Mixed methods assessment of accuracy for dynamic navigation in Implant Dentistry: A comparative study

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ABSTRACT

Aim & Hypothesis: Accurate position of the dental implants is required for adequate functional and esthetic results. Clinicians can place implants freehand, with static-guided techniques or via dynamic navigation systems. The primary aim of this study was to compare the accuracy of implants placed by practitioners with different levels of experience in a 3D printed-model in a clinical simulation, using a dynamic navigation system (DNS) compared with a 3D-printed stent. The secondary aim was to assess the participants' perception regarding DNS. Three hypotheses were developed: novice clinicians will place implants in a more ideal 3D position when using DNS; experienced clinicians will show no significant difference in accuracy when placing implants with DNS when compared with 3D-printed stent; and experienced clinicians who have placed dental implants will prefer static guides in comparison with dynamic guidance.

Materials & Methods: Sixty participants from Tufts University School of Dental Medicine were divided into novice and experienced groups. Novice participants were third and/or fourth year students with no prior implant experience, while experienced participants were postgraduate residents and faculty. Participants underwent two visits: an introductory session on dynamic navigation and an implant placement procedure using dynamic navigation and 3D-printed static guides. Preoperative planning involved fabricating static guides for the control group and using CBCT scans and software planning for the dynamic navigation group. Implants were placed in 3D-printed models, with placement recorded and specific drilling techniques employed for each method. Postoperative CBCT scans assessed implant placement accuracy. Participants completed surveys and interviews regarding their perceptions of implant placement methods. Statistical analysis compared outcomes between groups and methods using one-way ANOVA, Tukey's HSD, and Kruskal-Wallis tests.

Results:

A total of 560 measurements were analyzed, Considering Angler deviations, Vertical implant deviation and liner deviations. There is a statistically significant difference in mean angle Vertical implant deviation between the novice and expert groups at the tip and the base ($p < 0.001$). using static and dynamic implant guided surgery. There is not a statistically significant difference in liner deviations buccal–lingual and mesial–distal directions of the implant with novice and expert groups ($p > 0.05$) using static and dynamic implant guided surgery.

Conclusions:

While both Dynamic Guidance System (DGS) and Static Guidance System (SGS) have demonstrated accuracy in implant placement, it is crucial to maintain a safety margin for anatomical structures. This precaution is necessary due to the inherent deviation present in all dimensions of the space. Overall, providing data on the effectiveness and accuracy of all technologies and protocol combinations used in guided implant system manufacturing remains a significant research issue in clinical practice

Keywords: dynamic navigation; guided surgery; dental implants; computer- guided implantology, dental implant; accuracy

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CHAPTER I: INTRODUCTION

Accurate position of the dental implants is required for adequate functional and esthetic results. In order to avoid complications and to increase long-term success of the implant supported prosthesis it is critical to place implants in the ideal planned position, angle and depth that is prosthetically driven.[1,2]Methods for implant placement include the free-hand approach, laboratory-fabricated static surgical guide stents fabricated on models, computer-aided design/computer-aided manufacturing (CAD/CAM)-generated static guides (tooth, mucosal, or bone supported), the computer-assisted dynamic navigation, and robotically assisted dental surgical system.[3]

The placement of implants in accurate three-dimensional position allows for optimal support, stability, and functional restoration essential for an esthetic outcome. It is important to maintain an optimal position to avoid the probability of resorption of interproximal alveolar crest to the level of implants. A Saadoun et al., recommend keeping a mesiodistal distance of 2 mm between cervical implant face and natural tooth and a distance of at least 3 mm cervical between two implants.[4] These dimensions facilitate the maintenance of minimal amount of crestal bone needed and allow for better soft tissue fill and proper papilla bone support. Furthermore, anterior and posterior dimensions and angulation should also be taken into account for an ideal position. A high degree of accuracy in the placement of implants, although challenging, is very important for a favorable prosthetic outcome. Nevertheless, proper implant position is considered today an essential prerequisite for long-term maintenance of the prosthesis and the peri-implant tissue health. Poor treatment planning and deficient surgical procedures may lead to compromised implant position and thus predispose to compromised outcomes and short-or long-term complications [1,5]

I.1 Statement of the Problem

Novice clinicians who place implants can risk placing implants with incorrect angulation and positioning errors. To ameliorate these issues regarding inaccuracy and prosthetic complications, dynamic navigation systems have been developed for the clinical setting. Dental implant placement has been facilitated by progress in the field of 3D imaging, which allows implant planning with greater precision than 2D examinations and conventional freehand techniques. The perception of dynamic navigation technology is highly pertinent to how clinicians wish to perform implant surgeries in order to achieve successful prostheses and patient satisfaction.

Clinicians can place implants freehand, with static-guided techniques or via dynamic navigation systems. Many studies have compared these surgical techniques for the overall accuracy of implant placement, while also accounting for 3D positioning and angulation errors. A potential difficulty of 3D imaging arises when clinicians want to transfer the virtual planning to the clinical surgical site. The accuracy of this transfer is important to avoid complications and to minimize damage to critical anatomic structures in the oral cavity. Guided implant surgery increases accuracy when compared to freehand implant placement, but the errors have a cumulative effect in guided surgery. Maximum deviation usually occurs between planning and the final postoperative outcome.

Deviations result through the entirety of the process, from imaging to the transformation of data into a guide, to the improper positioning of the guide in the mouth [6]

According to a study by Ewers et al. (2004), computer-assisted surgery will significantly improve the quality and intraoperative safety for the placement of dental implants by avoiding damage to nerves and other neighboring teeth.[7] A study conducted by Block et al. (2017) measured and compared the accuracy and precision of dynamic navigation with freehand implant placement and guided implant placement. The authors of this study implemented a prospective cohort study and enrolled patients who had implants placed from the following dates: December 2014 through December 2016. The following implant placement techniques were compared: fully guided and partially guided dynamic navigation with freehand implant placement. Analysis of variance (ANOVA) was used to compare measurements and data from 478 patients with 714 placed implants were analyzed. The study concluded that the accuracy and precision for implant placement was higher with dynamic navigation technology .[3]

With every technology, it is important to consider the learning curve for using dynamic navigation system technologies. While accuracy and efficiency may improve with dynamic navigation, clinicians must be willing to learn how to adapt their clinical skills to computer-assisted surgery. A study conducted by Sun et al. (2018) analyzed the accuracy of the dental implant navigation system and established the learning curve according to operation site and operating time. A dental model was used to drill 3 missing teeth positions and the same clinician performed the procedure for five sets of models. The relative error between the preoperative planning and actual implant placed was analyzed. The study concluded that the learning curve for the dental implant navigation system retained a learning plateau after 5 tests. Dental implant surgery using a navigation system reduced overall errors of implant placement, and if dentists continuously use this technology, the implant procedures will be completed in a shorter amount of time. [8] A limitation of this study was that only one clinician performed all the procedures. The novelty of the proposed study is that we will compare novice with experienced clinicians. Since the study will be implemented in an academic setting, we will invite predoctoral and postgraduate students and faculty members to participate. The outcomes of this study will be able to support not only ways to facilitate safer care, but also ways to integrate this technology in the curriculum.

I.2 Research Aims/Hypothesis

The primary aim of this research was to evaluate the accuracy and perception of both novice and experienced clinicians in the use of static guided system and dynamic navigation technology in implant placement.

The following objectives were covered in the research:

(1) Compare the accuracy of the 3D implant placement in a 3D printed model using a dynamic navigation system (Inliant Dynamic Navigation System; Navigate Surgical Technologies, Ontario, Canada) and 3D-printed stent through an analysis of linear and angular deviations between the novice and experienced clinicians

(2) Assess the perception of the clinicians using the dynamic navigation implant system, based on a validated, qualitative survey

(3) Compare non-experienced and experienced clinicians when placing implants using Inliant Dynamic Navigation System for dynamic guidance.

Alternative Hypotheses:

A. Novice clinicians, with basic knowledge of dental implants and no implant placement experience will place implants in a more ideal 3D position when using Inliant System for dynamic guidance, when compared with using the 3D-printed stent;

B. Experienced clinicians with implant placement experience will show no significant difference in the accuracy of implant placement when using the Inliant System for dynamic guidance, when compared with a 3D-printed stent;

C. Experienced clinicians who have placed dental implants for 35 or more years will have a preference for static guides in comparison with dynamic guidance.

Background/Rationale:

Predoctoral dental students are still developing their skills when it comes to complicated orofacial surgical procedures. With the dynamic navigation technology, their transition to performing dental implant surgeries can be greatly improved. The use of dental implants is a profound challenge in modern dentistry and is globally expanding into mainstream dental practice. Implant dentistry is evolving but needs to reflect a standardized and structured approach in dental education with proper mentorship. The four stages related to implant dental education include: pre-clinical, basic-clinical, advanced-clinical and specialist level. A crucial factor when considering dental implant education is the length of time for practice; the more time spent practicing quality implant placement, the greater will be the support for novice clinicians placing implants.[9]

According to the literature on dynamic navigation, novice clinicians show better accuracy in implant placement with computer-aided technology than those placing them without dynamic navigation. A study compared the accuracy of implant placement using a freehand method versus a dynamic navigation system. [10] An inexperienced and experienced researcher conducted the study, as both placed implants using the navigation system or the freehand method. The results showed that the inexperienced clinician demonstrated more accuracy with the navigation system when compared with using freehand implant placement. The experienced clinician showed adequate angulation with the navigation system, but did not exhibit significant improvement in other parameters. Therefore, the navigation system is best suited for novice clinicians who wish to significantly improve accuracy in implant placement.

In this study, the dynamic surgical guidance will be performed using the Inliant® system. Inliant ® works by tracking real-time motion of the surgical handpiece and patient position. The surgery is planned around a preoperative CBCT scan, and a fiducial which is held in place by a stent-even during the surgery. A patient tracker is attached to the stent and is fully equipped with camera track markers (also located on the clinician handpiece) which then determines drill and patient position. Sensors attached to both patient and the hand-piece transfer three-dimensional positional information to cameras and no calibration is required for this software. The angulation and position of the drill is evaluated and superimposed on the CBCT scan in real-time. The same osteotomies requested with the static guide will be asked of the clinicians with the dynamic system.

I.3 Significance

Technological advancements changed the face of dentistry. The dynamic navigation system can be a tool to increase the surgeon's confidence for the dental implant placement surgery. This minimizes the time and efficiency of each procedure and improves patient care in the dental setting. By gaining a better understanding of dynamic navigation technology from the student/clinician perspective, TUSDM can incorporate this technology into the clinical curriculum. In addition to perspective, this study will also strive to measure accuracy of implant placement via computer-assisted surgery. The measure of accuracy in combination with perception of navigation technology can positively impact the way our clinicians perform implant surgery. This will also provide a better understanding of the advantages and disadvantages of this technology in comparison to conventional methods of implant placement. This study will also promote an established learning curve of dynamic navigation technology thereby improvements can be made upon how this technology is taught to both novice and experienced clinicians.

Chapter II: LITERATURE REVIEW

II.1. Guided Implants placement.

Traditional methods of implant placement, such as freehand techniques or the use of prosthetic surgical guides based on study models, often fall short in accurately replicating the planned implant position within the surgical site. However, the advent of digital technology in the medical field has led to the introduction of computer-assisted implant surgery (CAIS) in 1995 .[11] This groundbreaking approach enables the precise reproduction of the planned optimal implant position at the surgical site.

CAIS operates on the principle of combining computed tomography (CT) scans with specialized implant planning software. This integration allows for the virtual simulation of implant placement in the optimal three-dimensional position on multiplanar reconstruction images of the oral tissues. Once the ideal three-dimensional position is determined, two primary systems are employed to facilitate the transfer of the virtual plan to the surgical site: two ways to transfer the virtual planning information from the computer to the clinical situation: 1) a template-based (static) implant insertion; or 2) a computer-navigated (dynamic) implant insertion.[12]

The static system utilize a surgical guide generated via computer-aided design and computer-aided manufacturing (CAD/CAM). This guide includes an embedded "sleeve" that serves as a precise guide for implant drilling and placement, ensures the accurate transfer of the planned implant position [13, 14]

The dynamic system utilizes motion tracking technology to monitor both the implant drilling instruments and the patient's jaw position during surgery. Radiopaque markers, also known as fiducial markers, are attached to the patient's jaw during the CBCT to enable synchronization between the corresponding anatomy in the CT image and the surgical field.

During the procedure, tracking cameras are positioned to continuously monitor sensors attached to both the patient's jaw and the surgical handpiece. This real-time data is then displayed on a monitor, overlaid onto the virtual plan. Any three-dimensional deviation of the drill or implant from the virtual plan is immediately visible, allowing for real-time adjustments to drilling depth, angle, or implant position as needed.

Research by Block et al. (2017) and Somogyi-Ganss et al. (2015) demonstrates that both static and dynamic systems exhibit superior accuracy in transferring virtual implant positions to patients compared to conventional implant placement methods.[3,14]

II.2 Static guided implant placement benefits and implications.

A notable advancement in this domain is the digital fabrication of templates. Due to the relatively low dose and minimal soft tissue contrast of CBCT scans, the surface accuracy may not be adequate for generating the template directly. Thus, it becomes essential to scan the patient's cast and the wax-up of the prosthetic-oriented plan to superimpose onto the patient's CBCT dataset.

With modern systems, the need for a physical prosthetic wax-up can be eliminated. The virtual design of the restoration, essential for planning purposes, can be achieved using computer-aided design (CAD) programs. Guided by the virtual planning of the future restoration, the implant position can be meticulously planned.

Various methods, such as subtractive (e.g., milling) or additive (e.g., stereolithography, 3D printing, laser melting), are available for fabricating these templates[15,16]

The surgical splint facilitates bone drilling and implant placement precisely at the predetermined location, angulation, and depth . These surgical templates can be supported by teeth, mucosa, bone, or a combination of these structures . While Static Guidance System (SGS) is generally considered highly accurate, it does have its drawbacks SGS necessitates a wide range of mouth opening to accommodate specific instruments into the oral cavity, particularly in posterior regions. Moreover, the guide can impede irrigation during osteotomy, may be susceptible to fracture during surgery, and does not allow for last-minute planning adjustments, among other limitations. [17]

While guided implant surgery may reduce surgical invasiveness and enhance patient comfort. [18] discrepancies can arise between the planned implant position and the actual placement. This issue holds significant clinical importance, as it carries implications for both surgical and prosthetic outcomes. Such discrepancies have often been studied as a measure of surgical guide accuracy. [19] However, it's essential to approach this matter with caution, as these "errors" result from various sources throughout the guided implant placement procedure . These sources of error encompass dimensional inaccuracies in surgical guides , errors in data acquisition , management , merging , surgical guide stabilization, and bone characteristics . [20]

II.3 Dynamic guided implant placement benefits and implications.

Today, the top priority in implantology is the optimal prosthetic positioning of the implant. This task places significant demands on the surgeon, who has to accurately transfer information from the planning to the three-dimensional (3D) surgery field. Sensitive anatomic structures limited by restricted mouth opening need to be guarded, and bleeding controlled. [21]

Computer-assisted navigation, coupled with 3D imaging via cone beam computed tomography (CBCT), emerges as an ideal solution for enhancing the predictability of successful implant therapy. This technique, introduced over a decade ago, has facilitates higher precision compared to traditional freehand techniques, opening up new avenues of therapy for clinicians.[15]

Immediate loading of implants with prefabricated restorations is feasible thanks to the predictable results offered by this technique. Navigated implantology enables the potential for minimally invasive flapless surgery, leading to reduced postoperative complications, minimized surgical trauma, and shorter surgery times.[22]

The imaging data are initially transferred to the planning computer in DICOM format. Following virtual planning using the planning system, the data are then sent to the navigation computer. The navigation system utilizes a navigation body, either integrated with the template or the clip, which is equipped with reflective trackers.

Reflective trackers on the handpiece and the patient reflect a continuous transmitted light signal, which is captured by a camera. This signal allows for the real-time recording of the patient's coordinates in reference to the virtual data. With this alignment established, navigation-assisted implantation can commence. The navigation system provides visual feedback, displaying the alignment between the planned drill position and the actual position in real-time through an integrated target mode. Any discrepancies can be identified and corrected intraoperatively.[23]

Before commencing drilling, a registration process is employed to ascertain the position of the handpiece tip relative to a marker near the surgical site and to align it with the corresponding data. [24] A straightforward calibration is conducted using a distinct anatomical landmark, such as a fixed tooth, which is easily identifiable both in the patient and in the CBCT. This calibration ensures accuracy prior to drilling initiation. [25] Subsequently, the proximity to the planned position is visually demonstrated on the monitor, with crosshairs or bull's-eyes indicating targeted planning. Additionally, the monitor displays the distance of the drill tip in millimeters, the angle of the longitudinal axis, and the achieved drilling depth. [24]

While Dynamic Guidance System (DGS) seems to offer a more accurate guidance approach compared to the traditional freehand (FH) method, discrepancies between virtual planning and the actual clinical implant positions have been documented . The available data on the accuracy of the DGS system are scarce, and the literature published so far exhibits significant diversity.[25]

CHAPTER IV: RESEARCH METHODOLOGY

IV.I Study Design

The research was approved by the Social, Behavioral, and Educational Research – Institutional Review Board of Tufts University (IRB approval # NUMBER). Participants were composed of Tufts University School of Dental Medicine (TUSDM) undergraduate (UG) students, postgraduate (PG) residents, and faculty. A total of 60 participants were recruited and enrolled into 2 groups (30 participants in each group) for 2 implant placement techniques (dynamic navigation – “test” and 3D printed stents – “control”) using a 3D printed model. One group consisted of novice participants with no implant placement experience and the other group consisted of experienced participants, that have placed at least 10 implants previously. Each participant placed two implants in a 3D printed model, one using each implant placement method (3D-printed static surgical guide and dynamic navigation system).

The sample size for this research was determined by analyzing the data from a pilot study previously performed (IRB #12790, “Accuracy and Perception Evaluation of a Dynamic Navigation Implant System: A Pilot Study”). Up to 108 subjects were screened, A sample size calculation was done to compare between the two experienced groups (novice and experienced) as well as between static and dynamic navigation using two-way ANOVA. Results showed that in order to have sufficient power (80% or greater), a total of 60 participants overall was needed. Therefore, the first group (novice) was composed of 30 participants from the UG program at TUSDM, who have never placed an implant. The second group was composed of 30 participants from PG programs and/or faculty from TUSDM, who have placed 10 or more implants.

IV.2 Target Population:

<u>Inclusion and Exclusion Criteria</u>

<u>Inclusion criteria</u>

- The novice group followed certain inclusion parameters, which included:
  - Novice participants were comprised of third and/or fourth year TUSDM students who have never placed an implant;
  - Third and/or fourth year TUSDM students must have had successfully completed all pre-clinical courses and labs;
  - Third year TUSDM students must have had completed all requirements making them eligible to practice as student providers;
  - Participants must have had basic knowledge of implant placement; however, they should have never placed an implant before.
- The experienced group followed certain inclusion parameters, which included:
  - Experienced participants must have had placed at least 10 implants;
  - Only post-graduate residents and/or faculty from the following departments were considered:
    - Oral Maxillofacial Surgery

- Periodontology
- Prosthodontics
- Advanced Education in General Dentistry
- Comprehensive Care

<u>Exclusion criteria</u>

- The novice group followed certain exclusion parameters, which included:
    - TUSDM DMD International students (IS) who have had prior implant placement experience were not considered as novice participants;
    - Students who had failed to complete one or more pre-clinical requirements;
    - Students who had not been cleared to begin clinical training;
    - Students who had used dynamic navigation system (Inliant Dynamic Navigation System) in the past.
- The experienced group followed certain exclusion parameters, which included:
    - Faculty or post-graduate students who had not placed at least 10 implants;
    - Faculty or post-graduate students who had used Inliant in previous simulation exercises;
    - Participants from the following departments were not considered:
        - Orthodontics
        - Endodontics
        - Pediatric Dentistry
    - Participants who had used dynamic navigation system (Inliant Dynamic Navigation System) or other similar simulation systems in the past.

Subjects could be withdrawn from the study if the Principal Investigator thought it is in their best medical interest. Also, subjects could also be withdrawn from the study if they did not come to the second visit and did not answer the study team's attempts to re-schedule them.

Subjects could leave the research at any time, and it would not be held against them. If they refused to participate in the study or stopped being in this study, it did not affect their care or treatment outside this study, payment for their health care, or their health care benefits. Participation or the refusal to participate had no effect on a student's academic standing or faculty's employment status.

IV. 3 Recruitment Methods:

Participants were recruited from TUSDM, including undergraduate students, postgraduate residents, and faculty. Recruitment involved sending out emails to the TUSDM e-list, and volunteers could RSVP by responding to the email. A follow-up email was sent with a link to Tufts Qualtrics to collect information about participants' level of experience. Participants were categorized into novice and experienced groups based on the number of implants they had previously placed.

IV.4 Data collection:

Study Visits

Each subject was requested to participate in two visits.

The Informed Consent process occured at the first visit. A study investigator (MA) explained the study to the subject. Subject was given as much time as needed to read the ICF. All questions were answered. A signed copy of the ICF was given to the subject.

The first visit was a 30-minute introductory presentation through slides and videos of the dynamic navigation system. A live demonstration of the equipment was also performed. All questions were clarified. The first visit took approximately 1 hour.

