarks (c). Implant drilling and implant placement following live feedback from the system (d).

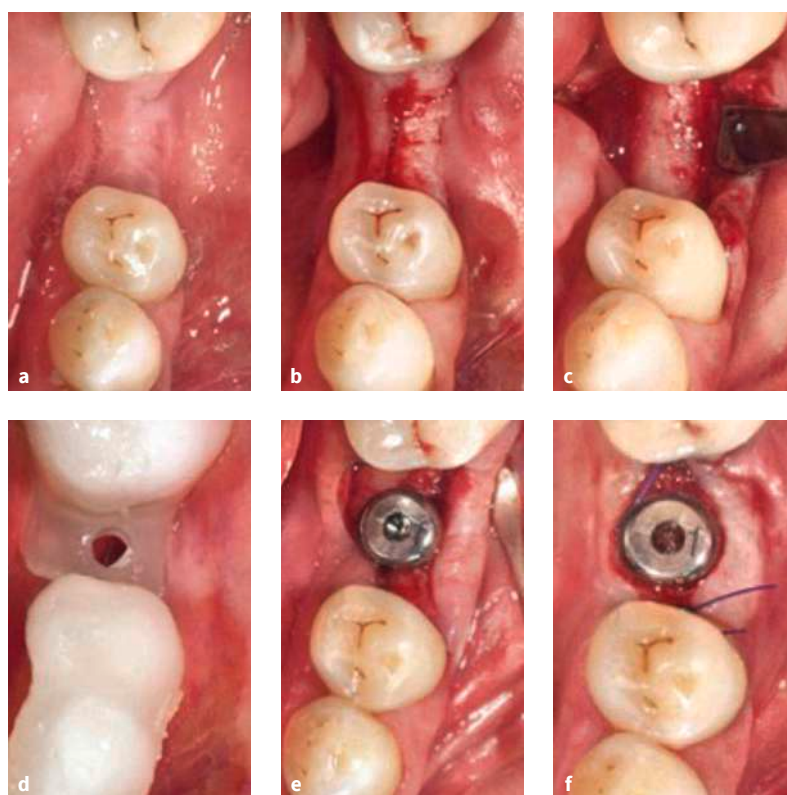
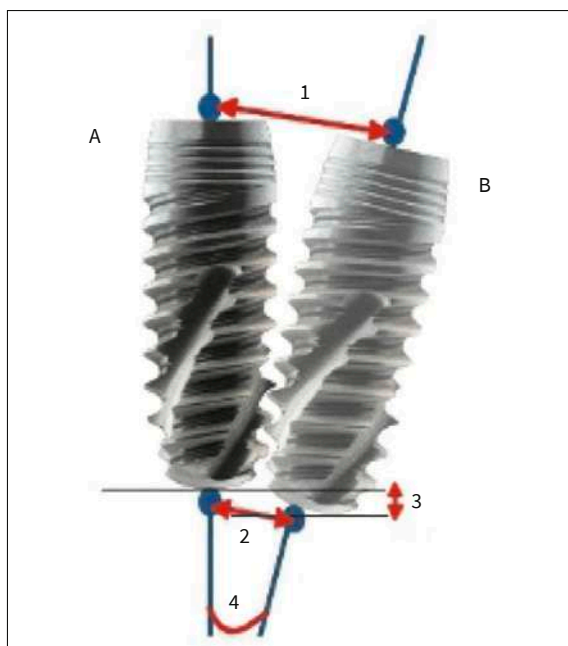


Fig 5a to f Surgical sequence in the SGS group.

3. Image toggle: Creates a noticeable shift in misaligned structures when toggling between images.

Fig 6 Measurements. 1, platform deviation; 2, apex deviation; 3, apico-coronally; 4, angular deviation; A, planned implant position; B, actual implant position following surgery. This figure was elaborated by the authors and used previously in Marques-Guasch et al.²⁷



If alignment appeared unsatisfactory at any stage, the entire process was restarted. Any necessary adjustments were made by the examiners to ensure the model matched the actual postsurgical position of the implant. If the overlay was deemed satisfactory, the software generated a model of the implant based on the postoperative scan, and the following data were recorded:

- platform deviation: deviation at the implant platform, expressed in millimetres;
- apex deviation: deviation at the apical part of the implant, expressed in millimetres;
- vertical deviation (apico-coronally): vertical distance between planned and actual implant positions, expressed in millimetres;
- angular deviation: axial deviation of the implant, expressed in degrees.