The second visit corresponded to the implant placement procedure in a 3D-printed model, where each subject placed the two implants. One implant was placed using the dynamic navigation system and the other implant was placed using a static guide. After the implant placement procedure, the study team verbally asked the surgeons a brief series of questions and recorded their answers.

Pre-Implant Placement - Treatment Planning

- 3D-printed static surgical guide method for implant placement

This phase was conducted by one of the investigators (MA) Volume data of each of the 60-designated 3D-printed models for this implant placement method were acquired by cone-beam computed tomography (CBCT). Digital scan of the models was obtained through a desktop impression scanner ((Straumann CARES 7 Series), and a digital treatment plan for implant position based on the ideal restoration was created along with the design of the static surgical guide (CoDiagnostiX; Straumann, Switzerland). Once the guide design was finalized, 60 surgical guides were printed with **Keystone KeyGuide – 3D Printing Resin** and manipulated following the manufacturer's instructions.

- Dynamic Navigation System method for implant placement

This phase was also conducted by one of the investigators prior to the recruitment of study groups. Stents were fabricated using thermoplastic beads to secure the Inliant radiographic fiducial over the opposite side of the surgical area of each 3D-printed model. Volume data of each of the 60 designated 3D-printed models for this implant placement method were acquired by cone-beam computed tomography (CBCT) in I mode (FOV = 10 cm), 100 kV and 10 mA. The DICOM files from the CBCT were imported into the Inliant Dynamic Navigation System software. The radiographic fiducial is automatically detected and located in the CBCT images, enabling mapping its pose in the image to be automatically mapped to its pose during the implant placement. Implants were planned in the software in optimized locations relative to the planned tooth position in the regions of tooth #29 as dictated by the CBCT radiographs. This preoperative CBCT and treatment planning were compared with postoperative CBCT scans of each model.

Figure 1: the Inliant radiographic fiducial over the opposite side of the surgical area on the 3D-printed model.

Implant placement procedure

The implant placement procedure was conducted in a single visit. Each subject placed an implant with each technique, starting with the one assigned according to randomization criteria. Randomization was performed by assigning a number to each participant and using Random.org. The starting technique for each participant (control or test) was randomized. In total, each participant placed 2 implants, one with the 3D-printed static guide and one using the Dynamic Navigation system.

- 3D-Printed Static Guide

A printed stent design was provided to all operators for use in preparing osteotomies in the areas of tooth 29 in the 3D-printed model. Profile drills (Straumann, Switzerland) were mounted in an angulated handpiece. The surgical guide was used to initiate osteotomies. Surgeons were asked to make osteotomies with a depth of 10 mm and a diameter of 4 mm to place the regular platform implant (Straumann, Switzerland).

- Dynamic Navigation System

The Inliant Dynamic Navigation system employs motion tracking technology to monitor the positions of both the dental drill and the patient during implant placement. Sensors on the 3D printed model and the hand-piece transmit three-dimensional positional data to cameras. This data allows the computer to calculate and display the virtual position of the instruments in relation to the image data in real-time. In this study, a mandibular stent with the Inliant radiographic fiducial was positioned, and the Inliant patient tracker was connected to it. The Inliant hand-piece, featuring patented markers, was utilized with Straumann drills. This system enables hands-free drilling to the pre-planned position, angle, and depth. The position of the drill tip, overlaid on CT images, dynamically guides the drilling process. Surgeons using the dynamic system performed the same osteotomies as those using the static guide. Bone-level regular platform implants, each 10 mm long, were then placed in the edentulous area of tooth 29 in the 3D-printed models.

IV.5 Data analysis:

Post Implant Placement

Accuracy Assessment

A postoperative CBCT of every model, conducted with the same settings as the preoperative scans, was taken to determine the position of the implant placed. This CBCT was used to compare the 3D position of each implant placed with the implant position virtually planned. The 3D position of the planned and placed implants was compared by overlapping the pre and postoperative computed tomography scans using dedicated software (CloudCompare software for the DNS group and co-DiagnostiX software for 3D-printed static guide group). Three deviation parameters were measured: linear deviations of buccal-lingual, linear deviations mesio-distal and angular deviations of the axis. This was enabled by processing of the sterolithographic interface (STL) -format data that was acquired from the optical scan overlapping the data from the treatment planning, which allowed simultaneous viewing of the axial, 3D, panoramic, and cross-sectional images on the computer monitor.

The accuracy was recorded according to the surgeons' group experience (novice and experienced). Once pre and postoperative coordinates of virtual implants were obtained, linear distances and angles were calculated. Coronal and apical errors consisted of the shortest distance from the preoperative planning to the postoperative overlay. This measurement was obtained by mathematically determining the coordinate of the projection of the initial virtual implant (center of the platform and center of the apex) onto the postoperative virtual implant and calculating the distance between these two points. Angles were calculated using the same two sets of coordinates.

Linear discrepancies in positions (Δx for mesial[+]-distal[−], Δy for buccal[+]-lingual[−], and Δz for coronal[+]-apical[−]) between the implants virtually planned and implants placed were calculated and recorded. Angular discrepancies (Δxz for mesial[+]-distal[−] and Δyz for buccal[+]-lingual[−] angulation) between the implants virtually planned and implants placed were calculated and recorded as well.

In addition, a reference model from each implant placement method was selected based on the results of the previous analysis. Straumann scanbodies were screwed to the implants, and models were scanned with a desktop impression scanner (Straumann CARES 7 Series). The 3D variation of implant position was analyzed through root mean square (RMS) error, and maximum deviation (positive and negative) which was obtained by overlapping the standard tessellation language (STL) data sets of each model onto the STL file of the reference model in each group using inspection software (Geomagic Design X; 3D Systems). Descriptive statistics (means ± standard deviations) were calculated for each group.

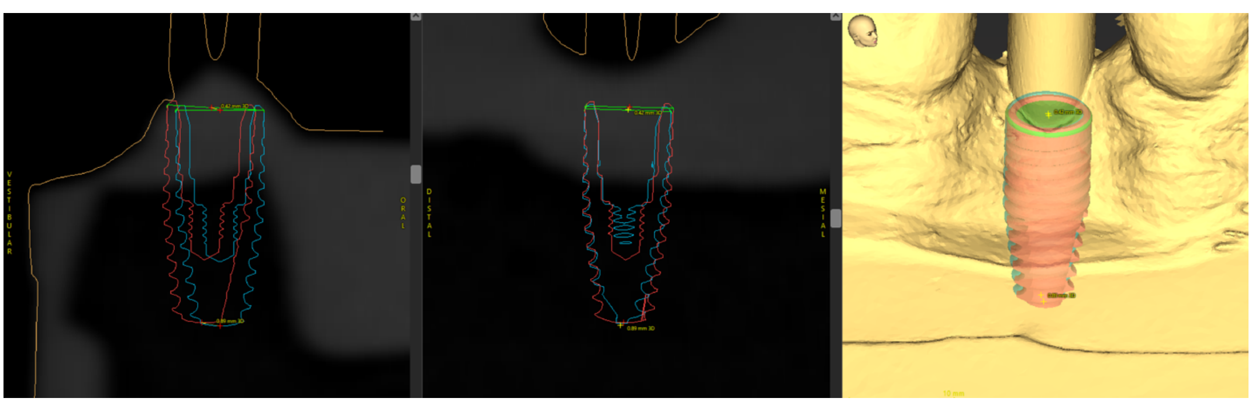


Figure 2: analysis using CoDiagnostix softwear

Figure 3: implant placement using inliant system

Surgeons' Perception – Survey and Interview

Survey: All participants were asked for their age and gender. They were also asked a series of questions regarding their previous experiences (Appendix 1).

Interview: Participants were then verbally asked a series of questions (Appendix 2) based on the survey used by Eve et al. (2014), to evaluate their experience placing implants using the dynamic navigation system. The interview consisted of statements about the subjects' comfort using the system, their perception of its value, and their desire to use it in the future. The answers were audio recorded on a tape recorder and transcribed using NVivo. If a subject did not want to be audio recorded, then a member of the research group took notes of the interview.

Thematic Analysis of Interviews

Data Familiarization:

- Researchers immersed themselves in the qualitative data collected from participants through interviews.
- Transcripts were reviewed multiple times to gain familiarity with the content and identify recurring patterns, ideas, or topics.

Coding Procedures:

1. Open Coding: Initial round of coding involved breaking down the data into smaller segments and assigning descriptive labels or codes to each segment.
   - Example: Coding segments related to advantages of dynamic navigation systems as "accuracy," "real-time visualization," and "flexibility."
2. Axial Coding: Similar codes were grouped together and organized into broader categories or themes based on their conceptual relevance.
   - Example: Codes related to challenges of dynamic navigation systems were grouped under the theme "Disadvantages of Dynamic Navigation System."
3. Selective Coding: Further refinement and consolidation of themes were performed, ensuring coherence and clarity in representing the data.
   - Example: Themes such as "Advantages of Static Guide" and "Disadvantages of Static Guide" were refined to capture nuanced perspectives.

Theme Identification:

- Themes were identified based on the patterns, similarities, and differences observed across the coded data.

- Each theme represented a coherent and meaningful pattern of participant responses or viewpoints on a particular aspect of the study topic.
- Themes were developed iteratively, with constant comparison of data segments to ensure consistency and accuracy.

Theme Review:

1. Peer Review: Preliminary themes and interpretations were reviewed by colleagues familiar with qualitative research methods.

- Feedback and suggestions from reviewers were incorporated to enhance the rigor and trustworthiness of the analysis.

Finalization of Themes:

- After thorough review and validation, the final set of themes was determined, representing the comprehensive analysis of the qualitative data.
- Themes were described and interpreted in the context of the study objectives, providing insights into participants' perspectives on dental implant placement techniques.

This thematic analysis demonstrates the systematic approach employed to analyze the qualitative data, from initial data familiarization to the finalization of themes. By following established coding procedures and engaging in rigorous review processes, researchers were able to ensure the reliability, validity, and interpretive depth of the study findings.

IV.6 Compensation:

Each subject received a $40 electronic gift card to Amazon upon completion of the second visit and interview section of the study.

IV.7 Risks

Potential risks included loss of confidentiality, which was minimized by storing identifiable information separately from collected data and using unique identifiers for data analysis. Participation or refusal to participate had no effect on academic standing or employment status.

IV.8 Benefits

There were no direct benefits to participants for participating in the study.

IV.9 Alternatives

Participants had the option not to participate in the study.

IV.10 Location of Research Activities

The research activities took place at Tufts University School of Dental Medicine.

IV.11 Confidentiality

A list of undergraduate (UG) students, postgraduate (PG) students, and faculty was developed based on the order of their responses to the recruitment email for inclusion in the study. In the event that a subject chose to discontinue participation, the next eligible subject on the list would be invited.

During the study visits, a list of participating students was utilized. After randomization at or after Visit 1, the subject's group assignment was noted. Subsequently, at Visit 2, this list was consulted to ensure the subject received the appropriate cases (either "test" or "control" group).

Each subject was assigned a unique identifier (subject ID number) to facilitate data coding and comparison between the two methods. The study team possessed a key linking subjects' names to their subject ID numbers, which was securely stored separately from collected data on a password-protected computer in Tufts BOX or in a locked cabinet within a secured room. Collected data only contained the subject ID. Upon completion of the study, this key was destroyed, leaving only de-identified information.

No identifiable information was collected in survey responses; only the subject ID was written on the survey. During interviews, the subject's identity was known to the interviewer, but subject identities were not disclosed to other study team members. Full names were not recorded, and first names were used sparingly. Although voices on audio recordings could be identifiable, the recordings were immediately destroyed after transcription, with a maximum period of 2 weeks after completion of recordings. At the time of data analysis, responses were aggregated without attribution to specific subjects to maintain subject confidentiality.

Participants were requested to sign a gift card receipt form acknowledging receipt of the gift card, which was stored separately from study data. All study data remained confidential and accessible only to investigators and research staff, stored securely on password-protected computers and Tufts BOX.

Access to data was restricted to study personnel only. Investigators permitted monitoring, audits, and regulatory inspections, providing direct access to study-related documentation.

IV.12 Data Storage

Study records were maintained securely, and electronic data were kept on password-protected computers and Tufts BOX. Records will be retained for at least 7 years following completion or termination of the study.

IV.13 Data Analysis

Statistical Analysis

A power calculation was performed using nQuery Advanced with the following assumptions: a type I error of 5%; a type II error of 1% to compare between experience levels; a type II error of 2.34% to compare between the static and dynamic systems; and a type II error of 18.80% for the interaction between experience level and implant placement system. Average RMS (SD) values were calculated for each group and system. The minimum required sample size was computed to be 30 subjects per experience group, totaling 60 subjects.

Descriptive statistics (means and standard deviations for continuous variables, counts and percentages for categorical variables) were calculated. Differences in accuracy between experience levels and simulator trials were compared using a mixed ANOVA. The assumption of normality was assessed graphically and with the Shapiro-Wilk test. Sphericity of the data was examined with Mauchly's test of sphericity, while homogeneity of error variance and covariance matrices were analyzed with Levene's test of equality of error variances and Box's test of equality of covariance matrices, respectively. Post-hoc pairwise comparisons were conducted using Tukey's HSD. Differences in responses to the post-exercise survey between education experience groups were investigated with one-way ANOVA and Tukey's HSD for post-hoc pairwise comparisons; if the assumption of normality was unmet, the Kruskal-Wallis test with Dunn's test for post-hoc pairwise comparisons was used instead. All p-values less than 0.05 were considered statistically significant, except for Box's test of equality of covariance matrices, where a p-value of less than 0.001 was considered statistically significant. The software SPSS (version 22, IBM) was used for the statistical analysis.

Open-ended questions were analyzed for common themes and subthemes.

<u>Blinding</u>

One blinded investigator analyzed the results of the implant placement, while another investigator analyzed the data from the interviews regarding the surgeons' perception about the dynamic navigation system. After the final analysis was completed by the blinded investigator, the identification of the groups was revealed.

CHAPTER V: FINDINGS

V.1 Participants' Characteristics:

A total of 54 individuals participated in this study. Participants of this mixed methods study were predoctoral dental students, residents and faculty from Tufts University School of Dental Medicine.

V.2 Quantitative Results

The study analyzed various types of deviation from preplanned implant positions, as outlined by Schneider et al. (2009). These deviations encompass discrepancies between the planned implant position and the actual clinical placement after surgery.[26]

- Implant platform deviation refers to any variation at the most coronal part of the implant (the connection or base), measured in both buccal–lingual and mesial–distal directions.

- Apical implant deviation denotes any discrepancy at the most apical part of the implant (the apex or tip), measured in both buccal–lingual and mesial–distal directions.

- Vertical implant deviation indicates any discrepancy measured apico-coronally at the most coronal part of the implant (the platform).

- Angular deviation describes any variation (expressed in degrees) of the entire implant body.

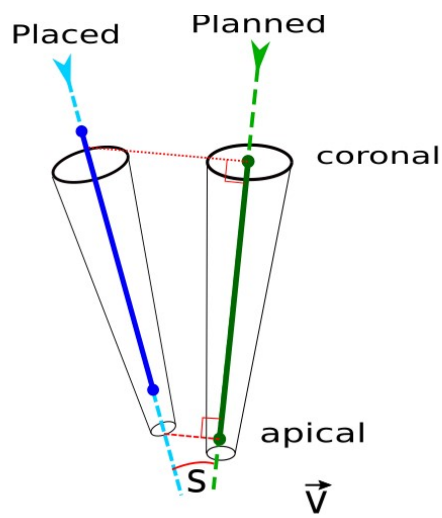


Figure 4. Diagram of apical and coronal distances, where coronal is the distance from top (coronal) point in planned to axis of placed implant, apical is the distance from apical point in planned to axis of placed implant and S is the angle between placed and planned axes.

1- Accuracy of implant placement using statics guided system

A total of 560 measurements were analyzed considering angular deviations, vertical implant deviation and linear deviations.

There was a statistically significant difference in mean angle between the novice (N) and expert (E) groups at the tip and the base ($p < 0.001$) with average N = 3.0 degrees, E = 1.8 degrees.

Regarding vertical implant deviation, there was a statistically significant difference in median tip and base apical between the novice and expert groups ($p < 0.001$), with average of N = -0.5mm , E = 0.1mm.

There was no statistically significant difference in linear deviations on buccal–lingual and mesial–distal directions of the implant plate form or apex between the novice and expert groups ($p > 0.05$).

2- Accuracy of implant placement using dynamic guided system

Measurements were analyzed considering angular deviations, vertical implant deviation and linear deviations.

There was a statistically significant difference in mean angle between the novice and expert groups ($p < 0.001$) with average N = 4.6 degrees, E = 3.4 degrees.

Regarding vertical implant deviation, there was no statistically significant difference in between the novice and expert groups ($p < 0.001$), with average of N = 1.0mm, E = 0.7mm.

There was no statistically significant difference in linear deviations buccal–lingual and mesial–distal directions of the implant plate form or apex between the novice and expert groups ($p = 0.91$).

3- Accuracy of implant placement of the novice group

There was a statistically significant difference in mean angle between the static (S) and dynamic (D) groups ($p < 0.001$) with average S= 3.0 degrees, D = 4.6 degrees.

Regarding vertical implant deviation, there was a statistically significant difference in between the static and dynamic modalities ($p = 0.02$) with average of S = -0.50mm, D = -0.05 mm.

There was no statistically significant difference in linear deviations on buccal–lingual and mesial–distal directions of the implant between the static and dynamic groups.

4- Accuracy of implant placement of the expert group

There was a statistically significant difference in mean angle between the static and dynamic groups ($p < 0.001$) with average S = 1.8 degrees, D = 3.4 degrees.

Regarding vertical implant deviation, there was a statistically significant difference in between the static and dynamic modalities ($p = 0.02$) with average of S = 0.10mm, D = -0.03 mm.

There was no statistically significant difference in linear deviations on the buccal–lingual and mesial–distal directions of the implant between the static and dynamic groups.

Consequently, the hypothesis that novice clinicians would place implants in a more ideal 3D position when using DNS and that experienced clinicians would show no significant difference in accuracy when placing implants with DNS when compared with 3D-printed stent were rejected.

ANGLE

Descriptives

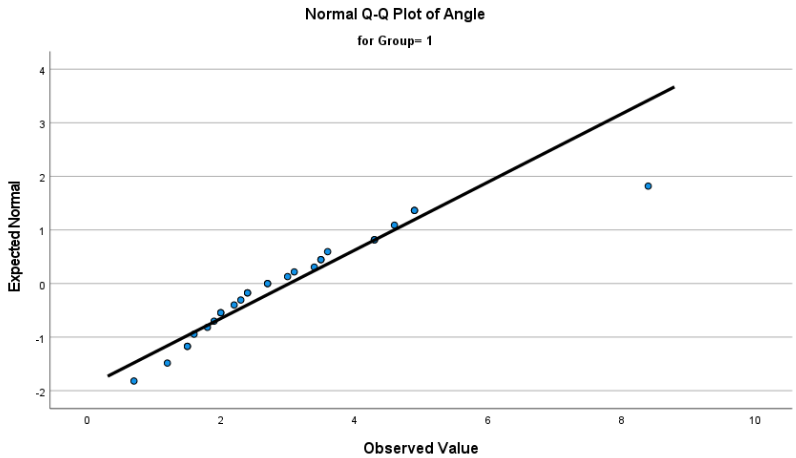
	Group			Statistic	Std. Error
Angle	1	Mean		3.025	.2970
		95% Confidence Interval for Mean	Lower Bound	2.416	
			Upper Bound	3.634	
		5% Trimmed Mean		2.903	
		Median		2.700	
		Variance		2.470	
		Std. Deviation		1.5717	
		Minimum		.7	
		Maximum		8.4	
		Range		7.7	
		Interquartile Range		2.2	
		Skewness		1.474	.441
		Kurtosis		3.734	.858
	2	Mean		1.881	.1131
		95% Confidence Interval for Mean	Lower Bound	1.648	
			Upper Bound	2.114	
		5% Trimmed Mean		1.855	
		Median		1.800	
		Variance		.333	
		Std. Deviation		.5769	
		Minimum		1.1	
		Maximum		3.1	
		Range		2.0	
		Interquartile Range		.9	
		Skewness		.634	.456
		Kurtosis		-.397	.887

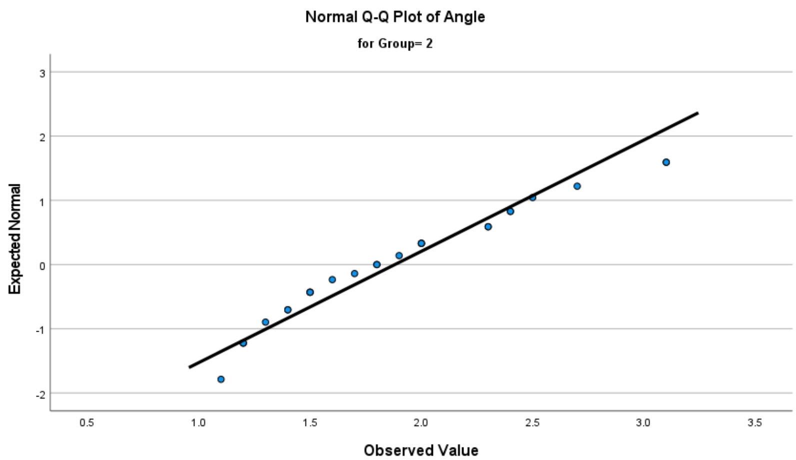
Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Group	Statistic	df	Sig.	Statistic	df	Sig.
Angle	1	.119	28	.200*	.894	28	.008
	2	.130	26	.200*	.935	26	.100

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction





Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance				95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
Angle	Equal variances assumed	11.550	.001	3.498	52	<.001	<.001	1.1442	.3271	.4878	1.8006
	Equal variances not assumed			3.600	34.617	<.001	<.001	1.1442	.3178	.4987	1.7897

BASE – DISTAL

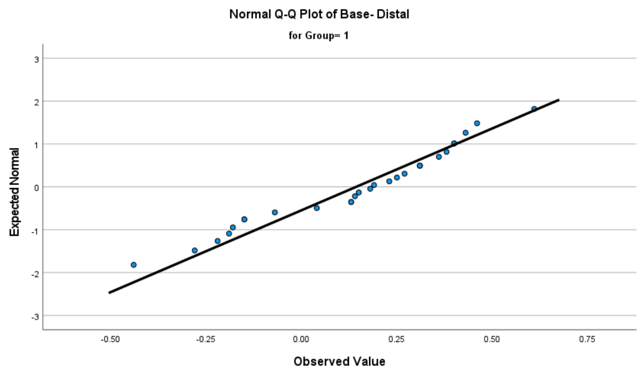
Descriptives

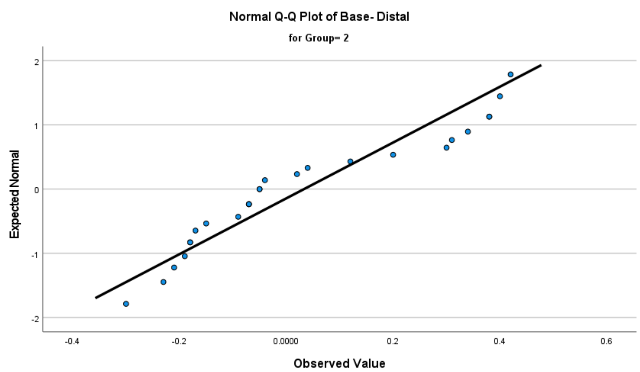
	Group			Statistic	Std. Error
Base- Distal	1	Mean		.1429	.04950
		95% Confidence Interval for Mean	Lower Bound	.0413	
			Upper Bound	.2444	
		5% Trimmed Mean		.1491	
		Median		.1850	
		Variance		.069	
		Std. Deviation		.26194	
		Minimum		-.44	
		Maximum		.61	
		Range		1.05	
		Interquartile Range		.48	
		Skewness		-.488	.441
		Kurtosis		-.552	.858
	2	Mean		.0331	.04512
		95% Confidence Interval for Mean	Lower Bound	-.0599	
			Upper Bound	.1260	
		5% Trimmed Mean		.0294	
		Median		-.0500	
		Variance		.053	
		Std. Deviation		.23009	
		Minimum		-.30	
		Maximum		.42	
		Range		.72	
		Interquartile Range		.48	
		Skewness		.513	.456
		Kurtosis		-1.203	.887

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Group	Statistic	df	Sig.	Statistic	df	Sig.
Base- Distal	1	.159	28	.068	.953	28	.230
	2	.202	26	.008	.890	26	.009

a. Lilliefors Significance Correction





Ranks

	Group	N	Mean Rank	Sum of Ranks
Base- Distal	1	28	30.64	858.00
	2	26	24.12	627.00
	Total	54		

Test Statistics[a]

	Base- Distal
Mann-Whitney U	276.000
Wilcoxon W	627.000
Z	-1.525
Asymp. Sig. (2-tailed)	.127
Exact Sig. (2-tailed)	.129
Exact Sig. (1-tailed)	.065
Point Probability	.001

a. Grouping Variable: Group

BASE – BUCCAL

Descriptives

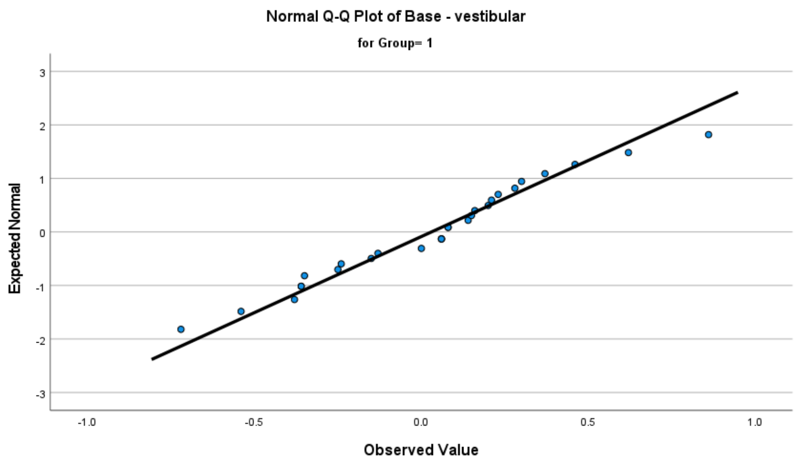
	Group			Statistic	Std. Error
Base - vestibular	1	Mean		.0300	.06646
		95% Confidence Interval for Mean	Lower Bound	-.1064	
			Upper Bound	.1664	
		5% Trimmed Mean		.0265	
		Median		.0700	
		Variance		.124	
		Std. Deviation		.35169	
		Minimum		-.72	
		Maximum		.86	
		Range		1.58	
		Interquartile Range		.47	
		Skewness		.050	.441
		Kurtosis		.226	.858
	2	Mean		.1046	.05582
		95% Confidence Interval for Mean	Lower Bound	-.0104	
			Upper Bound	.2196	
		5% Trimmed Mean		.1148	
		Median		.1200	
		Variance		.081	
		Std. Deviation		.28464	
		Minimum		-.49	
		Maximum		.52	
		Range		1.01	
		Interquartile Range		.48	
		Skewness		-.470	.456
		Kurtosis		-.547	.887

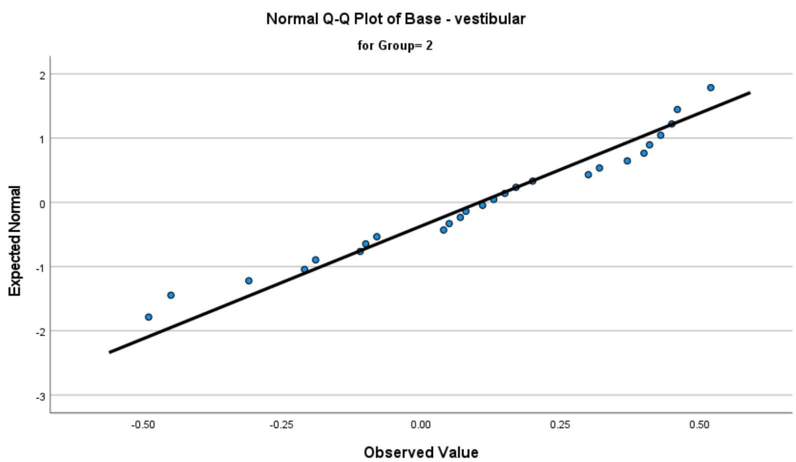
Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Group	Statistic	df	Sig.	Statistic	df	Sig.
Base - vestibular	1	.141	28	.162	.981	28	.866
	2	.103	26	.200*	.952	26	.262

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction





Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance		Mean	Std. Error	95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p	Difference	Difference	Lower	Upper
Base - vestibular	Equal variances assumed	.723	.399	-.853	52	.199	.398	-.07462	.08748	-.25016	.10093
	Equal variances not assumed			-.860	51.078	.197	.394	-.07462	.08680	-.24886	.09963

BASE - APICAL

Descriptives

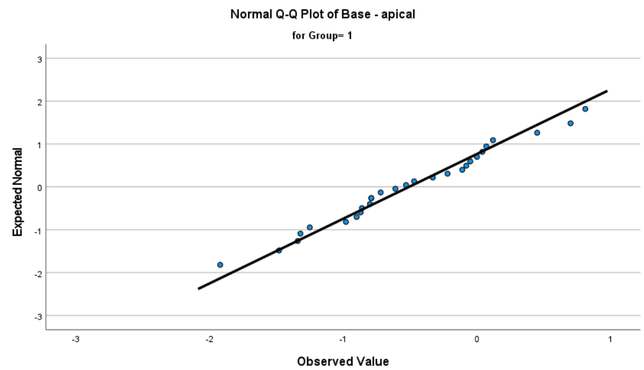
	Group			Statistic	Std. Error
Base - apical	1	Mean		-.5082	.12515
		95% Confidence Interval for Mean	Lower Bound	-.7650	
			Upper Bound	-.2514	
		5% Trimmed Mean		-.5083	
		Median		-.5700	
		Variance		.439	
		Std. Deviation		.66222	
		Minimum		-1.92	
		Maximum		.81	
		Range		2.73	
		Interquartile Range		.88	
		Skewness		.048	.441
		Kurtosis		-.300	.858
	2	Mean		.1300	.07910
		95% Confidence Interval for Mean	Lower Bound	-.0329	
			Upper Bound	.2929	
		5% Trimmed Mean		.1389	
		Median		.3100	
		Variance		.163	
		Std. Deviation		.40336	
		Minimum		-.50	
		Maximum		.60	
		Range		1.10	
		Interquartile Range		.81	
		Skewness		-.347	.456
		Kurtosis		-1.691	.887

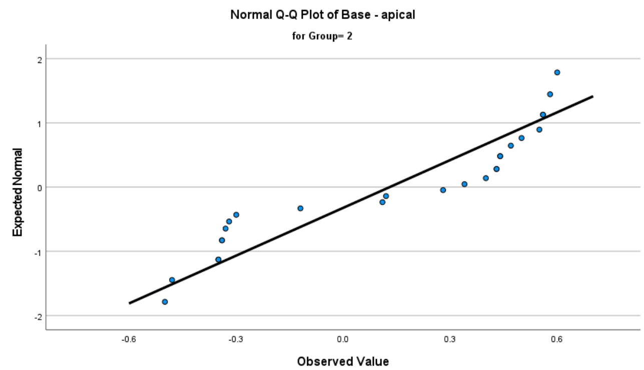
Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Group	Statistic	df	Sig.	Statistic	df	Sig.
Base - apical	1	.093	28	.200*	.983	28	.917
	2	.210	26	.005	.837	26	<.001

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction





Ranks

	Group	N	Mean Rank	Sum of Ranks
Base - apical	1	28	20.21	566.00
	2	26	35.35	919.00
	Total	54		

Test Statistics[a]

	Base - apical
Mann-Whitney U	160.000
Wilcoxon W	566.000
Z	-3.532
Asymp. Sig. (2-tailed)	<.001
Exact Sig. (2-tailed)	<.001
Exact Sig. (1-tailed)	<.001
Point Probability	.000

a. Grouping Variable: Group

TIP – DISTAL

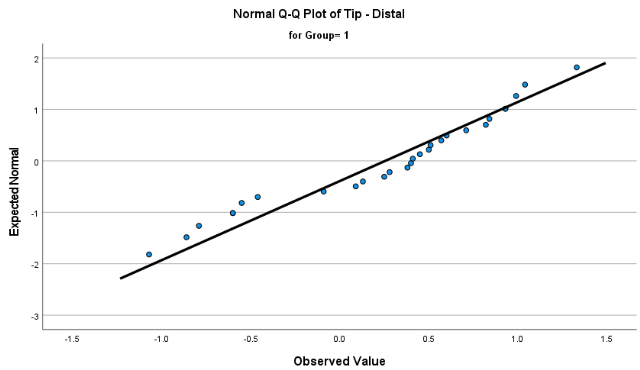
Descriptives

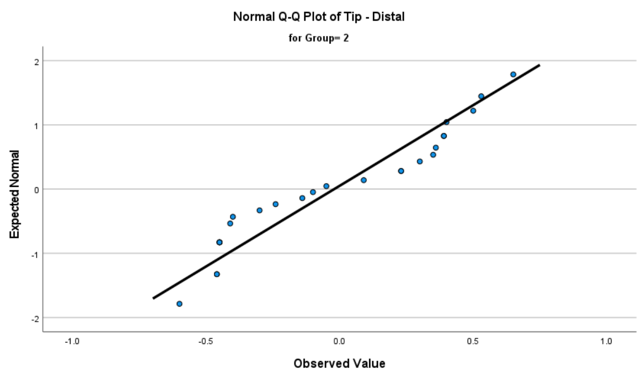
	Group			Statistic	Std. Error
Tip - Distal	1	Mean		.2550	.12284
		95% Confidence Interval for Mean	Lower Bound	.0029	
			Upper Bound	.5071	
		5% Trimmed Mean		.2702	
		Median		.4050	
		Variance		.423	
		Std. Deviation		.65003	
		Minimum		-1.07	
		Maximum		1.33	
		Range		2.40	
		Interquartile Range		1.16	
		Skewness		-.538	.441
		Kurtosis		-.694	.858
	2	Mean		-.0208	.07809
		95% Confidence Interval for Mean	Lower Bound	-.1816	
			Upper Bound	.1401	
		5% Trimmed Mean		-.0261	
		Median		-.0750	
		Variance		.159	
		Std. Deviation		.39817	
		Minimum		-.60	
		Maximum		.65	
		Range		1.25	
		Interquartile Range		.82	
		Skewness		.115	.456
		Kurtosis		-1.596	.887

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Group	Statistic	df	Sig.	Statistic	df	Sig.
Tip - Distal	1	.148	28	.121	.938	28	.101
	2	.176	26	.038	.893	26	.011

a. Lilliefors Significance Correction





Ranks

	Group	N	Mean Rank	Sum of Ranks
Tip - Distal	1	28	31.45	880.50
	2	26	23.25	604.50
	Total	54		

Test Statistics[a]

	Tip - Distal
Mann-Whitney U	253.500
Wilcoxon W	604.500
Z	-1.914
Asymp. Sig. (2-tailed)	.056
Exact Sig. (2-tailed)	.056
Exact Sig. (1-tailed)	.028
Point Probability	.001

a. Grouping Variable: Group

TIP – BUCCAL

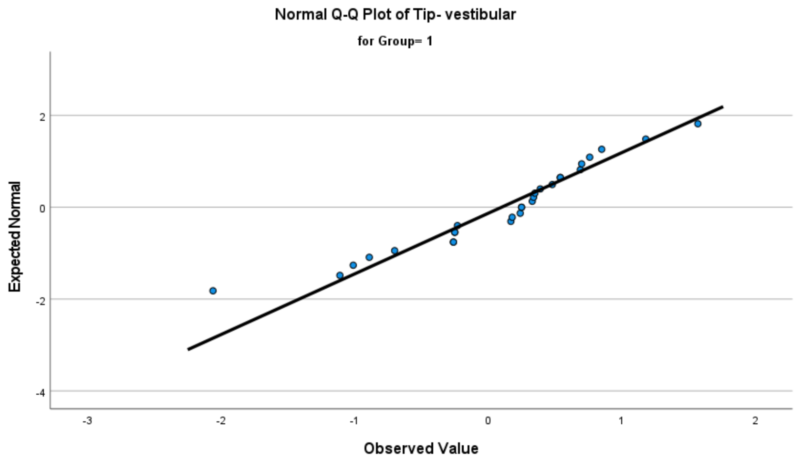
Descriptives

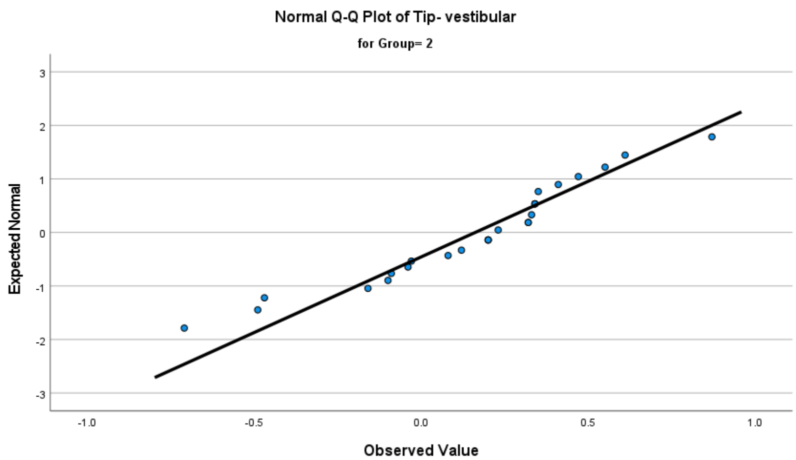
	Group			Statistic	Std. Error
Tip- vestibular	1	Mean		.0996	.14316
		95% Confidence Interval for Mean	Lower Bound	-.1941	
			Upper Bound	.3934	
		5% Trimmed Mean		.1290	
		Median		.2500	
		Variance		.574	
		Std. Deviation		.75751	
		Minimum		-2.06	
		Maximum		1.57	
		Range		3.63	
		Interquartile Range		.80	
		Skewness		-.829	.441
		Kurtosis		1.380	.858
	2	Mean		.1612	.06943
		95% Confidence Interval for Mean	Lower Bound	.0182	
			Upper Bound	.3041	
		5% Trimmed Mean		.1707	
		Median		.2150	
		Variance		.125	
		Std. Deviation		.35402	
		Minimum		-.71	
		Maximum		.87	
		Range		1.58	
		Interquartile Range		.40	
		Skewness		-.668	.456
		Kurtosis		.723	.887

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Group	Statistic	df	Sig.	Statistic	df	Sig.
Tip- vestibular	1	.180	28	.021	.945	28	.150
	2	.159	26	.089	.948	26	.212

a. Lilliefors Significance Correction





Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance				95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
Tip- vestibular	Equal variances assumed	8.528	.005	-.377	52	.354	.707	-.06151	.16300	-.38860	.26558
	Equal variances not assumed			-.387	38.873	.351	.701	-.06151	.15910	-.38336	.26034

TIP - APICAL

Descriptives

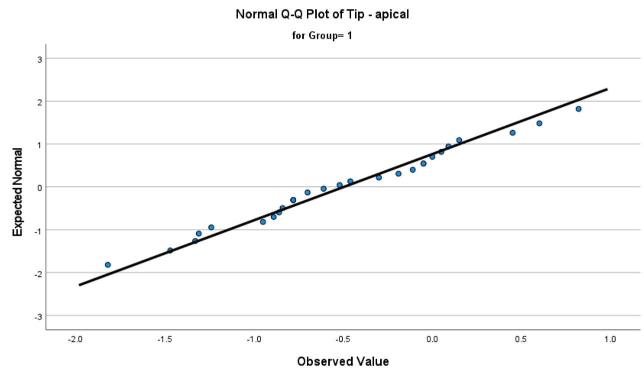
	Group			Statistic	Std. Error
Tip - apical	1	Mean		-.4957	.12245
		95% Confidence Interval for Mean	Lower Bound	-.7470	
			Upper Bound	-.2445	
		5% Trimmed Mean		-.4973	
		Median		-.5650	
		Variance		.420	
		Std. Deviation		.64795	
		Minimum		-1.82	
		Maximum		.82	
		Range		2.64	
		Interquartile Range		.87	
		Skewness		.053	.441
		Kurtosis		-.446	.858
	2	Mean		.0832	.07402
		95% Confidence Interval for Mean	Lower Bound	-.0696	
			Upper Bound	.2360	
		5% Trimmed Mean		.0861	
		Median		.1300	
		Variance		.137	
		Std. Deviation		.37008	
		Minimum		-.47	
		Maximum		.57	
		Range		1.04	
		Interquartile Range		.76	
		Skewness		-.198	.464
		Kurtosis		-1.706	.902

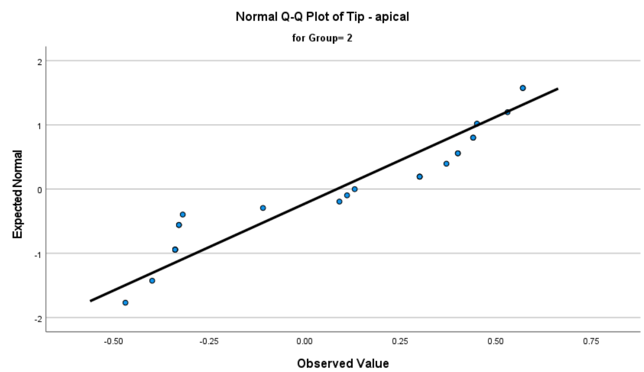
Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Group	Statistic	df	Sig.	Statistic	df	Sig.
Tip - apical	1	.098	28	.200*	.984	28	.927
	2	.222	25	.003	.858	25	.003

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction





Ranks

	Group	N	Mean Rank	Sum of Ranks
Tip - apical	1	28	20.34	569.50
	2	25	34.46	861.50
	Total	53		

Test Statistics[a]

	Tip - apical
Mann-Whitney U	163.500
Wilcoxon W	569.500
Z	-3.325
Asymp. Sig. (2-tailed)	<.001
Exact Sig. (2-tailed)	<.001
Exact Sig. (1-tailed)	<.001
Point Probability	.000

a. Grouping Variable: Group

Dynamic Implant Placement Accuracy - Comparison of Groups
ANGLE

Descriptives

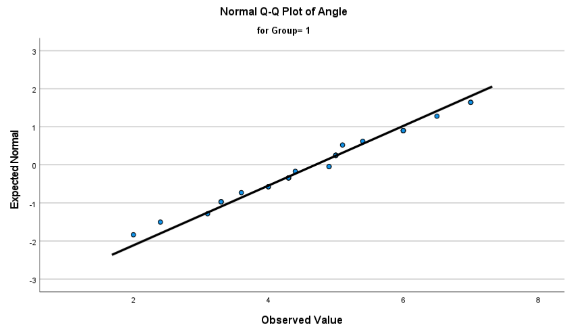
	Group			Statistic	Std. Error
Angle	1	Mean		4.693	.2368
		95% Confidence Interval for Mean	Lower Bound	4.208	
			Upper Bound	5.178	
		5% Trimmed Mean		4.708	
		Median		4.900	
		Variance		1.626	
		Std. Deviation		1.2753	
		Minimum		2.0	
		Maximum		7.0	
		Range		5.0	
		Interquartile Range		1.9	
		Skewness		-.110	.434
		Kurtosis		-.351	.845
	2	Mean		3.414	.2588
		95% Confidence Interval for Mean	Lower Bound	2.874	
			Upper Bound	3.954	
		5% Trimmed Mean		3.337	
		Median		3.300	
		Variance		1.406	
		Std. Deviation		1.1859	
		Minimum		1.5	
		Maximum		6.8	
		Range		5.3	
		Interquartile Range		1.7	
		Skewness		.983	.501
		Kurtosis		1.982	.972

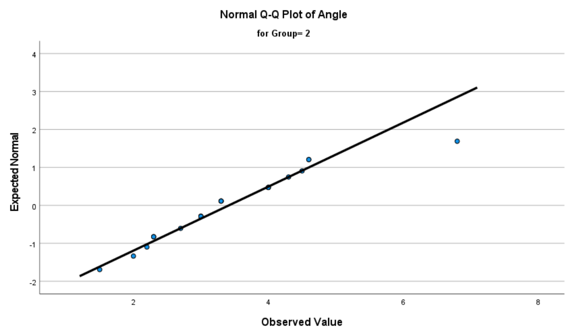
Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Group	Statistic	df	Sig.	Statistic	df	Sig.
Angle	1	.116	29	.200*	.974	29	.664
	2	.157	21	.188	.931	21	.144

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction





Independent samples t-test

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance				95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
Angle	Equal variances assumed	.271	.605	3.603	48	<.001	<.001	1.2788	.3550	.5651	1.9925
	Equal variances not assumed			3.646	44.988	<.001	<.001	1.2788	.3508	.5723	1.9853

Among dynamic placements, there was a statistically significant difference in mean angle between the novice and expert groups ($p < 0.001$).