A detailed scheme of measurements is provided in Fig 6.

The evaluation process was performed by two blinded examiners independently (MSN and JGA), referred to as Examiner 1 and Examiner 2. Immediately after the surgery, CBCT scans were taken using the previously mentioned standardised method, and then imported into EvalNav for evaluation.

Following satisfactory alignment, the software generated a model of the actual implant position,

from which platform, apex, vertical and angular deviations were measured.

Statistical analysis

First, descriptive statistics were calculated, namely mean, standard deviation, minimum, maximum, median and quartiles. A Shapiro-Wilk test, with results yielding *P* values greater than 0.05, confirmed the normality of the data, leading to the adoption of a parametric analysis method. Quantile-quantile plots and distribution graphs were used to ensure the absence of outliers and the acceptability of data symmetry and kurtosis, ensuring that the mean values were not skewed compared to the medians. For inferential analysis, 95% confidence intervals (CIs) were estimated for each deviation. An independent samples *t* test was conducted to explore whether mean deviation values were influenced by the guidance technique used. This test was also applied to examine deviations in relation to patient and implant characteristics such as sex, arch and implant size. The Pearson linear correlation coefficient was calculated to assess the relationship between deviation and patient age.

Additionally, to evaluate the uniformity of groups based on independent factors, a chi-square test and Fisher exact test were employed. The threshold for statistical significance was set at 5% ($\alpha = 0.05$).

Results

A total of 25 implants were placed uneventfully in 10 patients, achieving a minimum of 25 Ncm insertion torque. The mean age of the total sample was 58.4 years (53.5 years for the SGS group and 63.8 years for the DGS group). Most implants were placed in the maxilla (76%) and in the premolar and molar area (48% and 44%, respectively). The exact implant locations, categorised by guidance system (SGS vs DGS), along with specific placement contexts (single-tooth gaps) are detailed in Table 1. In the DGS group, women were the recipients of all the implants (100%). Conversely, in the SGS group, the percentage of implants received by women was significantly lower, at just 30.8%. All this information

and details on implant distribution are summarised in Table 2.

The analysis assessed whether the study variables were distributed comparably across guidance systems. The only significant difference observed was in the sex of participants; however, further analysis using multiple model estimation showed that neither the sex of the participants nor any other variable affected the accuracy of the system.

Coronal deviation

Mean implant deviation at the implant platform was 1.17 ± 0.75 mm (95% CI 0.72 to 1.63 mm) and 1.17 ± 0.71 mm (95% CI 0.72 to 1.62 mm) for the SGS and DGS group, respectively (Table 3). No statistically significant differences were found between groups ($P = 0.983$). Subsequent analysis revealed that none of the independent variables had a significant effect on accuracy, as no statistically significant differences were observed.

Apical deviation

Mean implant apex deviation for the SGS group was 2.39 ± 1.22 mm (95% CI 1.65 to 3.13 mm) and 1.75 ± 0.59 mm (95% CI 1.37 to 2.13 mm) for the DGS group. No statistically significant differences between groups were found ($P = 0.112$), as shown in Table 3. None of the independent variables had any influence on the apical accuracy.

Vertical deviation

Mean vertical implant deviation was 0.79 ± 0.50 mm (95% CI 0.49 to 1.09 mm) and 0.61 ± 0.51 mm (95% CI 0.29 to 0.94 mm) for the SGS and DGS groups, respectively. No statistically significant differences were found between groups ($P = 0.403$) (Table 3). Sex, age, implant location, arch and implant size did not affect the vertical accuracy.

Angular deviation

Mean angular deviation was 10.96 ± 5.63 degrees (95% CI 7.56 to 14.4 degrees) and 4.72 ± 2.63 degrees (95% CI 3.05 to 6.39 degrees) for the SGS and DGS

groups, respectively. Statistically significant differences between groups were found ($P = 0.002$), as demonstrated in Table 3. Subsequent examinations revealed that none of the independent variables showed statistically significant differences.