Dynamic Implant Placement Accuracy - Comparison of Groups
BASE - DISTAL

Descriptives

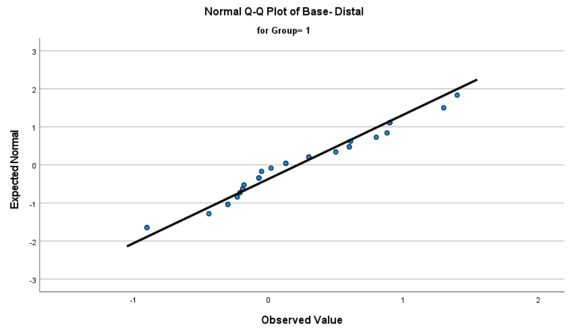
	Group			Statistic	Std. Error
Base- Distal	1	Mean		.2193	.11004
		95% Confidence Interval for Mean	Lower Bound	-.0061	
			Upper Bound	.4447	
		5% Trimmed Mean		.2176	
		Median		.1300	
		Variance		.351	
		Std. Deviation		.59258	
		Minimum		-.90	
		Maximum		1.40	
		Range		2.30	
		Interquartile Range		.91	
		Skewness		.139	.434
		Kurtosis		-.494	.845
	2	Mean		.2033	.08913
		95% Confidence Interval for Mean	Lower Bound	.0174	
			Upper Bound	.3893	
		5% Trimmed Mean		.2243	
		Median		.3100	
		Variance		.167	
		Std. Deviation		.40845	
		Minimum		-.90	
		Maximum		.90	
		Range		1.80	
		Interquartile Range		.54	
		Skewness		-.719	.501
		Kurtosis		1.325	.972

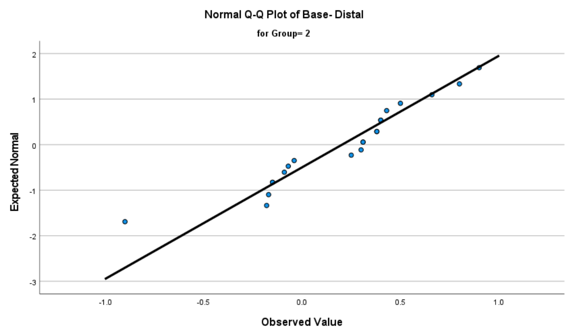
Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Group	Statistic	df	Sig.	Statistic	df	Sig.
Base- Distal	1	.124	29	.200*	.963	29	.398
	2	.165	21	.140	.930	21	.137

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction





Independent Samples t-test

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance				95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
Base- Distal	Equal variances assumed	4.297	.044	.106	48	.458	.916	.01598	.15008	-.28578	.31774
	Equal variances not assumed			.113	47.917	.455	.911	.01598	.14161	-.26876	.30071

Among dynamic placements, there was no statistically significant difference in the mean base distal between the novice and expert groups ($p = 0.91$).

Dynamic Implant Placement Accuracy - Comparison of Groups
BASE - BUCCAL

Descriptives

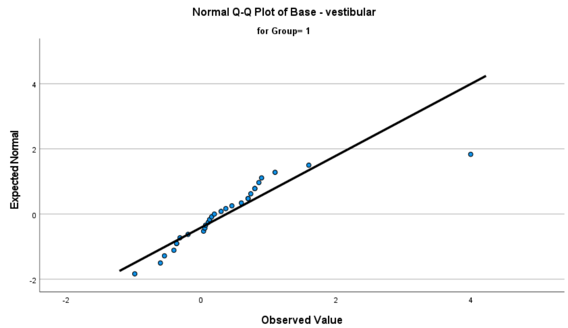
	Group			Statistic	Std. Error
Base - vestibular	1	Mean		.3779	.16849
		95% Confidence Interval for Mean	Lower Bound	.0328	
			Upper Bound	.7231	
		5% Trimmed Mean		.2870	
		Median		.2000	
		Variance		.823	
		Std. Deviation		.90734	
		Minimum		-.98	
		Maximum		4.00	
		Range		4.98	
		Interquartile Range		1.02	
		Skewness		2.265	.434
		Kurtosis		8.483	.845
	2	Mean		.0990	.09365
		95% Confidence Interval for Mean	Lower Bound	-.0963	
			Upper Bound	.2944	
		5% Trimmed Mean		.1053	
		Median		.0600	
		Variance		.184	
		Std. Deviation		.42917	
		Minimum		-.72	
		Maximum		.80	
		Range		1.52	
		Interquartile Range		.71	
		Skewness		-.034	.501
		Kurtosis		-.933	.972

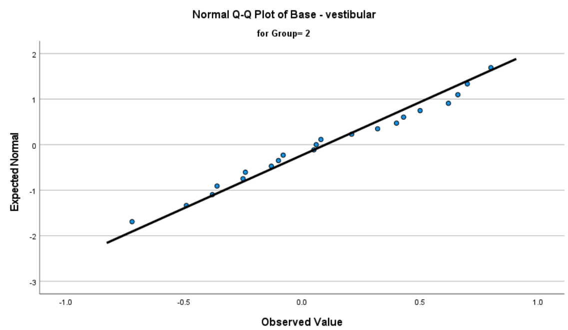
Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Group	Statistic	df	Sig.	Statistic	df	Sig.
Base - vestibular	1	.179	29	.018	.811	29	<.001
	2	.092	21	.200*	.971	21	.748

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction





Mann-Whitney U

Ranks

	Group	N	Mean Rank	Sum of Ranks
Base - vestibular	1	29	27.57	799.50
	2	21	22.64	475.50
	Total	50		

Test Statistics[a]

	Base - vestibular
Mann-Whitney U	244.500
Wilcoxon W	475.500
Z	-1.180
Asymp. Sig. (2-tailed)	.238
Exact Sig. (2-tailed)	.242
Exact Sig. (1-tailed)	.121
Point Probability	.002

a. Grouping Variable: Group

Among dynamic placements, there is not a statistically significant difference in median base vestibular between the novice and expert groups ($p = 0.24$).

Dynamic Implant Placement Accuracy - Comparison of Groups
BASE - APICAL

Descriptives

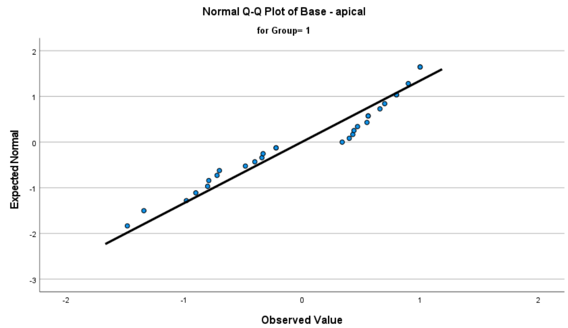
	Group			Statistic	Std. Error
Base - apical	1	Mean		-.0031	.13843
		95% Confidence Interval for Mean	Lower Bound	-.2867	
			Upper Bound	.2805	
		5% Trimmed Mean		.0208	
		Median		.3400	
		Variance		.556	
		Std. Deviation		.74548	
		Minimum		-1.48	
		Maximum		1.00	
		Range		2.48	
		Interquartile Range		1.32	
		Skewness		-.360	.434
		Kurtosis		-1.155	.845
	2	Mean		-.3124	.16021
		95% Confidence Interval for Mean	Lower Bound	-.6466	
			Upper Bound	.0218	
		5% Trimmed Mean		-.2915	
		Median		-.3500	
		Variance		.539	
		Std. Deviation		.73416	
		Minimum		-1.92	
		Maximum		.90	
		Range		2.82	
		Interquartile Range		1.27	
		Skewness		-.222	.501
		Kurtosis		-.332	.972

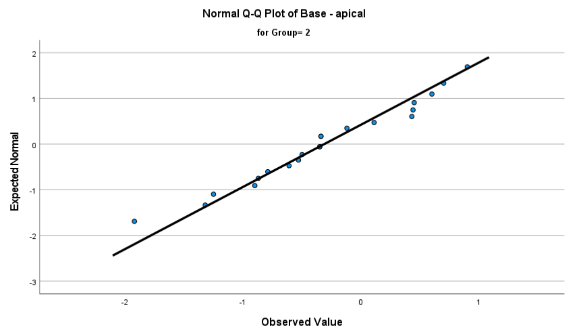
Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Group	Statistic	df	Sig.	Statistic	df	Sig.
Base - apical	1	.195	29	.007	.922	29	.033
	2	.134	21	.200*	.970	21	.725

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction





Mann-Whitney U test

Ranks

	Group	N	Mean Rank	Sum of Ranks
Base - apical	1	29	27.93	810.00
	2	21	22.14	465.00
	Total	50		

Test Statistics[a]

	Base - apical
Mann-Whitney U	234.000
Wilcoxon W	465.000
Z	-1.386
Asymp. Sig. (2-tailed)	.166
Exact Sig. (2-tailed)	.169
Exact Sig. (1-tailed)	.084
Point Probability	.002

a. Grouping Variable: Group

Among dynamic placements, there was no statistically significant difference in the median base apical between the novice and expert groups ($p = 0.17$).

Dynamic vs. Static Implant Placement Accuracy - NOVICE Group
ANGLE

Descriptives

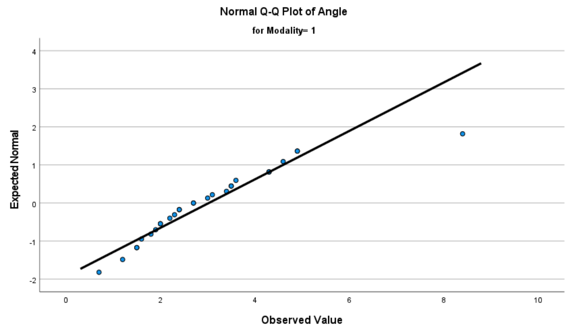
	Modality			Statistic	Std. Error
Angle	1	Mean		3.025	.2970
		95% Confidence Interval for Mean	Lower Bound	2.416	
			Upper Bound	3.634	
		5% Trimmed Mean		2.903	
		Median		2.700	
		Variance		2.470	
		Std. Deviation		1.5717	
		Minimum		.7	
		Maximum		8.4	
		Range		7.7	
		Interquartile Range		2.2	
		Skewness		1.474	.441
		Kurtosis		3.734	.858
	2	Mean		4.693	.2368
		95% Confidence Interval for Mean	Lower Bound	4.208	
			Upper Bound	5.178	
		5% Trimmed Mean		4.708	
		Median		4.900	
		Variance		1.626	
		Std. Deviation		1.2753	
		Minimum		2.0	
		Maximum		7.0	
		Range		5.0	
		Interquartile Range		1.9	
		Skewness		-.110	.434
		Kurtosis		-.351	.845

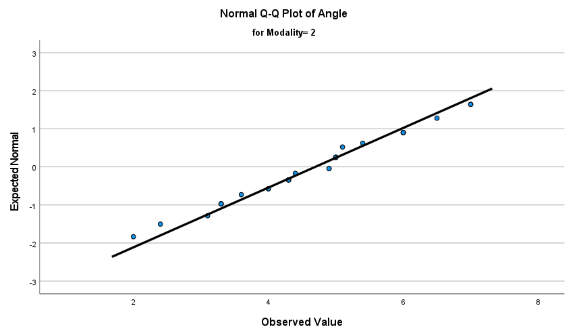
Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Modality	Statistic	df	Sig.	Statistic	df	Sig.
Angle	1	.119	28	.200*	.894	28	.008
	2	.116	29	.200*	.974	29	.664

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction





Independent samples t-test

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance				95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
Angle	Equal variances assumed	.485	.489	-4.407	55	<.001	<.001	-1.6681	.3785	-2.4266	-.9096
	Equal variances not assumed			-4.391	51.983	<.001	<.001	-1.6681	.3799	-2.4304	-.9058

Among novices, there was a statistically significant difference in mean angle between the static and dynamic modalities ($p < 0.001$).

Dynamic vs. Static Implant Placement Accuracy - NOVICE Group
BASE - DISTAL

Descriptives

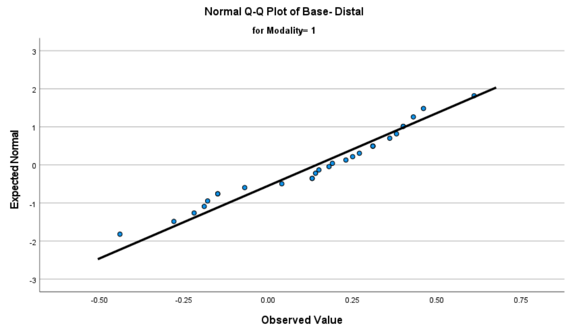
	Modality			Statistic	Std. Error
Base- Distal	1	Mean		.1429	.04950
		95% Confidence Interval for Mean	Lower Bound	.0413	
			Upper Bound	.2444	
		5% Trimmed Mean		.1491	
		Median		.1850	
		Variance		.069	
		Std. Deviation		.26194	
		Minimum		-.44	
		Maximum		.61	
		Range		1.05	
		Interquartile Range		.48	
		Skewness		-.488	.441
		Kurtosis		-.552	.858
	2	Mean		.2193	.11004
		95% Confidence Interval for Mean	Lower Bound	-.0061	
			Upper Bound	.4447	
		5% Trimmed Mean		.2176	
		Median		.1300	
		Variance		.351	
		Std. Deviation		.59258	
		Minimum		-.90	
		Maximum		1.40	
		Range		2.30	
		Interquartile Range		.91	
		Skewness		.139	.434
		Kurtosis		-.494	.845

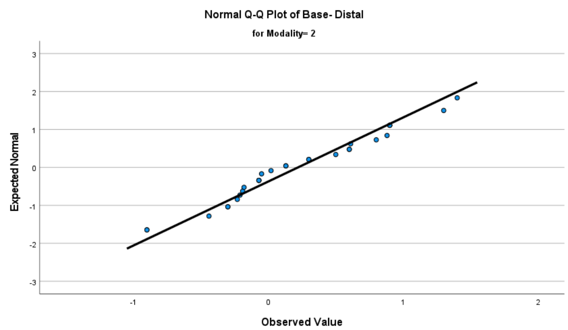
Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Modality	Statistic	df	Sig.	Statistic	df	Sig.
Base- Distal	1	.159	28	.068	.953	28	.230
	2	.124	29	.200*	.963	29	.398

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction





Independent samples t-test

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance		Mean	Std. Error	95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p	Difference	Difference	Lower	Upper
Base- Distal	Equal variances assumed	18.193	<.001	-.626	55	.267	.534	-.07645	.12212	-.32119	.16828
	Equal variances not assumed			-.634	38.831	.265	.530	-.07645	.12066	-.32055	.16764

Among novices, there was no statistically significant difference in mean base distal between the static and dynamic modalities ($p = 0.53$).

Dynamic vs. Static Implant Placement Accuracy - NOVICE Group
BASE - BUCCAL

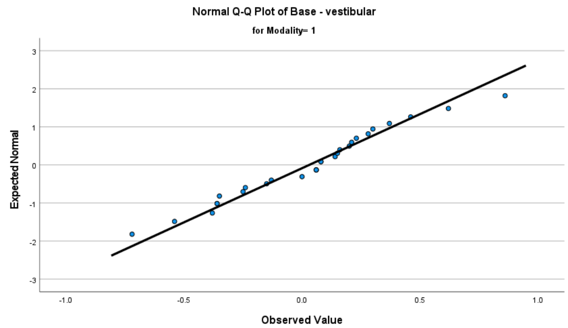
Descriptives

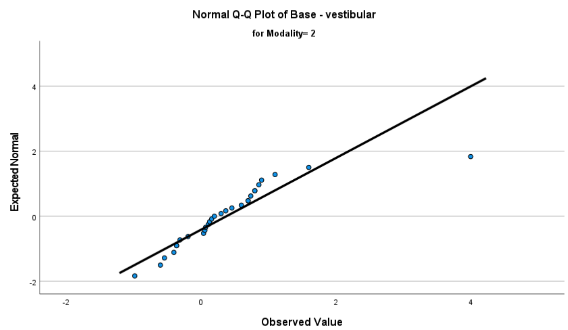
	Modality			Statistic	Std. Error
Base - vestibular	1	Mean		.0300	.06646
		95% Confidence Interval for Mean	Lower Bound	-.1064	
			Upper Bound	.1664	
		5% Trimmed Mean		.0265	
		Median		.0700	
		Variance		.124	
		Std. Deviation		.35169	
		Minimum		-.72	
		Maximum		.86	
		Range		1.58	
		Interquartile Range		.47	
		Skewness		.050	.441
		Kurtosis		.226	.858
	2	Mean		.3779	.16849
		95% Confidence Interval for Mean	Lower Bound	.0328	
			Upper Bound	.7231	
		5% Trimmed Mean		.2870	
		Median		.2000	
		Variance		.823	
		Std. Deviation		.90734	
		Minimum		-.98	
		Maximum		4.00	
		Range		4.98	
		Interquartile Range		1.02	
		Skewness		2.265	.434
		Kurtosis		8.483	.845

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Modality	Statistic	df	Sig.	Statistic	df	Sig.
Base - vestibular	1	.141	28	.162	.981	28	.866
	2	.179	29	.018	.811	29	<.001

a. Lilliefors Significance Correction





Mann-Whitney U test

Ranks

	Modality	N	Mean Rank	Sum of Ranks
Base - vestibular	1	28	25.36	710.00
	2	29	32.52	943.00
	Total	57		

Test Statistics[a]

	Base - vestibular
Mann-Whitney U	304.000
Wilcoxon W	710.000
Z	-1.629
Asymp. Sig. (2-tailed)	.103
Exact Sig. (2-tailed)	.105
Exact Sig. (1-tailed)	.052
Point Probability	.001

a. Grouping Variable: Modality

Among novices, there was no statistically significant difference in the median base vestibular offset between the static and dynamic modalities ($p = 0.11$).

Dynamic vs. Static Implant Placement Accuracy - NOVICE Group
BASE – APICAL

Descriptives

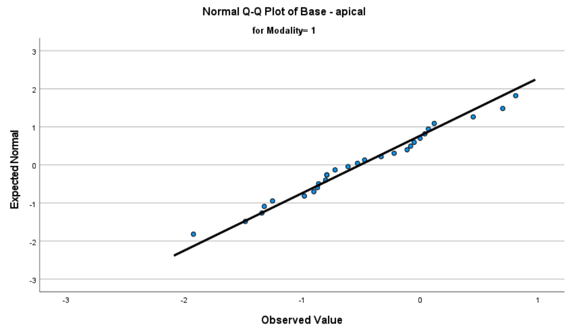
	Modality			Statistic	Std. Error
Base - apical	1	Mean		-.5082	.12515
		95% Confidence Interval for Mean	Lower Bound	-.7650	
			Upper Bound	-.2514	
		5% Trimmed Mean		-.5083	
		Median		-.5700	
		Variance		.439	
		Std. Deviation		.66222	
		Minimum		-1.92	
		Maximum		.81	
		Range		2.73	
		Interquartile Range		.88	
		Skewness		.048	.441
		Kurtosis		-.300	.858
	2	Mean		-.0031	.13843
		95% Confidence Interval for Mean	Lower Bound	-.2867	
			Upper Bound	.2805	
		5% Trimmed Mean		.0208	
		Median		.3400	
		Variance		.556	
		Std. Deviation		.74548	
		Minimum		-1.48	
		Maximum		1.00	
		Range		2.48	
		Interquartile Range		1.32	
		Skewness		-.360	.434
		Kurtosis		-1.155	.845

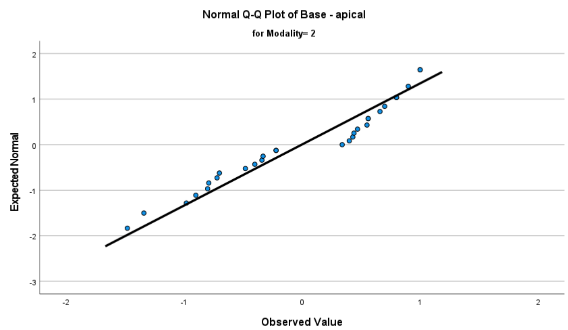
Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Modality	Statistic	df	Sig.	Statistic	df	Sig.
Base - apical	1	.093	28	.200*	.983	28	.917
	2	.195	29	.007	.922	29	.033

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction





Mann-Whitney U test

Ranks

	Modality	N	Mean Rank	Sum of Ranks
Base - apical	1	28	23.68	663.00
	2	29	34.14	990.00
	Total	57		

Test Statistics[a]

	Base - apical
Mann-Whitney U	257.000
Wilcoxon W	663.000
Z	-2.379
Asymp. Sig. (2-tailed)	.017
Exact Sig. (2-tailed)	.017
Exact Sig. (1-tailed)	.008
Point Probability	.000

a. Grouping Variable: Modality

Among novices, there was a statistically significant difference in median base apical between the static and dynamic modalities (p = 0.02).

Dynamic vs. Static Implant Placement Accuracy - EXPERIENCED Group
ANGLE

Descriptives

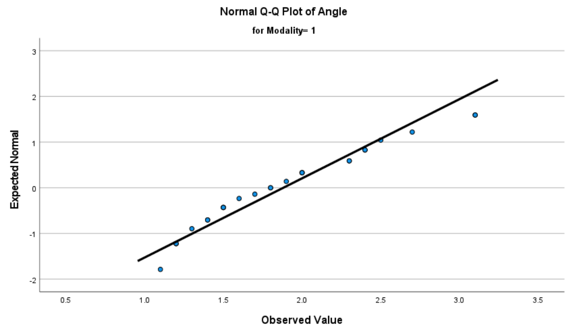
	Modality			Statistic	Std. Error
Angle	1	Mean		1.881	.1131
		95% Confidence Interval for Mean	Lower Bound	1.648	
			Upper Bound	2.114	
		5% Trimmed Mean		1.855	
		Median		1.800	
		Variance		.333	
		Std. Deviation		.5769	
		Minimum		1.1	
		Maximum		3.1	
		Range		2.0	
		Interquartile Range		.9	
		Skewness		.634	.456
		Kurtosis		-.397	.887
	2	Mean		3.414	.2588
		95% Confidence Interval for Mean	Lower Bound	2.874	
			Upper Bound	3.954	
		5% Trimmed Mean		3.337	
		Median		3.300	
		Variance		1.406	
		Std. Deviation		1.1859	
		Minimum		1.5	
		Maximum		6.8	
		Range		5.3	
		Interquartile Range		1.7	
		Skewness		.983	.501
		Kurtosis		1.982	.972

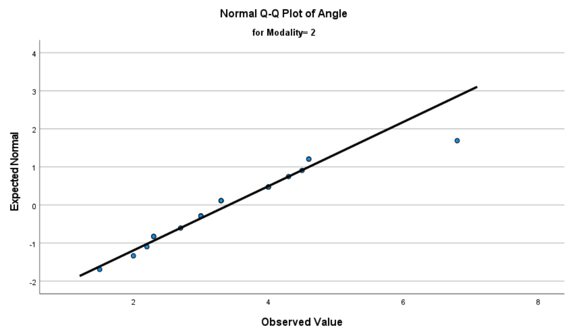
Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Modality	Statistic	df	Sig.	Statistic	df	Sig.
Angle	1	.130	26	.200*	.935	26	.100
	2	.157	21	.188	.931	21	.144

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction





Independent Samples t-test

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance				95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
Angle	Equal variances assumed	7.207	.010	-5.808	45	<.001	<.001	-1.5335	.2640	-2.0653	-1.0017
	Equal variances not assumed			-5.430	27.571	<.001	<.001	-1.5335	.2824	-2.1125	-.9546

Among the experienced, there was a statistically significant difference in mean angle between the static and dynamic modalities ($p < 0.001$).

Dynamic vs. Static Implant Placement Accuracy - EXPERIENCED Group
BASE - DISTAL

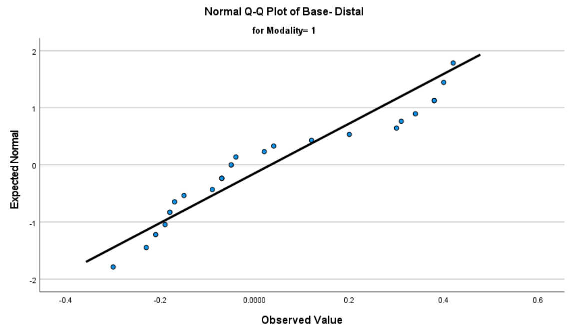
Descriptives

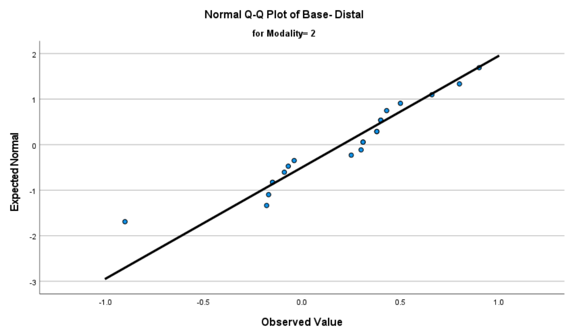
	Modality			Statistic	Std. Error
Base- Distal	1	Mean		.0331	.04512
		95% Confidence Interval for Mean	Lower Bound	-.0599	
			Upper Bound	.1260	
		5% Trimmed Mean		.0294	
		Median		-.0500	
		Variance		.053	
		Std. Deviation		.23009	
		Minimum		-.30	
		Maximum		.42	
		Range		.72	
		Interquartile Range		.48	
		Skewness		.513	.456
		Kurtosis		-1.203	.887
	2	Mean		.2033	.08913
		95% Confidence Interval for Mean	Lower Bound	.0174	
			Upper Bound	.3893	
		5% Trimmed Mean		.2243	
		Median		.3100	
		Variance		.167	
		Std. Deviation		.40845	
		Minimum		-.90	
		Maximum		.90	
		Range		1.80	
		Interquartile Range		.54	
		Skewness		-.719	.501
		Kurtosis		1.325	.972

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Modality	Statistic	df	Sig.	Statistic	df	Sig.
Base- Distal	1	.202	26	.008	.890	26	.009
	2	.165	21	.140	.930	21	.137

a. Lilliefors Significance Correction





Independent samples t-test

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance		Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p			Lower	Upper
Base- Distal	Equal variances assumed	5.492	.024	-1.803	45	.039	.078	-.17026	.09442	-.36042	.01991
	Equal variances not assumed			-1.704	29.990	.049	.099	-.17026	.09990	-.37429	.03378

Among the experienced, there was no statistically significant difference in the mean base distal between the static and dynamic modalities ($p = 0.10$).

Dynamic vs. Static Implant Placement Accuracy - EXPERIENCED Group
BASE - BUCCAL

Descriptives

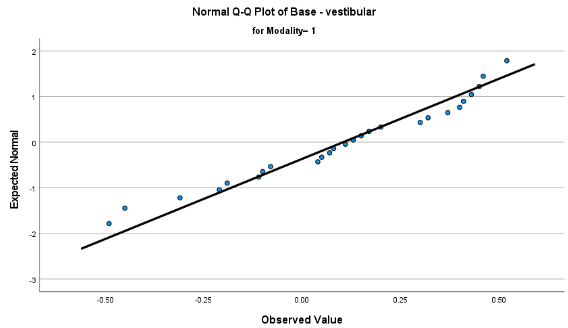
	Modality			Statistic	Std. Error
Base - vestibular	1	Mean		.1046	.05582
		95% Confidence Interval for Mean	Lower Bound	-.0104	
			Upper Bound	.2196	
		5% Trimmed Mean		.1148	
		Median		.1200	
		Variance		.081	
		Std. Deviation		.28464	
		Minimum		-.49	
		Maximum		.52	
		Range		1.01	
		Interquartile Range		.48	
		Skewness		-.470	.456
		Kurtosis		-.547	.887
	2	Mean		.0990	.09365
		95% Confidence Interval for Mean	Lower Bound	-.0963	
			Upper Bound	.2944	
		5% Trimmed Mean		.1053	
		Median		.0600	
		Variance		.184	
		Std. Deviation		.42917	
		Minimum		-.72	
		Maximum		.80	
		Range		1.52	
		Interquartile Range		.71	
		Skewness		-.034	.501
		Kurtosis		-.933	.972

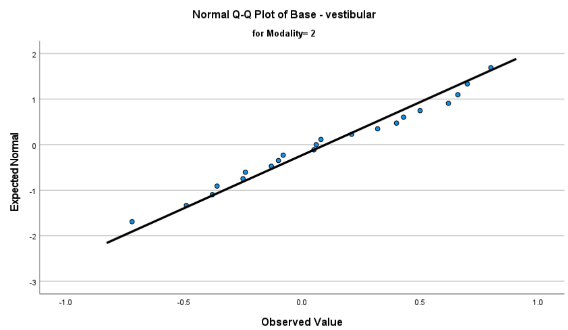
Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Modality	Statistic	df	Sig.	Statistic	df	Sig.
Base - vestibular	1	.103	26	.200*	.952	26	.262
	2	.092	21	.200*	.971	21	.748

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction





Independent samples t-test

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance				95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
Base - vestibular	Equal variances assumed	5.204	.027	.053	45	.479	.958	.00557	.10450	-.20492	.21605
	Equal variances not assumed			.051	33.366	.480	.960	.00557	.10903	-.21616	.22729

Among the experienced, there was no statistically significant difference in the mean base vestibular between the static and dynamic modalities (p = 0.96).

Dynamic vs. Static Implant Placement Accuracy - EXPERIENCED Group
BASE - APICAL

Descriptives

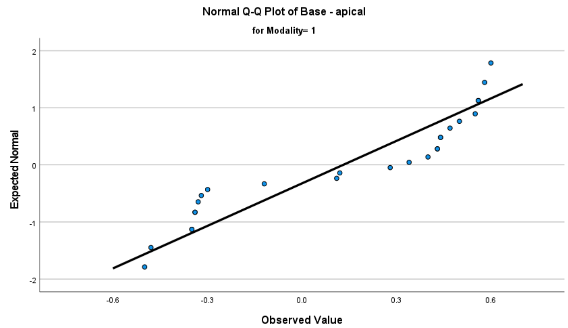
	Modality			Statistic	Std. Error
Base - apical	1	Mean		.1300	.07910
		95% Confidence Interval for Mean	Lower Bound	-.0329	
			Upper Bound	.2929	
		5% Trimmed Mean		.1389	
		Median		.3100	
		Variance		.163	
		Std. Deviation		.40336	
		Minimum		-.50	
		Maximum		.60	
		Range		1.10	
		Interquartile Range		.81	
		Skewness		-.347	.456
		Kurtosis		-1.691	.887
	2	Mean		-.3124	.16021
		95% Confidence Interval for Mean	Lower Bound	-.6466	
			Upper Bound	.0218	
		5% Trimmed Mean		-.2915	
		Median		-.3500	
		Variance		.539	
		Std. Deviation		.73416	
		Minimum		-1.92	
		Maximum		.90	
		Range		2.82	
		Interquartile Range		1.27	
		Skewness		-.222	.501
		Kurtosis		-.332	.972

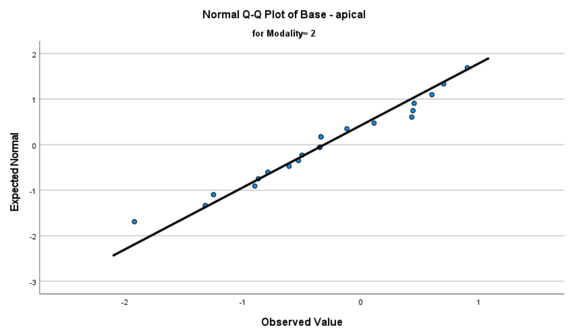
Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Modality	Statistic	df	Sig.	Statistic	df	Sig.
Base - apical	1	.210	26	.005	.837	26	<.001
	2	.134	21	.200*	.970	21	.725

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction





Mann-Whitney U test

Ranks

	Modality	N	Mean Rank	Sum of Ranks
Base - apical	1	26	28.08	730.00
	2	21	18.95	398.00
	Total	47		

Test Statistics[a]

	Base - apical
Mann-Whitney U	167.000
Wilcoxon W	398.000
Z	-2.270
Asymp. Sig. (2-tailed)	.023
Exact Sig. (2-tailed)	.022
Exact Sig. (1-tailed)	.011
Point Probability	.000

a. Grouping Variable: Modality

Among the experienced, there was a statistically significant difference in median base apical between the static and dynamic modalities ($p = 0.02$).

V.3 Qualitative Results

All 54 participants completed interviews regarding their experiences with implant placement methods. Responses were analyzed to evaluate participants' perceptions of the techniques used.

Emerging Themes:

Themes emerging from the iterative process of thematic analysis were classified into four categories:

1. Comparative Analysis
2. Experiential Perspectives
3. Practice & Training
4. Utilization & Application

Within the Comparative Analysis, four subthemes emerged: (1) Advantages of Dynamic Navigation System, (2) Disadvantages of Dynamic Navigation System, (3) Advantages of Static Guide, and (4) Disadvantages of Static Guide.

The Experiential Perspectives theme encapsulated three subthemes: (1) Experience Placing Implants with Dynamic Navigation System, (2) Learning Process with Dynamic Navigation System, and (3) User-Friendliness for New Practitioners.

The Practice & Training encapsulated two subthemes: (1) Recommendations for Dynamic Navigation System Practice, and (2) Incorporation into Preclinical Training.

As for the Utilization & Application theme, three subthemes surfaced: (1) Recommendations for Dynamic Navigation Usage, (2) Challenges in Implementing Dynamic Navigation System, and (3) Potential Drawbacks in the Application of Dynamic Navigation System.

Theme 1: Comparative Analysis

This theme discusses the advantages and disadvantages of both the dynamic navigation system and the static 3D printed guides for dental implant placement. The subthemes under this theme delve into the specific benefits and drawbacks of each technique, allowing for a comprehensive comparison between the two methods among the two groups.

Overall, novice participants highlighted several advantages of the dynamic navigation system, including real-time visualization, enhanced accuracy, and reduced patient appointment time. However, they also identified challenges such as complexity, increased procedure time, and limited manual control, which may impact the system's usability and adoption, especially among inexperienced practitioners. Experienced participants identified several benefits of the dynamic navigation system, including real-time adjustment to the treatment plan, precision, and reduced waiting time to perform procedure. However, they also highlighted challenges such as increased procedure complexity, learning curve, and limited manual feedback, which may impact the system's integration into clinical practice.

a. **Advantages of Dynamic Navigation System**

   Advantages of Dynamic Navigation System for NOVICE Participants:

   1. **Real-Time Visualization:** Novice participants noted that the dynamic navigation system provided real-time visual feedback during implant placement, allowing them

to see the depth, angulation, and three-dimensional position accurately. This feature instilled a sense of confidence and safety in the procedure, as they could visually confirm the implant's position.

"I would say advantages is you are able to see a visual of your length in which you want to place the implant and also gain confidence in how far buccal, mesial, distal and lingual that you want it so you have good accuracy with the virtual display".
"It felt like I was safer like I actually wasn't questioning about how I was placing it correctly or not because I could see it. So yes, it felt safer for the dynamic. I think it's an advantage, because while placing it with the guide, it felt easier because I was just placing it. But it was kind of blind because I was placing it and then trusting the guide, but I don't really know where is it going? What's happening in there versus the other technique, it felt more like, you know, I was seeing what I'm doing."

2. **Enhanced Accuracy:** The system's ability to precisely measure depth and control angulation was highlighted as a significant advantage. Novice participants felt that this level of accuracy could result in ideal implant placement, contributing to better treatment outcomes.
   "I wasn't questioning about how I was placing it correctly or not because, you know, I could see it. So yes, so it felt it felt safer for the dynamic".
   "I would say advantage would be more accuracy, which is depicted on the fact you are able to see the mesial and distal dimension along with the buccal lingual dimensions which you don't get on the static. I would say that's the biggest advantage".

3. **Reduced Patient Appointment Time:** Participants appreciated that the dynamic navigation system potentially reduced the number of appointments required for patients, as there was no need to prepare a surgical guide beforehand. This streamlined process could lead to increased efficiency in dental practices.
   "Some advantages are definitely the fact that you can do all of your treatment planning and implant placement on the same day."
   "The fact that it reduces the time in the patient's appointment that they need to come in because you don't have to have the surgical guide prepared."

4. **Learning Tool:** Participants viewed the dynamic navigation system as a valuable learning tool for gaining proficiency in implant placement. While acknowledging a learning curve, they believed that with practice, the system could improve their implant placement skills and understanding.
   "I think in terms of learning and gaining confidence or a better understanding on how implants are placed that it is a great model to use".

5. **Reduced Material in Patient's Mouth:** Novice participants noted that the dynamic navigation system required less material in the patient's mouth compared to traditional static guides. This could potentially enhance patient comfort and reduce procedural complexity.
   "I think the advantage is that there's not much material in the patient's mouth".

Advantages of Dynamic Navigation System for EXPERIENCED Participants:

1. **Real-Time Adjustment:** Experienced participants noted that the dynamic navigation system allowed for real-time adjustments during implant placement, providing flexibility in positioning and angulation. This feature was perceived as advantageous for achieving precise placement without the need for additional imaging.
   "With the static guide you don't know the accuracy of it until you take another CBCT, so that's probably an advantage of the dynamic navigation. You could see like in real time".
   "Maybe sometimes there is a discrepancy between your planning and what is going on. In real time, you have the chance to adjust and modify, whereas in the guided you would just, you know, throw the guide, and go in free hand."

2. **Reduced Waiting Time:** Participants appreciated the immediate availability of the dynamic navigation system, eliminating the need to wait for guide fabrication or laboratory procedures. This aspect saved time and reduced reliance on external resources, enhancing clinical workflow efficiency.
   "You don't have to wait for the guide fabrication or pay for the laboratory or the materials".
   "Advantage is probably less preparation time and to just do it right then and there".

3. **Enhanced Precision:** The dynamic navigation system was praised for its precision in guiding implant placement, ensuring optimal positioning in real time. Participants

valued the ability to visualize the procedure accurately and make adjustments as needed, leading to improved clinical outcomes.

"I like that you could see what you're doing in real time in terms of angulation deviation. And like the positioning of your drill. And, that I think that is easier to you, you can carry out your surgery in the same day, I heard, compared to doing a guided surgery".

4. **Single-Appointment Procedure:** Experienced participants highlighted the advantage of planning and performing surgery in the same appointment using the dynamic navigation system. This streamlined approach eliminated the need for multiple visits and facilitated comprehensive treatment planning and execution.

   "The advantage would be that could be performed same appointment, planning and surgery, that we don't have the laboratory potentially getting in the process."

5. **Improved Visualization:** The system's visualization capabilities were lauded by participants, particularly its ability to display angulation and drill positioning in real time. This visual feedback aided in decision-making and ensured accurate implant placement without relying solely on tactile sensation.

   "One of the advantages is having, you know, direct access in case you want to do a free hand type of surgery".

   "I think at some point after we got used to it, you can be guided precisely, but at the same time have some freedom for correction".

b. Disadvantages of Dynamic Navigation System

Disadvantages of Dynamic Navigation System for NOVICE Participants:

1. **Complexity and Learning Curve:** Novice participants acknowledged that the dynamic navigation system presented a learning curve and required practice to master. They highlighted challenges such as handpiece alignment with the camera and the need to identify specific markers on the screen.