Discussion

This preliminary pilot study suggests that DGS and SGS show comparable ability to accurately replicate planned implant positions, including coronal and apical horizontal deviations, as well as vertical implant deviations; however, DGS offers improved precision in angular deviation.

The aesthetic outcome and long-term success of the implant restoration are influenced significantly by placing the dental implant in the correct anatomical and ideal prosthetic position.^{2,30} Dental implant malposition is a well-known trigger for the development of peri-implantitis.³¹ It has been proven that the use of either a static guide with a fully guided drilling sequence or a dynamic system is significantly more accurate than the freehand method, regardless of whether the cases are partially or completely edentulous.^{32,33} In fact, a recent study revealed that although a pilot drill guide was less reliable than a full guide, the mere use of a static pilot drill guide was sufficient to achieve more precise results than those obtained through the freehand method.³⁴

A limited number of clinical comparisons between fully guided protocols employing static guides and DGS have been documented previously, with no significant differences in precision reported.^{21,23,35-37} It is important to note, however, that in the referenced studies, the operators had prior experience with both systems, which likely contributed to the comparable precision observed. This is particularly relevant for the DGS, as it has a steep learning curve.^{20,22,27} In contrast, SGS does not involve a significant learning curve, and the influence of the human factor on the accuracy of the procedure seems to be reduced.^{38,39} Despite these findings, the complexity of the dynamic system, with its higher costs and technical demands, raises the question of whether such complexity is always necessary.

Table 1 Distribution of specific implant placements and their clinical contexts, including corresponding deviations in coronal, apical, vertical and angular positioning

Group	Arch	Tooth site	Specific placement context	Coronal deviation, mm	Apical deviation, mm	Vertical deviation, mm	Angular deviation, degrees
SGS	Maxilla	14	Single gap	1.26	2.54	0.35	9.25
	Maxilla	15	Single gap	1.21	1.32	1.18	8.56
	Maxilla	24	Single gap	0.21	3.32	1.39	14.78
	Maxilla	25	Single gap	1.67	5.29	1.02	23.25
	Maxilla	14	Single gap	1.23	1.63	1.39	5.29
	Maxilla	24	Single gap	0.9	2.23	0.15	9.00
	Maxilla	25	Single gap	0.43	1.87	1.14	6.48
	Mandible	44	Single gap	1.42	2.14	0.14	10.57
	Mandible	46	Single gap	0.43	2.78	0.79	14.16
	Maxilla	16	Single gap	1.64	0.24	0.06	12.20
	Maxilla	17	Single gap	0.54	2.55	0.66	17.59
	Maxilla	23	Single gap	1.20	1.69	1.33	1.30
	Maxilla	26	Single gap	3.10	3.51	0.62	10.09
	Maxilla	26	Single gap	3.10	3.51	0.62	10.09
DGS	Mandible	36	Single gap	0.97	1.04	0.02	0.67
	Mandible	44	Single gap	0.68	1.58	0.07	5.21
	Mandible	46	Single gap	0.54	1.77	0.34	7.10
	Maxilla	13	Single gap	1.27	1.91	0.68	1.71
	Maxilla	15	Single gap	0.78	1.60	1.18	8.41
	Maxilla	16	Single gap	1.48	1.47	0.08	7.74
	Mandible	46	Single gap	0.74	1.65	1.14	3.96
	Maxilla	24	Single gap	1.93	2.41	0.95	5.35
	Maxilla	25	Single gap	0.50	0.90	0.70	6.94
	Maxilla	26	Single gap	0.40	1.29	0.67	5.49
	Maxilla	36	Single gap	2.43	2.82	0.02	2.85
	Maxilla	37	Single gap	2.27	2.56	1.52	1.24

The present investigation is among the first to conduct a preliminary randomised study directly comparing the precision of DGS with that of SGS. This distinction is crucial, as it highlights the potential for achieving comparable accuracy in implant placement with a more accessible and cost-effective alternative in many clinical scenarios than the dynamic method.