   "I would say one major disadvantage to me it was the HANDPIECE itself. When you try to align the hand piece with the camera and at the same time trying to place the implant. It is super hard because I couldn't get comfortable in a position that I can do a proper support while I'm using the handpiece and the same time keep it on tracking with the camera. That was the biggest disadvantage for me."

   "I think it's kind of difficult to navigate it at first, but I do see that there are more pros than cons. It's just hand placement. Learning how to identify like where to place the green circle. It's just that it takes practice."

2. **Increased Procedure Time:** Some participants noted that using the dynamic navigation system could extend the duration of the procedure due to adjustments required for angulation correction. This aspect was considered a disadvantage, especially in clinical settings where time efficiency is crucial.

   "The dynamic system, it can help correct for angulation when you're looking at it, but the disadvantage would be the amount of time it takes, so when you're working with a patient and the amount of correction you have to do to adjust for the angulation."

3. **Limited Manual Control:** Participants expressed concerns about the limited manual control afforded by the dynamic navigation system compared to traditional guides. They felt that relying solely on visual feedback without tactile sensation could pose challenges, particularly for novice practitioners.

   "I think the disadvantage is you have to be a little more precise when placing the drill in the patients' mouth and it's not as guided for the dynamic navigation."

   "I found that for me it was a little bit difficult to get everything lined up and angulated properly on dynamic versus for the second one with the guide, it kind of just did it for me and made sure that the angulation was kind of good."

4. **Perceived Safety Concerns:** One participant expressed feelings of uncertainty and discomfort when using the dynamic navigation system, particularly regarding handpiece manipulation and drill control. This perceived lack of control raised safety concerns during the procedure.

   "I did feel like I was guessing at some point and that was a little scary. I did feel safer with the normal guide, but I do see if you get used to the other one, how it can be ok."

Disadvantages of Dynamic Navigation System for EXPERIENCED Participants:

1. **Increased Procedure Complexity:** Experienced participants noted that using the dynamic navigation system added complexity to the procedure, requiring simultaneous focus on the patient and the software interface. This multitasking aspect could potentially complicate the workflow, especially for clinicians accustomed to traditional methods.

"I would say that dynamic one would take more time and it needs to focus on the patient and on the dynamic software as well at the same time. So, in my experience, I feel it makes things more complicated."

2. **Learning Curve:** Participants acknowledged a learning curve associated with the dynamic navigation system, particularly in terms of calibration and software navigation. This initial adjustment period could prolong procedure time and necessitate additional training to achieve proficiency.
   "The difficulty is like just getting used to it. It was my first time trying it. So, I still have a learning curve. I didn't really know how to do all the little technical stuff."
   "For dynamic one I feel the learning curve is longer because you need to adapt for this system."

3. **Limited Manual Feedback:** Some participants expressed concerns about the lack of mechanical feedback when using the dynamic navigation system, particularly in narrow or sloped ridge scenarios. Without tactile sensation or mechanical guidance, controlling the drill's entry point and trajectory could be challenging.
   "I think there is no mechanical feedback. The drill is a little bit in the air. It's really hard for you to control the drill like that."

4. **Overreliance on Screen:** Participants noted that the dynamic navigation system required constant attention to the computer screen, diverting focus away from the surgical field. This shift in focus could potentially lead to missed intraoral events or

complications, highlighting the importance of maintaining awareness of both the screen and the patient.

"I feel the focus is more on the screen itself, more than the surgical field, and that is kind of not what we used to. I would want to look at the surgical site."

"It's a little bit difficult to keep an eye on both the computer and the patient's mouth, so I think it's a disadvantage because sometimes if you look at the computer, maybe you miss things that can happen intraorally, and this could be a problem. You can damage the tissues or have complications."

5. **Technical Challenges:** Participants encountered technical challenges such as calibration procedures and sensor adaptation, which added complexity to the workflow and interrupted the surgical process. These challenges, combined with the need for constant screen monitoring, contributed to the system's perceived drawbacks.

   "There is a lot of additional steps when it comes to calibration. It takes a lot of time."

Comparison of Novice and Experienced Participants' Perspectives on Dynamic Navigation System:

Advantages:

- ***Novice Participants:***
  - Appreciated real-time visualization for increased confidence.
  - Noted reduced patient appointment time and enhanced accuracy.
  - Viewed the system as a valuable learning tool for skill development.
- ***Experienced Participants:***
  - Highlighted real-time adjustment and precision for optimal placement.

    - Acknowledged immediate availability and single-appointment procedures.
    - Praised improved visualization and decision-making during surgery.

Disadvantages:

- ***Novice Participants:***
    - Encountered complexity and learning curve in system operation.
    - Expressed concerns about limited manual control and perceived safety.
    - Felt distracted by the need for constant screen monitoring during procedures.
- ***Experienced Participants:***
    - Noted increased procedure complexity and technical challenges.
    - Acknowledged a learning curve and the need for constant screen attention.
    - Experienced difficulties in narrow or sloped ridge scenarios due to limited feedback.

Overall:

- ***Novice Participants:***
    - Found the system beneficial for learning but faced challenges in operation.
    - Valued real-time visualization and accuracy but felt hindered by complexity.
- ***Experienced Participants:***
    - Appreciated the precision and efficiency of the system but encountered technical and procedural challenges.
    - Found the system advantageous for experienced clinicians but highlighted the importance of adaptation and proficiency.

c. Advantages of Static Guide

Advantages of Static 3D Printed Guides for NOVICE Participants:

1. **Satisfactory and Straightforward Experience:** Novice participants found the use of static guides to be very satisfactory and straightforward, implying ease of use and a positive user experience.

   "Using static guides was very satisfactory for me. It made the whole process straightforward and easy to follow, which was great for someone like me who's just starting out."

2. **Reliability and Foolproof Nature:** Participants expressed confidence in static guides, considering them as the "gold standard" in implant placement. They described them as reliable and foolproof, having been extensively studied and proven effective.

   "I see static guides as the gold standard. They've been extensively studied and proven effective, so I trust them completely. It's like having a reliable map guiding you every step of the way."

3. **Time Efficiency:** Novice participants appreciated the time efficiency of static guides, noting that they require less time for implant placement compared to dynamic navigation systems. They found static guides to be quicker and more efficient, particularly for novice practitioners.

   "What I really liked about static guides is how quick and efficient they are. They saved me a lot of time during implant placement compared to the dynamic systems. For someone new to this, time efficiency is crucial."

4. **User-Friendly and Easy to Learn:** Participants described static guides as user-friendly and easy to learn, allowing for precise depth and angulation with minimal complexity. They found it straightforward to use and understand, facilitating better planning and execution of implant procedures.

   "Static guides are so user-friendly and easy to learn. I found it simple to understand how to use them for precise depth and angulation. It's like following a step-by-step guide that anyone can grasp."

5. **Comfort and Ease of Use:** Participants found static guides to be more comfortable and easier to use compared to dynamic navigation systems. They appreciated the simplicity and ease of placing implants using static guides, which contributed to a smoother overall experience.

   "Using static guides was definitely more comfortable for me. It felt easier and less stressful compared to the dynamic systems. I appreciated the simplicity and how smoothly everything went."

6. **Safety and Reliability:** Novice participants perceived static guides as a safe option, especially for those new to implant placement. Despite their longer time for fabrication, participants considered static guides to be reliable and suitable for ensuring patient safety.

   "I feel safer using static guides, especially as a beginner. Even though they take longer to fabricate, I know they're reliable and won't lead to any surprises during the procedure. Patient safety is always my top priority."

7. **Potential for Future Utilization:** Participants expressed enthusiasm for incorporating static guides into their future practice. They viewed static guides as a valuable tool and hoped to utilize them more extensively in their clinical work.
   "I'm excited about incorporating static guides into my future practice. They've proven to be such a valuable tool, and I can see myself using them extensively in my clinical work. It's definitely something I want to explore further."

Advantages of Static 3D Printed Guides for EXPERIENCED Participants:

1. **Straightforward and Easy to Use:** Participants expressed satisfaction with the straightforward nature of using static guides. They found the process easy and user-friendly, which contributed to a positive experience.
   "Using static guides is just so straightforward. It's like following a well-defined path every time. The process is easy to understand and execute, which makes it a breeze to use."

2. **Accuracy and Reliability:** Experienced participants highlighted the accuracy and reliability of static guides, emphasizing that they provide very accurate placement for implants. They considered static guides to be the standard of care and the best way to place implants due to their consistent results.
   "Static guides are the gold standard for a reason. They offer unmatched accuracy and reliability in implant placement. I trust them implicitly because they consistently deliver precise results."

3. **Time Efficiency:** Participants noted that using static guides can be quick and convenient, especially when the guide is fabricated accurately and the plan is precise. This time efficiency contributes to a streamlined treatment process.
"When everything is set up properly, static guides can save a lot of time. The process becomes quite efficient, especially when you have a well-fabricated guide and a precise treatment plan. It streamlines the entire procedure."

4. **Familiarity and Comfort:** Many participants expressed their familiarity and comfort with static guides, having used them for years. They found static guides to be a tool they trust and are accustomed to using, making the process easier and more efficient.
"I've been using static guides for years now, and they've become like second nature to me. There's a level of familiarity and comfort that comes with using them, which makes the whole process smoother and more efficient."

5. **Convenience and User-Friendliness:** Participants described the static guide procedure as convenient, fast, and user-friendly. They appreciated its ease of use and convenience in clinical practice, particularly when properly designed and fitted.
"Static guides are incredibly convenient to use. They're fast, user-friendly, and fit seamlessly into my clinical workflow. When everything aligns properly, it's like having a reliable assistant guiding you through the procedure."

d. Disadvantages of Static Guide

Disadvantages of Static 3D Printed Guides for NOVICE Participants:

1. **Time-Consuming Planning & Preparation:** Novice participants highlighted the time-consuming nature of planning and preparing static guides, contrasting it with the more straightforward process of using dynamic navigation systems. They noted that creating static guides required multiple appointments for printing and separate CBCT scans, adding to the overall duration of preparation.
   "It takes quite a while to get the static guides ready. You have to go for multiple appointments for scans and printing, which makes the whole process feel a bit drawn out."

2. **Limited Adjustability:** Participants noted that static guides lack flexibility during the procedure, as adjustments for angulation or fitting cannot be made while the patient is in the chair.
   "Once it's printed, you can't really adjust it. So, if something doesn't fit right during the procedure, you're kind of stuck."

3. **Lack of Real-Time Feedback:** Novice participants expressed concerns about the lack of real-time feedback on measurements of depth and angulation with static guides, leading to uncertainty and potential debates regarding accuracy. While static guides were generally perceived as easier and more comfortable to use, participants also noted their limitations in providing precise measurements and feedback.
   "I wish there was a way to see the measurements in real-time while we were working. It would have made me feel more confident about what I was doing."

"It was easy to use once we got the hang of it, but I still felt a bit unsure about whether everything was going according to plan."

4. **User Error Potential:** Some participants mentioned the possibility of user error, particularly related to factors that may impact fit and therefore the accuracy of the guide. *"There's definitely room for error, especially if something doesn't fit right or if we didn't plan everything perfectly."*

5. **Room for Improvement:** Participants observed that while static guides generally work well, there is room for improvement, indicating potential challenges or inconsistencies in their effectiveness.
"I think there could be some improvements to make the process smoother and more reliable, especially for beginners like us."

Disadvantages of Static 3D Printed Guides for EXPERIENCED Participants:

While the experienced group generally viewed 3D printed static guides positively, these potential disadvantages highlight areas where caution and attention to detail are warranted to ensure optimal outcomes during implant placement procedures:

1. **Digital Plan Discrepancies and Fabrication Reliability:** Several participants highlighted the risk of discrepancies between the digital plan and the fabricated guide, underscoring the critical importance of accurate fabrication and planning. Neglecting these steps could lead to challenges during implant placement."

"One concern we have with static guides is the possibility of discrepancies between the digital plan and the final fabricated guide. Even minor variations could impact the accuracy of implant placement if not carefully addressed."

"We acknowledge the reliability of static guides, but it's crucial to emphasize the dependency on proper fabrication and planning. Any errors in these stages could lead to significant challenges during implant placement."

"If static guides aren't meticulously designed and accurately fitted, there's a risk of inaccuracies during implant placement. Ensuring proper conversion from scans to guide design is imperative to minimize these potential pitfalls."

2. **Dependency and Overreliance:** Some participants expressed concern that practitioners might become too dependent on static guides, potentially limiting their ability to adapt or problem-solve in situations where the guide may not provide optimal guidance. Some participants cautioned against practitioners becoming overly reliant on technology, suggesting that while static guides are useful tools, they should not replace fundamental clinical skills and decision-making.

   "While static guides are valuable tools, there's a risk of practitioners becoming overly dependent on them. It's essential to maintain clinical skills and decision-making abilities, rather than relying solely on technology to guide every step of the procedure."

3. **Limited Flexibility and Adaptability:** Static guides may lack flexibility and adaptability during the procedure, particularly if adjustments need to be made on the

spot. This could potentially limit the practitioner's ability to address unforeseen challenges during implant placement.

"A limitation of static guides is their lack of flexibility and adaptability during the procedure. This could pose challenges if adjustments need to be made on the fly to address unexpected anatomical variations or surgical complexities."

Comparison of Novice and Experienced Participants' Perspectives on 3D Printed Static Guides:

Advantages:

- ***Novice Participants:***
- Found static guides straightforward and easy to use, contributing to increased confidence.
- Appreciated the accuracy and reliability of static guides for precise implant placement.
- Viewed static guides as valuable learning tools that facilitate skill development in implant placement.
- ***Experienced Participants:***
- Praised the accuracy and reliability of static guides, considering them the gold standard for implant placement.
- Acknowledged the time efficiency of static guides, leading to quick and convenient procedures.
- Expressed familiarity and comfort with static guides, having used them for years, which streamlined their workflow.

Disadvantages:

- ***Novice Participants:***
    - Noted potential limitations in adjustability during the procedure, leading to challenges in adapting to unforeseen circumstances.
    - Expressed concerns about dependency on proper fabrication and planning, as inaccuracies could affect the outcome.
    - Encountered a learning curve associated with static guides, particularly in understanding the fabrication process and adapting to their use.
- ***Experienced Participants:***
- Cautioned against potential discrepancies between the digital plan and the fabricated guide, which could affect implant placement accuracy if not addressed.
- Expressed concerns about overreliance on static guides, potentially limiting adaptability and problem-solving skills during procedures.
- Emphasized the importance of maintaining fundamental clinical skills and decision-making abilities, cautioning against excessive dependency on technology.

Overall:

- ***Novice Participants:***
    - Found static guides beneficial for learning but faced challenges in adapting to their use and potential limitations.
    - Valued the accuracy and reliability of static guides but encountered hurdles in overcoming the learning curve and dependency on proper fabrication.
- ***Experienced Participants:***
    - Appreciated the precision and efficiency of static guides but encountered technical and procedural challenges.

- Found static guides advantageous for experienced clinicians but emphasized the importance of adaptation and proficiency in maintaining clinical skills.

Theme 2: Experiential Perspectives

This theme focuses on the experiences and perspectives of the practitioners using both system: the dynamic navigation system and static guides for dental implant placement. It encompasses aspects such as the actual experience of using these technologies, the learning process involved, and how user-friendly they are, particularly for new practitioners.

a. Experience Placing Implants with Dynamic Navigation System

NOVICE Group's Experience Placing Implants with Dynamic Navigation System

1. Initial Difficulty and Learning Curve: Novice participants described the experience as challenging initially, citing difficulties in adapting to the system's operation.

"To me, I would say it was hard."

"I think initially it was only difficult trying to track, find the tracking."

2. Real-Time Planning and Visualization: Participants acknowledged the advantage of real-time planning and visualization offered by the dynamic navigation system.

"It was a good experience... in real time, plan and place the implant."

"It was cool to be able to see it in different angles... and be able to change the angulation in real time."

3. Physical and Mental Stress: Some participants experienced physical and mental stress due to the demands of using the system.

"It was a little bit harder placing it... it was a little bit more stressful I guess."

"I'd say it was harder than I thought... it was hard to change the angulations."

4. Need for Practice and Adaptation: Participants highlighted the need for practice and adaptation before feeling comfortable using the system clinically.

"It takes a little while to get used to... until I feel comfortable enough."

"It was a good experience... but obviously it's harder... in real life."

5. Mixed Feelings and Learning Experience: Despite the challenges, participants expressed mixed feelings about the experience, viewing it as a valuable learning opportunity.

"It was a good experience... there's learning curves with everything."

"It was a good experience... I think it's going to help, like placing more implants better."

6. Safety and Precision Perceptions: Some participants felt safer and appreciated the precision offered by the dynamic navigation system.

"I felt safer because I... was seeing what I'm doing."

"I find with more expertise, it gets better."

EXPERIENCED Group's Experience Placing Implants with Dynamic Navigation System

1. Challenges and Learning Curve: Experienced participants described the experience as challenging, citing a steep learning curve and the need for practice.

"Maybe this is the first time I used something like that dynamic software... It's just not making things easier for me.

"It's definitely a work in progress... It just needs a little playing around to get used to it."

2. Physical and Mental Stress: Some participants experienced physical and mental stress while using the system, describing it as heavy and stressful.

"It wasn't fun and it was very heavy... it was just more stressful to be honest."

"I mean, most of my implant placement was done by the static surgical guide... but this one, it's more like a free hand, but you really have to distract yourself."

3. Distraction and Coordination Challenges: Participants mentioned challenges in coordinating their hand movements with the screen and staying focused on the procedure.

"I would say if I need to simultaneously look at the screen, but also like in the mouth or on the model, it's kind of distracting."

"It was kind of hard to coordinate with the screen... pay attention on the screen."

4. Perceived Benefits with Practice: Despite the initial challenges, participants expressed optimism about the potential benefits with practice and familiarity.

"Initially there's some steep learning curve... once I got used to it... it could be a really good system."

"There's a learning curve... but I feel so much more comfortable with the static one."

5. Technical and Procedural Considerations: Participants acknowledged technical aspects and procedural considerations, such as angulation and calibration, requiring attention.

"At the beginning it's a little bit difficult to understand the angulation... maybe it's a little bit technical."

"The first time it's hard to really orient yourself along with what's going on on the screen."

Comparison of the novice and experienced groups based on their perspectives on using a dynamic navigation system for implant placement:

- ***Novice Participants:***
    - Challenges and Learning Curve:

      - Novice participants found the system initially challenging and noted a learning curve in operation.

- Quotes highlighted difficulties in tracking and adapting to the system's requirements.

- Safety and Confidence:

  - Despite challenges, participants appreciated the real-time visualization feature, which increased their confidence during the procedure.

  - Real-time feedback instilled a sense of safety, allowing novices to visually confirm the implant's position.

- Physical Comfort and Stress:

  - Some novices expressed physical discomfort and stress while using the system, particularly with hand positioning and stress during the procedure.

- Perceived Benefits:

  - Participants acknowledged the potential benefits of the system, including increased precision and safety, once they become proficient with its operation.

  - Real-time visualization and accuracy were viewed as advantageous for learning and skill development.

- ***Experienced Participants:***
  - Challenges and Learning Curve:

    - Experienced participants also faced challenges and a learning curve when using the dynamic navigation system.

    - Quotes highlighted difficulties in coordination, distraction, and adapting to the system's requirements.

  - Efficiency and Precision:

- Despite challenges, experienced participants valued the system's precision and efficiency once proficiency was achieved.

- Real-time adjustment and visualization were praised for enhancing precision during implant placement.

- Technical and Procedural Considerations:

  - Technical aspects such as angulation, calibration, and coordination with the screen were noted as important considerations during the procedure.

  - Participants emphasized the need for attention to detail and procedural accuracy when using the system.

- Optimism with Practice:

  - Experienced participants expressed optimism about the system's potential benefits with practice and familiarity.

  - Despite initial challenges, they believed that proficiency with the system could lead to improved efficiency and outcomes.

Overall Comparison:

- **Challenges and Learning Curve:**

  - Both novice and experienced participants faced challenges and noted a learning curve when using the dynamic navigation system.

- **Safety and Confidence:**

  - Novices appreciated the safety and confidence instilled by real-time visualization, while experienced participants valued the precision and efficiency of the system.

- **Physical Comfort and Stress:**

  - Novices and experienced participants alike experienced physical discomfort and stress during the procedure, albeit for different reasons.

- **Perceived Benefits:**

  - Both groups acknowledged the potential benefits of the system, including increased precision and safety, once proficiency was achieved.

b. Learning Process with Dynamic Navigation System

Learning Process with Dynamic Navigation System: NOVICE Perspectives

1. Initial Learning Curve: Participants described a learning curve associated with using the dynamic navigation system. They noted improvements in comfort and proficiency with each subsequent drill size.

"I noticed that I did get better after I did the initial drill... I felt more comfortable using it."

2. Understanding Hardware and Software: Novices emphasized the importance of understanding both the hardware and software components of the system. Learning involved comprehending the system's real-life applications and its translation into the computer interface.

"Understanding how the hardware is used in practice... and how it compares to the simulation... was key."

3. Ease of Instruction and Hands-On Learning: Participants found the learning process straightforward, especially with clear instruction from researchers. Hands-on learning with visual aids provided a realistic perspective, aiding comprehension.

"It was pretty self-explanatory... Once someone teaches you how to use it, it's pretty standard."

4. Accelerated Learning with Limited Experience: Limited prior implant experience facilitated faster learning with the dynamic navigation system. Novices could adjust to angulation and spatial awareness more easily, enhancing their learning curve.

"Seeing my colleagues... made me learn a lot faster... Adjusting for angulation with the dynamic guide was easier."

5. Improvement Over Time: Despite initial challenges, participants noted improvement with practice and familiarity. Mental notes and adjustments led to increased comfort and efficiency during subsequent placements.

"It definitely got easier... I felt like I was improving through the different burs."

6. Positive Feedback on Learning Process: Overall, participants found the learning process clear, straightforward, and conducive to skill development. They expressed a desire for more exposure to such systems to further enhance their learning.

"I think the learning process is amazing... It was really good... I felt safe and secure."

Learning Process with Dynamic Navigation System: Experienced Perspectives

Overall, participants viewed the learning process as manageable and the system as a valuable tool for future applications, despite the need for adaptation and practice.

1. Ease of Learning with Time Commitment: Participants found the learning process relatively straightforward but noted that it required additional time and focus due to the simultaneous management of patient movement and system operation.

"It's pretty easy to learn the process, but it will take more time... You have to focus on two things."

"It was pretty straightforward and self-explanatory... I think it was easy."

2. Improvement Over Time: Despite initial challenges, participants reported improvement with practice, particularly in targeting and calibration.

“I definitely got better at finding the target quicker... It was pretty easy to get better in that amount of time."

3. Preference for More Control: Some participants expressed a preference for systems with greater control or familiarity, indicating a need for further training with dynamic navigation.

"I still prefer the static one... because it might need more training."

4. Challenges with Tracking and Patient Interaction:c Participants noted challenges associated with ensuring continuous tracking and balancing attention between the screen and patient's mouth.

"The thing that didn't really improve over time was the fact that you really need to be careful that the machine was tracking."

5. Repetitive Calibration Process: While the learning curve was not perceived as steep, participants mentioned the repetitive nature of the calibration/measurement process as a potential challenge.

"Honestly, it's not that complicated. It's just repetitive, mainly with the calibration."

Comparison of Novice and Experienced Participants' Learning Process with Dynamic Navigation System:

- ***Novice Participants:***
    - Learning Curve Perception:

      - Initially challenging, described as a learning curve.

      - Some participants needed guidance and time to adapt to the system's operation.

    - Improvement Over Time:

      - Noticed progress with practice, particularly in drill control and angulation.

- Found it easier after gaining familiarity with the system's functions and feedback.

  - Self-Explanatory Nature:

    - Once understood, deemed straightforward and easy to use.

    - Appreciated effective instruction and visual aids provided by the system.

  - Feedback on Learning Experience:

    - Seen as a valuable learning opportunity, especially for those with limited implant placement experience.

    - Spatial awareness and handpiece control were noted as key areas of improvement.

- ***Experienced Participants:***

  - Learning Curve Assessment:

    - Acknowledged a learning curve but perceived it as manageable with practice.

    - Highlighted the need for adaptation to simultaneous patient interaction and system operation.

  - Skill Development Over Time:

    - Reported improvement in targeting and calibration with successive drills.

    - Initially struggled with patient interaction and tracking but showed progress with practice.

  - Preference for Familiarity:

- Some expressed a preference for systems offering more control or traditional methods.

- Despite this, recognized the potential benefits of dynamic navigation for precision and efficiency.

- Overall Evaluation:

  - Viewed the learning process positively, with a recognition of the system's p otential for enhancing surgical precision.

  - Identified areas for improvement, particularly in patient tracking and system integration.

Overall:

Novice participants encountered initial challenges but recognized the system's educational value and potential for skill development. ***Experienced participants,*** while also facing a learning curve, showed quicker adaptation and emphasized the system's role in enhancing precision and efficiency. Both groups highlighted the importance of practice and adaptation to fully utilize the dynamic navigation system.

c. User-Friendliness for New Practitioners.

User Friendliness for New Practitioners - NOVICE Participants

Overall, novice participants viewed static guides as a more user-friendly option for beginners, emphasizing simplicity and control, while recognizing the potential benefits of dynamic navigation with increased experience.

1. **Preference for Static Guide:** Novice participants tended to favor the static guide for its perceived simplicity and control, especially for those with limited experience.
   "To me, I would say the surgical stent is easier for the first timers or the people with less experience because it's a little bit more guided and more controlled than the dynamic."
   "The guided method I think is much easier because it takes a lot of the aspect of getting the right angulation, location out of your hands and makes that part easy."
   Many participants expressed a preference for starting with the static guide before transitioning to dynamic systems, citing concerns about technology reliance and potential system failures.
   "I think it's better to start off analog... Whereas if you have a surgical guide. As long as it's printed, you can place the implant."

2. **Challenges with Dynamic Navigation:** Novice participants highlighted challenges with dynamic navigation, including the need for continuous adjustment, spatial awareness difficulties, and the distracting nature of simultaneous screen and hand coordination.
   "The static Guide is a lot more user friendly just because it you're not really adjusting for angulation too much. While the dynamic got, I felt like I had to consistently move the drill into like an ideal position and it was a lot of adjusting."

3. **Visual Learning with Dynamic System:** Despite the perceived complexity, some participants acknowledged the dynamic system's visual aids and potential for enhancing learning through hands-on experience.

"I think it's a great Model to kind of help with that visual."

"I feel like seeing my colleagues... that actually made me learn a lot faster."

4. **Gradual Transition to Dynamic System:** Many participants recommended starting with static guides for initial implant placements and gradually transitioning to dynamic systems with increased proficiency.
   "I think the standard guided one is probably a better way to start... and then kind of progress to the computerized version."

User Friendliness for New Practitioners - EXPERIENCED Participants

Experienced participants generally leaned towards recommending static guides for novice practitioners due to their simplicity, predictability, and perceived safety, while recognizing the potential for dynamic systems with increased proficiency.

1. **Preference for Static Guide:** Experienced participants generally favored the static guide for novice practitioners, citing its predictability, direct visualization, and reduced margin of error.
   "I would definitely see the static guide is going to be a lot probably easier for someone who has not placed implants before to use."
   The static guide was perceived as an ideal choice for beginners due to its simplicity, reduced chance of deviation, and straightforward usage.
   "Yes, definitely the static guides. I feel like they're straightforward, easy to use. So yeah, I would go for the guides."

"I would highly recommend static guide for beginners... it saves time, it's easier to use, more user friendly."

"I still think that the traditional static... it's more user friendly because once you understand ahead of time which instruments you need to use, then it's like from the first implant is really easy."

2. **Concerns About Dynamic Navigation:** While acknowledging the potential benefits, experienced participants expressed reservations about the dynamic navigation system's suitability for beginners, citing safety concerns, learning curves, and the need for technical proficiency.

   "This kind of software? I don't think it will inhibit... I don't think it's a very safe tool for the Beginner."

   "I would definitely recommend this static placement for multiple reasons. #1 there's less chance of deviation and errors. You know you have a more strict protocol with the guide. Compared to the navigation, which up to a certain point it's a navigated free hand type of surgery."

3. **Preference for Predictability:** Participants highlighted the static guide's predictability and reduced complexity, making it more suitable for beginners compared to the dynamic system.

   "I would definitely recommend this static placement... there's less chance of deviation and errors."

4. **Static Guide as an Intermediate Step:** Some participants suggested that the dynamic system could serve as an intermediate step for practitioners transitioning from static guides to freehand techniques.
   "Nevertheless, it feels that the dynamic could be like a good intermediate step for someone who's willing to go free hand."

Comparison: User Friendliness of Static Guides for Novice Practitioners

- ***Novice Participants:***

Novices generally favored static guides for their simplicity, direct guidance, and ease of use, particularly appreciating the predictability and reduced complexity.

- ***Experienced Participants:***

Experienced participants also leaned towards static guides for beginners, highlighting their predictability, reduced chance of error, and time-saving benefits, while expressing reservations about the complexity and safety of dynamic navigation for novices.

- ***Shared Perception:***

Both groups agreed on the suitability of static guides for novice practitioners due to their straightforward nature, direct visualization, and reduced margin of error, while acknowledging the potential benefits of dynamic systems with increased proficiency.

- ***Differing Concerns:***

While novices primarily focused on the ease of use and direct guidance provided by static guides, experienced participants raised concerns about the safety and learning curve associated with dynamic navigation for beginners.

- ***Overall Consensus:***

Both groups agreed that static guides offer a more user-friendly option for novice practitioners, with experienced participants emphasizing their predictability and time-saving benefits, while also acknowledging the potential for dynamic systems as an intermediate step in skill development.

Both novice and experienced participants lean towards recommending static guides for novice practitioners due to their simplicity, predictability, and perceived safety. While novices appreciated the direct guidance and ease of use provided by static guides, experienced participants also raised concerns about the safety and learning curve associated with dynamic navigation for beginners. Despite these concerns, both groups recognized the potential for dynamic systems as an intermediate step in skill development.

Theme 3: Practice & Training

In this theme, the emphasis is on practical aspects related to the implementation of both techniques in dental practice and training. It covers recommendations for practicing with the dynamic navigation system, strategies for training practitioners to use it effectively, and the potential incorporation of these technologies into preclinical training programs.

a. Recommendations for Dynamic Navigation System Practice

Recommendations for Dynamic Navigation System Practice: NOVICE Perspectives

1. Confidence Building:

"Yeah, I think the more times you do it, you learn the tips and tricks as what makes it quicker and how it's easier place to implant."

2. Value for Skill Development:

"Yes, because I believe if you gain confidence with dynamic that it should be a lot easier free handing implants in general and a stent could always be used at any time or it would just seem a lot easier in general."

"Oh, definitely because I think you know, just having my hands steady needs some practice."

3. Consideration of Benefits:

"Yeah, definitely. I think because you can cut down number of visits in terms of making the surgical guide with the scans and everything. I think it's definitely worth it if you can practice more."

4. Preference for Precision:

"I actually would recommend it because I think it has the capability to be a little bit more precise than the surgical guide, so I would recommend it."

Recommendations for Dynamic Navigation System Practice: EXPERIENCED Perspectives

1. Situational Benefit:

"Yes, in certain situations I find it really helpful, especially for like narrower spaces, for example, laterals."

2. Preference for Traditional Guide:

"I still think fully guided is better."

"If they had the same cost on the patient and me as a dentist, then I would prefer using the static guide over the dynamic guide."

3. Need for Practice and Comparison:

"I would definitely want to try more so that I can be good at it and compare that with what I'm already used to, which is the traditional guide."

"Practice is important in this system. Before you go to patient, so it takes time."

Comparison:

- ***Novice* Perspectives vs. *Experienced* Perspectives:** While novices generally expressed openness and willingness to recommend the dynamic navigation system, experienced practitioners showed more nuanced responses. They highlighted situational benefits, expressed preferences for traditional guides, and emphasized the need for practice and cost considerations. Overall, experienced practitioners were more cautious and selective in recommending the dynamic system, reflecting their deeper experience, and understanding of implant placement techniques.

b. Incorporation into Preclinical Training

Incorporation of Dynamic Navigation System into Preclinical Training: NOVICE Perspectives

1. Interest and Advantages of Exposure: Novice participants expressed enthusiasm for learning new technologies and recognized the potential benefits of incorporating the dynamic navigation system into their training. They appreciated the combination of camera and tracking systems and foresee its application in their future practice.

"I would definitely think this is going to be fun to learn all the new technologies and I really admire the idea of you incorporating the camera system with the tracking system."

"Digital dentistry is up and coming and something that's going to be at the forefront of dentistry... I think that having that tool will be able to help students in practice."

"I think it's a good teaching tool... It can kind of guide them in the direction of how to angle their hand piece, how to angle the osteotomy and place the implant."

2. Enhanced Learning Experience: Participants anticipated that using the dynamic navigation system would enhance their learning experience by providing hands-on application and improving retention. They highlighted the visual aspect of the system, which allowed for a more descriptive understanding of implant placement compared to traditional methods.

"This would be a great learning tool to be able to apply it hands on and make learning a lot easier and to help with retention."

"You can see the directions of how to place an implant... So I think this would be a great learning tool."

"Just visually, you can see the process in a more descriptive way."

"I think it just be useful in the sense of like you are broadening your experience... it's just cool to be able to parallel the theory with the practice."

"To take the PowerPoints and put them into perspective and like a type it on or something, it's really fun. But I can relate it to just clinical experience."

"I felt like I understood more of what I was doing. Looking at the screen, seeing the length, seeing actually how deep the implant was going. In undergrad clinic, we don't really get that much exposure on CBCTs, today I felt I actually got exposure to it and I actually understood how it's helpful when placing implants."

"I feel like especially in our implantology course, this would be beneficial. There's times when we read the lectures and it just leaves the concept to imagination. I think it would be beneficial for students to actually see how difficult it is to place an implant; how steady your hand needs to be. I think it would be extremely beneficial having it in pre-clinic."

"I think it just be useful in the sense of like you are broadening your experience, we're already taught virtual implant treatment planning, and now you're kind of putting that to use. It's just cool to be able to parallel the theory with the practice".

3. Precision and Skill Development: The dynamic navigation system was seen as a tool to develop precision and emphasize the importance of accuracy in preclinical practice. Participants believed that exposure to this technology would help them understand what constituted a successful implant and contribute to their skill development.

"I think it will kind of help students learn precision and the importance of being precise, so kind of adding that to preclinical practice I think is a big benefit."

"Being introduced in dental school will give us an idea of what good implants look like. So yeah, I think it would be really beneficial."

4. Technology Exposure: Given the digital nature of dentistry, participants recognized the importance of exposure to advanced technologies like the dynamic navigation system. They believed that incorporating this tool into their training would prepare them for the digital landscape of modern dental practice and ensure they were competent in using such systems upon graduation.

"First and foremost, we're in a digital world. Digital dentistry is up and coming and something that's going to be at the forefront of dentistry, if not already very soon, so I absolutely think it's advantageous for students to be able to get exposure to this, and I think that as an adjunct specifically, it definitely should be a system that is taught and explored, and students need to be tested on it, have competencies because we are in a digital world and I think that having that tool will be able to help students in practice. Like once you graduate after school."

Incorporation of Dynamic Navigation System into Preclinical Training: EXPERIENCED Group Perspectives

1. Awareness and Exposure: Members of the experienced group acknowledged the importance of introducing the dynamic navigation system to students to familiarize them with available technologies. While they didn't view it as the primary method for implant placement, they recognized its value as an educational tool.

"I think it's a good idea to have it in these lectures just for the students to know what's there in the market but not as like a main tool to place implants."

"They have to know that there is this kind of technology. But that's it."

2. Training and Curriculum Integration: Experienced participants emphasized the need for comprehensive training on how to set up and calibrate the dynamic navigation system. They suggested integrating it into the curriculum as an add-on, with ample hands-on training before its use on actual patients.

"I think it'd be really helpful learning how to set up the program and set up the patient and calibrate everything so ahead of time doing that didactically could be really helpful."

"I think it would be a great add-on and it should be part of the curriculum... I think it would be better if they had more training hands-on before using on an actual patient."

3. Educational Benefits: They highlighted the educational benefits of the dynamic navigation system, particularly in visualizing the precise nature of implant placement and understanding deviations from the predicted position. Participants saw it as a valuable tool for enhancing preclinical learning experiences.

"It would aid in allowing students to visualize the precise nature of implant placement, as well as the angulation and just how easily your free hand can deviate from your predicted implant position."

"I think you know the navigation system for preclinical courses is really nice because you can see the CT and try to learn and adjust your hand based on the navigated system compared to like static."

4. Suitability and Recommendation: While not recommended for predoctoral students who do not yet perform implant procedures, experienced participants saw potential value in using the dynamic navigation system for specific groups, such as first-year residents in periodontics or prosthodontics.

"For general students, no, because they don't place implants anyway. But in terms of preclinical training for like first year residents in perio or pros, I think this would be a fantastic adjunct."

"It would be nice to use as a preclinical tool because it actually shows where your implant goes instantly."

5. Learning and Skill Development: Experienced participants expressed preferences for fully guided surgery but acknowledged the potential learning experience provided by the dynamic navigation system, particularly in understanding the 3D aspects of implant placement. They saw it as a valuable adjunct to preclinical learning.

"I still think fully guided surgery is better. It would be a good learning experience converting from lab to freehand, but it's not that accurate compared to the current fully guided system."

"It could be a good adjunct for preclinical learning because then you would understand the 3D part of implant placement."

Comparison:

- ***Novice* vs. *Experienced* Perspectives:** Experienced participants expressed a more cautious approach towards the integration of dynamic navigation systems into preclinical training. While acknowledging its potential educational benefits, they emphasized the importance of awareness and exposure to the technology without overly relying on it. They highlighted concerns regarding accuracy, and the need for hands-on training before clinical application.

Theme 4: Utilization & Application

The final theme addresses the broader aspects of utilizing and applying the dynamic navigation system in dental implant placement. It includes recommendations for its usage in clinical settings, challenges encountered in implementing this technology, and potential drawbacks that may arise during its application.

a. Recommendations for Dynamic Navigation Usage

NOVICE Group Recommendations for Dynamic Navigation Usage:

1. **Training Emphasis:** Novice participants stressed the need for comprehensive training on dynamic navigation systems, advocating for hands-on practice sessions to familiarize students with the technology and its application.
2. **Enhanced Learning Experience:** Participants highlighted the potential of dynamic navigation systems as a teaching tool in preclinical courses, citing its real-time guidance and visualization features for implant placement as beneficial for student learning.
3. **Precision and Skill Development:** There was a consensus among novice participants regarding the role of dynamic navigation systems in enhancing precision and skill development during implant placement. They recommended integrating this technology into the curriculum to facilitate skill acquisition.

4. **Exposure to Digital Dentistry:** Participants underscored the importance of exposing students to dynamic navigation systems as part of their dental education to prepare them for the digital advancements in dental practice.

EXPERIENCED Group Recommendations for Dynamic Navigation Usage:

1. **Awareness and Education:** Experienced participants suggested introducing dynamic navigation systems to students to familiarize them with available technologies in the market. However, they cautioned against relying solely on this technology for implant placement.
2. **Integration into Curriculum:** Participants recommended integrating dynamic navigation systems into the curriculum as an adjunct tool for preclinical training, emphasizing the need for adequate training and hands-on experience before clinical application.
3. **Educational Benefits:** Experienced participants emphasized the educational benefits of dynamic navigation systems, particularly in enhancing students' visualization of precise implant placement and understanding of 3D aspects.
4. **Suitability for Specific Programs:** While not universally recommended for all dental students, the experienced group proposed incorporating dynamic navigation systems into specialized programs, such as periodontology or prosthodontics, where it can serve as a valuable adjunct for preclinical learning.

Comparison table of the recommendations provided by both the novice and experienced groups regarding the utilization of dynamic navigation systems:

Recommendation	Novice Group	Experienced Group
Emphasized Training	Comprehensive training with hands-on practice sessions	Integration into curriculum with adequate training
Integration into Education	Advocated for integration into preclinical courses	Suggested as an adjunct tool in the curriculum
Skill Development	Highlighted role in precision and skill development	Emphasized educational benefits, especially in 3D visualization
Exposure to Digital Dentistry	Stressed importance of exposure to digital dentistry	Recommended for awareness and education
Specialized Programs	Not specified	Proposed integration into specialized programs, if applicable

Table Y. This table provides a concise overview of the key recommendations made by each group regarding the utilization of dynamic navigation systems.

b. Challenges in Implementing Dynamic Navigation System

Challenges in Implementing Dynamic Navigation System for the NOVICE Group:

1. **Technical Complexity:** Novice participants found the dynamic navigation system to be technically challenging due to its learning curve. Calibration and adjustment processes in the dynamic system were perceived as more complex compared to the static guide.

   "The dynamic system has a learning curve. It's harder to get better at it."

   "With the dynamic, there's a lot of calibration and stopping points in between compared to the static guide."

   "The dynamic system requires calibration and adjustments, making it more complex to use compared to the static guide."

2. **Cognitive Load:** Using the dynamic system required heightened attention to the screen during implant placement, adding to the mental workload. Participants noted that maintaining focus on the dynamic navigation system while performing the procedure could be mentally taxing.

   "With the dynamic system, you have to be attentive, looking at the screen when placing the implant. It requires more focus and cognitive effort."

   "The dynamic navigation system demands attention to the screen while performing the procedure, which can be mentally taxing."

3. **Adaptation and Familiarity:** Novice users expressed difficulty adapting to the dynamic system's workflow and interface, leading to a longer learning curve.

Lack of familiarity with the dynamic navigation system made it harder for novice participants to achieve proficiency compared to the static guide.

"The dynamic system has a learning curve, so it's harder to get better. It requires more practice and adaptation compared to the static guide."

"I find myself leaning towards the static because I'm more comfortable with it and have used it more. There's a level of familiarity that makes the static guide more appealing."

4. **Time Consumption:** Setup, calibration, and adjustment processes in the dynamic system were reported to consume more time during procedures. Novice participants experienced delays in completing procedures due to the time required to navigate the technical aspects of the dynamic navigation system.

   "The dynamic system takes more time to figure out how to angulate the drill, which could be challenging."

   "Even when you start the drill, you have to worry about whether the dynamic navigation system is picking up the tracker and anatomy correctly, which adds to the time consumption."