Despite the fact that both techniques were able to achieve the planned goals, the results of this investigation reveal that inaccuracies are inevitable between implant planning and implant placement in both of the investigated techniques. Although SGS and DGS demonstrated comparable mean deviations in terms of horizontal and vertical positioning, the maximum deviations observed were

notably higher in the SGS group than the DGS group. For instance, the maximum apical deviation in the SGS group was 5.29 mm compared to 2.82 mm in the DGS group, and the maximum angular deviation in the SGS group was 23.25 degrees compared to 8.41 degrees in the DGS group. These findings underscore the potential risks associated with the SGS approach, particularly in cases where implants are placed near critical anatomical structures. Even when maintaining a safety margin of 2 mm,⁴⁰ such high variance could still result in injury to adjacent anatomical structures. The ability of the DGS system to provide continuous real-time feedback during drilling likely contributed to its reduced maximum deviations and statistically superior angular precision, with mean angular deviation of 4.72 degrees

Table 2 Implant distribution between groups

Variable		Group		SGS		DGS	
		Total n	%	n	%	n	%
Sex	Total	25	100.0	13	100.0	12	100.0
	Men	9	36.0	9	69.2	0	0.0
	Women	16	64.0	4	30.8	12	100.0
Arch	Total	25	100.0	13	100.0	12	100.0
	Maxilla	19	76.0	11	84.6	8	66.7
	Mandible	6	24.0	2	15.4	4	33.3
Implant size, mm	Total	25	100.0	13	100.0	12	100.0
	3.5 × 8.5	3	12.0	2	15.4	1	8.3
	3.5 × 10.0	11	44.0	7	53.8	4	33.3
	4.0 × 10.0	11	44.0	4	30.8	7	58.3
Age	N	25	NA	13	NA	12	NA
	Mean ± standard deviation	58.4 ± 13.5	NA	53.5 ± 11.7	NA	63.8 ± 13.8	NA
	Minimum	40.0	NA	40.0	NA	45.0	NA
	Maximum	85.0	NA	64.0	NA	85.0	NA
	Quartile 1	50.0	NA	40.0	NA	56.0	NA
	Median	59.0	NA	63.0	NA	59.0	NA
	Quartile 3	64.0	NA	64.0	NA	74.0	NA
Implant location	Total	25	100.0	13	100.0	12	100.0
	Canine	2	8.0	1	7.7	1	8.3
	Premolar	12	48.0	8	61.5	4	33.3
	Molar	11	44.0	4	30.8	7	58.3

in the DGS group compared to 10.96 degrees in the SGS group, enhancing its precision and minimising the likelihood of clinically significant errors. This highlights the importance of selecting an appropriate guidance system based on the proximity of vital structures and the specific clinical scenario.

In contrast, SGS utilises a static pilot drill primarily for initial drilling. During the subsequent steps in the drilling sequence, the shaft of the drill, which is a similar width to the pilot drill, was fitted into the osteotomy and passed through the guide hole. This allowed it to serve as a direction pin to verify the angulation and alignment with the planned position at each step. The accuracy achieved by the DGS group was comparable to that obtained by Yimarj et al²¹ and Kaewsiri et al.²³ The results reported in the latter study were more precise than those of the present study, however, with the differences falling within a narrow margin of 0.5 mm. This difference can be attributed to several factors. Firstly, Kaewsiri

et al²³ focused on the placement of single implants, whereas the present study involved multiple implant placement. Additionally, the surgeon in the study by Kaewsiri et al²³ had a considerable amount of previous experience, having placed over 50 implants using this technique. This factor is highly relevant, as different authors have emphasised the substantial learning curve associated with DGS.^{20,22,26,27} According to Kaewsiri et al,²³ a practitioner's precision improves markedly after having placed at least 10 implants, suggesting that reaching a basic level of proficiency in this technique requires a certain amount of hands-on experience. An in vitro study²⁶ found that the learning curve extends further, requiring placement of around 30 implants to reach a plateau. Additionally, Pellegrino et al⁹ observed that experienced surgeons tend to perform DGS procedures significantly faster than those without prior experience, highlighting the role of practice in enhancing both accuracy and efficiency. Jorba et al²⁰ pointed out, however,