5. **Physical Discomfort:** The dynamic system's handpiece was perceived as heavier, causing physical discomfort or fatigue during prolonged use. Maintaining proper hand positioning with the dynamic navigation system was challenging and could strain the practitioner's wrists or hands.

   "The dynamic system's handpiece is heavier, making it physically more demanding compared to the static guide."

"With the dynamic system, you have to force your hand to be in the right angle, which can be uncomfortable during prolonged procedures."

Challenges in Implementing Dynamic Navigation System for the NOVICE Group:

1. **Technical Complexity:** Experienced practitioners expressed the view that the dynamic navigation system entails a steep learning curve, especially for those accustomed to static guides. They highlighted the challenges associated with calibrating the dynamic system and ensuring accurate tracking, particularly for individuals unfamiliar with its operation. Some practitioners noted the complexity involved in transitioning from traditional static guides to the dynamic navigation system, emphasizing the need for a thorough understanding of its technical intricacies.
   "The dynamic navigation system requires a steep learning curve, especially for those accustomed to static guides."
   "Calibrating the dynamic system and ensuring accurate tracking can be technically challenging, particularly for those unfamiliar with its operation."

2. **Cognitive Load:** Participants noted that utilizing the dynamic navigation system requires heightened attention and concentration, which can be mentally taxing during the implant placement procedure. They highlighted the cognitive load associated with managing the dynamic system, emphasizing the need to focus on the screen while performing the procedure. Some practitioners suggested that the cognitive demands of the dynamic navigation system may detract from other

critical aspects of the procedure, such as patient interaction and overall clinical decision-making.

"Using the dynamic navigation system demands heightened attention to the screen, which can be mentally taxing during the implant placement procedure."

"The cognitive load associated with managing the dynamic navigation system may detract from other aspects of the procedure, such as patient interaction."

3. **Adaptation and Familiarity:** Experienced practitioners indicated that transitioning to the dynamic navigation system posed challenges, particularly for those accustomed to traditional static guides. They mentioned the need to adapt to new interfaces and workflows, highlighting the differences between static and dynamic systems. Some participants emphasized the importance of retraining and adjustment for practitioners familiar with static guides, suggesting that the dynamic navigation system's workflow and user interface may differ significantly from traditional methods.

   "Experienced practitioners may find it challenging to transition from static guides to the dynamic navigation system due to ingrained habits and familiarity with traditional techniques."

"The dynamic navigation system's interface and workflow may require significant adaptation for practitioners who have primarily used static guides in the past."

4. **Time Consumption:** Practitioners noted that implementing the dynamic navigation system could result in increased procedure times, especially during the initial stages of implementation and training. They highlighted the setup and

calibration process as potential contributors to prolonged procedures, requiring practitioners to invest additional time in familiarizing themselves with the system. Some participants mentioned delays and interruptions during procedures as practitioners navigated the technical complexities of the dynamic navigation system, impacting overall efficiency and workflow.

"The setup and calibration process for the dynamic navigation system can prolong procedure times, especially during initial implementation and training stages."

"Practitioners may experience delays and interruptions during procedures as they navigate the technical intricacies of the dynamic navigation system."

5. **Physical Discomfort:** Experienced practitioners acknowledged the potential for physical discomfort or fatigue when using the dynamic navigation system, particularly during extended procedures. Some participants mentioned the challenge of maintaining correct hand positioning and alignment with the dynamic navigation system, especially in demanding cases requiring prolonged concentration and precision.

   "Maintaining the correct hand positioning and alignment with the dynamic navigation system may strain the practitioner's wrists or hands over time, particularly in demanding cases."

Comparison of novice and experienced perspectives on the implementation of the dynamic navigation system:

Aspect	Novice Group	Experienced Group
Technical Complexity	Learning curve with calibration and adjustments	Steep learning curve, especially for those accustomed to static guides
Cognitive Load	Demands heightened attention	Similar cognitive demands
Adaptation & Familiarity	Challenges in learning the technology	Transition challenges emphasized, need for retraining
Time Consumption	Prolongs procedures, setup, and calibration time-consuming	Increased procedure times, especially during the initial stages of implementation and training.
Physical Discomfort	Discomfort with heavier handpiece, precise hand positioning	Challenge of maintaining correct hand positioning and alignment

Table X. This table provides a concise comparison of how novice and experienced groups perceive the challenges associated with implementing the dynamic navigation system.

c. **Potential Drawbacks in the Application of Dynamic Navigation System**

Potential Drawbacks in the Application of Dynamic Navigation System for the NOVICE group:

1. **Patient Movement and Environmental Factors:** Novices expressed concerns about challenges in real-life patient scenarios due to factors like patient movement and distractions.
   "In my opinion, I think it's going to have more problems with an uncontrolled environment like the patient moving around, there's bleeding, there are many other distracting factors."

2. **Over-Reliance and Lack of Traditional Skills Development:** Participants highlighted the risk of students relying too heavily on the dynamic system, potentially hindering their development of traditional implant placement skills.
   "The drawbacks would definitely probably be students relying on it and not being able to or not like having to be forced to figure it out traditionally on their own."

3. **Hand Coordination Challenges:** Novices mentioned difficulties in hand coordination, especially with the placement of the dynamic system's components, affecting stability and precision.
   "Some drawbacks would be definitely the amount of time it takes to register all the drills. Get that in the patient's mouth. This is a surgery. So, if the patient is awake and you're spending 20-30 minutes just adjusting for angulation, then you're essentially causing harm to your patient."

4. **Training and Technique Sensitivity:** Novices noted the need for extensive training to master the dynamic system and its technique-sensitive nature.
   "Training. I mean, if you don't have the enough training without the surgical guide, it was hard to keep the target in the center. So, it does need the training time before you get started."

5. **Time Consumption and Complexity:** Participants mentioned concerns about the time-consuming setup and calibration process of the dynamic system, potentially prolonging procedures.

   "I think it takes too much time like to make the perfect to have it in a perfect placement before you start to drill it, whereas the more conventional way of having a set is already ready for you."

6. **Cost:** Some novices highlighted potential drawbacks related to the cost of the system.

   "Maybe kind of expensive machine."

Potential Drawbacks in the Application of Dynamic Navigation System for the EXPERIENCED group:

1. **Loss of Physical Boundary Awareness:** Experienced practitioners highlighted concerns about the lack of physical boundaries when using the dynamic navigation system, which could lead to unintentional errors in implant placement.

   "There is no physical boundary. So, if you go into the wrong direction… It's like driving a car, you know, you keep pressing the pedal but you know, it's just like even though there is a pedestrian there, you will just run him over."

2. **Limited Visualization and Dependence on Technology:** Participants expressed challenges related to visualization and reliance on the screen rather than direct patient observation during procedures.

"It takes away the visualization. Being the number one thing where you have to look at the screen rather than the patient, you're not sure if your patient will move so that I feel like was as difficult."

3. **Training and Learning Curve:** Some experienced practitioners mentioned the steep learning curve associated with the dynamic navigation system and the need for adequate training to use it effectively.
   "It would take more time and then it has a kind of a steep learning curve and you would need to switch off your instinct when you're basically built to look to the patient."

4. **Cost and Practicality Concerns:** Cost considerations and practicality issues were raised, particularly regarding the investment in training and the system's suitability for real-life clinical scenarios.
   "Cost is probably an issue and probably not being more practical towards patients because you don't understand the saliva and the movement and everything."

5. **Distractions and Over-Reliance on Technology:** Experienced practitioners cautioned against distractions during procedures and the potential risk of over-reliance on the technology, emphasizing the importance of maintaining awareness of the patient's condition.

"I think one of the things is the distractions to the surgeon. So, like for the regular distractions attracting to the surgeon when they are placing implants, especially with challenging anatomy features, it could be a little bit tricky."

6. **Accuracy and Trust Issues:** Concerns were raised regarding the accuracy of the system and the need for practitioners to trust the technology while remaining vigilant for potential discrepancies.
"If the length, like the anatomy mark, is not accurate, and if we fully trust what we see on the screen, sometimes it's not reflected clinically."

Comparison of the novice and experienced groups regarding their perspectives on the potential drawbacks in the application of dynamic navigation implant systems:

Drawbacks	Novice Group	Experienced Group
Technical Complexity	Learning curve with calibration and stopping points	Calibration and accurate tracking can be challenging
	Difficulty with hand coordination due to system placement	Loss of physical boundary awareness
		Dependence on technology for visualization
		Steep learning curve and need for adequate training
Cognitive Load	Increased focus and cognitive effort required	Increased distractions during procedures

		Risk of over-reliance on technology
Adaptation and Familiarity	Need for adaptation and practice	Challenges in transitioning from traditional techniques
		Lack of trust in system accuracy and potential errors
Time Consumption	Time-consuming setup and calibration process	Prolonged procedure times due to technical intricacies
		Potential delays and interruptions during procedures
Physical Discomfort	Discomfort due to system's handpiece	Physical discomfort or fatigue from bulkier or heavier instruments
		- Strain on wrists or hands from maintaining correct positioning
Cost and Practicality Concerns	- Concerns about time consumption and patient well-being	- Cost considerations and practicality issues
		- Lack of practicality in real-life clinical scenarios
Dependence and Trust Issues	- Risk of reliance on technology and neglecting traditional techniques	- Trust issues related to system accuracy and potential errors

		- Need for maintaining awareness of patient's condition
Overall Challenges	- Various challenges including training, accuracy, and time consumption	- Challenges related to distractions, accuracy, and trust

Table X. This table provides a concise overview of the perspectives of both novice and experienced groups on the potential drawbacks of using dynamic navigation implant systems, highlighting similarities and differences between the two groups.

Comparative Analysis:

- The advantages of the dynamic navigation system, such as real-time visualization and enhanced precision, were particularly evident among experienced practitioners who appreciated its flexibility and adaptability to complex cases. Novice participants, however, noted challenges related to technical complexity and cognitive load, suggesting a steeper learning curve for those transitioning from traditional techniques.
- Conversely, both novice and experienced groups acknowledged the familiarity and simplicity of static guides, highlighting their user-friendliness and time efficiency. However, experienced practitioners emphasized the importance of maintaining patient focus and tactile feedback, whereas novices expressed concerns about potential over-reliance on guided systems and limited opportunities for skill development.

Experiential Perspectives:

- Experienced practitioners shared insights into their learning process with dynamic navigation systems, noting the importance of patience, practice, and adaptation to optimize proficiency. Novice participants, meanwhile, described their initial challenges with hand coordination, calibration, and visual-spatial awareness, underscoring the need for structured training and mentorship.
- User-friendliness for new practitioners emerged as a critical consideration, with experienced clinicians highlighting the importance of guided instruction and gradual exposure to advanced technologies. Novices emphasized the value of hands-on experience and peer collaboration in enhancing their confidence and competence with dynamic navigation systems.

Practice and Training:

- Recommendations for dynamic navigation system practice emphasized tailored training programs and immersive learning experiences, tailored to the skill level, and learning preferences of participants. Experienced practitioners advocated for ongoing professional development and integration into advanced training curricula, while novices underscored the need for foundational knowledge and technical skill development.
- Incorporating dynamic navigation systems into preclinical training programs was seen as beneficial for exposing students to emerging technologies and bridging the gap between theoretical knowledge and clinical practice. Both novice and experienced groups emphasized the importance of mentorship and peer support in fostering a collaborative learning environment and fostering professional growth.

Utilization and Application:

- Recommendations for dynamic navigation usage highlighted its potential as an adjunctive tool in specific clinical scenarios, such as complex cases or first-year resident training programs. Experienced practitioners emphasized the value of strategic planning and interdisciplinary collaboration in optimizing treatment outcomes and patient satisfaction.
- Challenges in implementing dynamic navigation systems included technical complexities, cognitive load, and time consumption, particularly for novice practitioners. However, both groups recognized the potential benefits of guided systems in improving accuracy, efficiency, and patient safety, suggesting opportunities for continued innovation and refinement in dental implantology practice.

CHAPTER VI: DISCUSSION

Dynamic and static navigation systems for implant placement exhibit a notable degree of accuracy, usually displaying deviations of around 0.5mm and an angle of approximately 4 degrees, which aligns with findings from another study indicating a 1mm deviation and a 5-degree angle by Widmann, G. 2005.[27] This level of accuracy may facilitate the fabrication of restorations prior to implant placement, allowing for immediate delivery post-surgery. However, it's crucial to note that due to occasional higher deviations in the apical region, maintaining a minimum distance of 1.5 mm from sensitive anatomical structures is imperative. In complex cases, a greater distance may be necessary.[28]

One notable advantage of transitioning from analog to digital templates is the flexibility to postpone the decision regarding the need for navigated surgery until after the CBCT scan, as there is no requirement for a radiologic template. Preoperative planning can be executed with precision and safety through guided implant surgery, without the possibility of adjustments during surgery, as is the case with dynamic navigation. In both dynamic and static systems, the accurate transfer of the planned implant position relies heavily on correct CBCT evaluation and the experience of the practitioner. Achieving the precise fit and stabilization of the guide, essential for static navigation, can be accomplished by utilizing remaining teeth or temporary implants.[29] Literature findings vary, although studies have demonstrated similar error rates between inexperienced and skilled surgeons. Notably, novice groups exhibit significant improvement in accuracy when utilizing guided methods. The precision reported in studies involving dynamic systems is comparable to that achieved with static techniques. However, few studies on dynamic navigation have specifically examined the influence of experience.

Furthermore, there is a lack of research investigating differences in implant placement accuracy based on experience levels.[10,30]

Jorba-García et al. 2019 conducted an in vitro study, reporting an average coronal 3D deviation of 1.29 ± 0.46 mm and an average apical 3D deviation of 1.33 ± 0.50 mm. Their research evaluated the accuracy of implant placement by both a skilled surgeon and a student, using both a dynamic navigation system and a conventional free-hand technique. The authors concluded that utilizing a dynamic navigation system enhanced the ability to place implants with greater accuracy compared to free-hand techniques, especially for less experienced operators. However, they did not directly compare the accuracy values between the skilled and inexperienced operators or used static guided system.[10]

In both methods, limited interocclusal space or restricted mouth opening serve as exclusion criteria for posterior region implantation. In dynamic navigation, initial investment costs are substantial, whereas static navigation entails ongoing high expenses. Literature highlights the necessity of a learning curve with dynamic navigation to attain precision in implant positioning.[31]

The findings of this study indicate that static system may be regarded as a dependable and easily learned technique, even for inexperienced individuals. It enables satisfactory outcomes in terms of accuracy.

In a systematics review and meta-analysis of Marques-Guasch, Jordi, et al. (2023), The Cochrane and Medline databases were searched to locate randomized controlled clinical trials (RCTs) as well as prospective and retrospective case series. The objective was to address the specific question: "Which implant guidance tool offers greater accuracy and security in implant placement surgery?" The implant deviation coefficient was computed for four distinct parameters: coronal and apical horizontal, angular, and vertical deviations. Statistical significance was determined at a p-value of 0.05 after applying the eligibility criteria. A total of twenty-five publications were incorporated in this systematic review. The results show a non-significant difference between the dynamic guided surgery and static guided surgery, in all of the assessed parameters: coronal (n = 4 WMD = 0.02 mm; $p = 0.903$), angular (n = 4 WMD = -0.62°; $p = 0.085$), and apical (n = 3 WMD = 0.08 mm; $p = 0.401$). Concluded, Dynamic Guidance System (DGS) emerges as a viable alternative treatment option, demonstrating comparable accuracy to Static Guidance System (SGS). Moreover, DGS proves to be superior in terms of accuracy, security, and precision compared to the Freehand (FH) method when transferring the pre-surgical virtual implant plan to the patient.[23]

Surgical guides play a crucial role in static computer-guided implant surgery, with their dimensional accuracy being essential for successful and safe procedures. Two primary factors influencing the overall accuracy of computer-guided implant surgery are the intaglio surface (the internal surface of the surgical guide fitting the supporting teeth or mucosa) and the sleeves' housings. The accuracy of the intaglio surface ensures proper adaptation to the supporting tissues and structures, while the accuracy of the sleeves' housings, where guiding elements are inserted, ensures alignment between the planned and achievable implant axes, as well as correct positioning in the apico-coronal direction. Both of these critical factors in surgical guides should closely match the shapes, axes, and overall position outlined in the CAD project. Therefore, the three-dimensional (3D) accuracy of the intaglio surface and sleeves' housings are vital features in surgical guides, which may be influenced by their manufacturing process.[33]

Both additive and subtractive computer-aided manufacturing (CAM) technologies are available for fabricating surgical guides. Comparative studies investigating the corresponding accuracy are scarce, and there is no clear evidence as to whether milling or 3D printing technology can deliver surgical guides with superior accuracy. It's important to note that milling and 3D printing encompass various technologies, systems, and equipment, each with its unique features and advantages. [33]

Additionally, modifications are still feasible in the post-manufacturing stage, and variations in materials and technological processes can impact the final product's accuracy .[34] Therefore, careful consideration of the specific clinical and laboratory settings, along with the degree of manufacturing protocol standardization, is necessary.

Lo Russo et al. (2023) conducted a study examining the impact of fabrication technology, support type, and arch type on the accuracy of static surgical guides. The results revealed that milled surgical guides exhibited significantly lower median deviations of the intaglio surface in contact with the mucosa (0.05 mm) compared to 3D-printed guides (-0.07 mm) when compared with the reference STL file. Furthermore, generalized estimated equation models indicated that the axial deviations of the sleeves' housings (median of 0.82 degrees for milling and 1.37 degrees for 3D printing) were significantly influenced by fabrication technology ($p = 0.011$), with milling showing superior results. The type of support and the combined effect of fabrication technology and sleeve-to-crest angle ($p = 0.003$) also played significant roles. Additionally, the linear deviation of the center points (medians of 0.12 mm for milling and 0.21 mm for 3D printing) was significantly impacted by the type of support ($p = 0.001$), with milling demonstrating slightly better performance compared to 3D printing.[35]

The dynamic navigation process comprises five key steps: image processing, virtual implant planning, calibration, registration, and surgical operation. Errors can manifest at each stage and accumulate throughout the workflow. Hence, comprehending each step is essential for identifying sources of error. Several factors impacting the overall accuracy of implant positioning when utilizing Dynamic Guidance System (DGS) were identified in various studies (Platzer 2013, Emery, R.W.; Merritt 2016) .[36,37] These factors include:

1. Maladjustment, movement, or loss of the guide or jaw attachment, or patient movement during surgery or during the CT scan.

2. Susceptibility of the system to hand tremors, which can contribute to deviation.

3. Influence of non-operative factors, such as the process of obtaining CT-CBCT data.

4. Target registration errors (TREs), referring to imperfect coordination of the tracking system between the drill tip and the corresponding point on the CBCT image after registration.

5. Optical tracking affected by noise generated by mechanical, thermal, or optical changes since the last calibration of the system.

The operator's experience and the steep learning curve associated with dynamic implant navigation are frequently cited as sources of error in the literature .[8,]

CONCLUSIONS:

While both Dynamic Guidance System (DGS) and Static Guidance System (SGS) have demonstrated accuracy in implant placement, it is crucial to maintain a safety margin for anatomical structures. This precaution is necessary due to the inherent deviation present in all dimensions of the space. Overall, providing data on the effectiveness and accuracy of all technologies and protocol combinations used in guided implant system manufacturing remains a significant research issue in clinical practice.

LIMITATIONS OF THE STUDY:

The employed study design (in vitro) might limit the generalization of the results, namely the external validity. In fact, in a clinical environment, different variables could impair the performance of implant surgery and consequently the implant placement accuracy. Another limitation of this study is the lack of focus on other variables, like implant position (anterior/posterior), because of the sample size.

APPENDICES

Appendix 1. Review of previous experiences.

- Age:
- Gender:
- Any previous implant placement experience including an approximate total number of implants placed
- Any prior digital simulation (dentistry or non-dentistry related) experiences including video games (These include but not limited to: PC video games, video game consoles, virtual reality consoles and/or hand held video games.), simulation courses, or demos alike
- Any prior courses on implants or pre-clinical course relevant to implant placement including but not limited to:
    - Implant dentistry didactic course
    - Implant dentistry clinical course
    - Implant dentistry CE course

Appendix 2. Accuracy and Perception Evaluation of a Dynamic Navigation Implant System

1. Could you describe any significant advantage or disadvantages in the dynamic navigation implant system when compared to static guide?
2. Describe your experience placing implants by dynamic navigation.
3. How would you describe the process of learning the dynamic navigation system as you progress through the implant placement procedure?
4. Considering the learning curve, do you find one technique more user-friendly for practioners who are new to implant placement? Why?
5. Would you recommend spending more time practicing on the dynamic navigation system and performing exercises such as simultaneous multiple implant placement procedures?
6. In what ways do you feel the dynamic navigation system would be a useful adjunct to current preclinical training provided in the regular class lectures and laboratory demonstrations?
7. In what ways do you feel the dynamic navigation system can create potential drawbacks as a surgical simulation tool for dental implant placement practice training?
8. Describe your overall assessment about placing implants with static guides.
9. Can you share any specific challenges or limitations you have encountered when using either the dynamic navigation system or static 3D printed guide?
10. Which implant placement guidance technique did you consider easier, static guidance or dynamic navigation? Could you please explain why you though this technique was easier for you?

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