Table 3 Implant accuracy according to each group

Factor		Group		
		Total	SGS	DGS
Coronal	n	25	13	12
	Mean ± standard deviation	1.17 ± 0.72	1.17 ± 0.75	1.17 ± 0.71
	Minimum	0.21	0.21	0.40
	Maximum	3.10	3.10	2.43
	P value	0.983		
Apical	n	25	13	12
	Mean ± standard deviation	2.08 ± 1.01	2.39 ± 1.22	1.75 ± 0.59
	Minimum	0.24	0.24	0.90
	Maximum	5.29	5.29	2.82
	P value	0.112		
Vertical	n	25	13	12
	Mean ± standard deviation	0.70 ± 0.50	0.79 ± 0.50	0.61 ± 0.51
	Minimum	0.02	0.06	0.02
	Maximum	1.52	1.39	1.52
	P value	0.403		
Angular	n	25	13	12
	Mean ± standard deviation	7.97 ± 5.40	10.96 ± 5.63	4.72 ± 2.63
	Minimum	0.67	1.30	0.67
	Maximum	23.25	23.25	8.41
	P value	0.002		

that prior experience with freehand surgery does not necessarily translate to better accuracy with DGS unless the surgeon has specific experience with the latter technique. These insights reinforce the idea that both practice and experience with the DGS system are crucial for achieving optimal outcomes.

It is also important to highlight that even experienced surgeons may benefit from a fully guided approach rather than a pilot guided approach.⁴¹ Hence, the slightly lower accuracy in the present study compared to those conducted by Yimarj et al²¹ and Kaewsiri et al²³ can be contextualised within these parameters, underlining the influence of both surgical complexity and the surgeon’s experience on implant placement precision. Notably, the fact that DGS achieved comparable horizontal deviations or even superior angular accuracy to SGS when used by an operator without experience (noting that experience is pivotal for higher precision) underscores the significant potential DGS offers over SGS.

This study has several limitations that should be acknowledged. First, all surgical procedures were

performed by a third-year resident with extensive prior training in implant dentistry. Nevertheless, their relative inexperience compared to senior specialists may have influenced the accuracy outcomes. Although the operator had a solid clinical foundation, she had no prior hands-on experience with DGS or SGS. This factor is particularly relevant for dynamic systems, which are known to involve a steep learning curve. Thus, operator experience must be considered when interpreting the results and comparing them to those of studies conducted by highly experienced surgeons. Second, the study included a limited number of patients and implants, and no formal a priori power analysis was conducted. The sample size was based on logistical feasibility, the availability of eligible patients, and consistency with comparable studies in the literature. Therefore, the findings should be interpreted as preliminary. Finally, a notable peculiarity of the present study is that, despite the random allocation of patients to each technique, all implants placed using DGS were placed in women. This unique distribution did not significantly impact the overall accuracy of implant placement when an independent samples *t* test was conducted to compare outcomes between the groups.

Although the sample size is limited, this pilot study provides initial insights into the comparative accuracy of dynamic navigation and static pilot drill guides in implant surgery, establishing a foundation for future larger-scale investigations. The DGS system investigated in this study was Navident 3. Unlike SGS, which relies on static templates and has remained relatively unchanged, DGS technology continues to evolve at a rapid pace. For instance, Navident Evo, the successor to Navident 3, features significant advancements, including improved ergonomics and an intuitive interface that facilitate handling and potentially reduce the steep learning curve associated with dynamic systems. These improvements may also contribute to increased precision in implant placement. However, the pace of technological advancement in DGS can sometimes outstrip the ability of scientific evidence to keep up, making it challenging to thoroughly validate newer systems before they are widely adopted. Although the present study provides valuable insights into the performance of Navident 3, future research

comparing Navident Evo with its predecessor could offer a deeper understanding of the impact of these technological advancements on clinical outcomes. Given the small and homogenous group sizes, it is evident that neither DGS nor the SGS pilot drill guide is entirely free from inaccuracies; however, DGS demonstrates superior angular accuracy and a positive trend for apical precision, even when the operator is inexperienced with this technique.

Conclusion

This pilot study suggests that while both SGS and DGS demonstrated comparable accuracy in implant placement, DGS may offer advantages in angular precision and lower maximum deviations. These preliminary findings indicate that DGS has the potential to be a safer and more reliable option for implant placement, particularly in cases where critical anatomical structures are in proximity. However, these conclusions should be interpreted with caution due to the preliminary nature of this study and its limited sample size. Future research with larger sample sizes and diverse clinical scenarios is necessary to validate these findings and further explore their implications for clinical practice.

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