國立臺灣大學牙醫專業學院臨床牙醫學研究所

碩士論文

Graduate Institute of Clinical Dentistry
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Master´s Thesis

在兩種骨密度的後下顎骨區比較動態導航與靜態導航植入傾斜植體的位置準確性

Accuracy of tilted implant position through dynamic navigation vs static navigation on posterior mandible with two bone densities

何利爾

Florian Samayoa Javier Edgardo

指導教授：王東美博士

Advisor: Tong-Mei Wang, Ph.D.

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口試委員會審定書

在兩種骨密度的後下顎骨區比較動態導航與靜態導航植入傾斜植體的位置準確性

ACCURACY OF TILTED IMPLANT POSITION THROUGH DYNAMIC NAVIGATION VS STATIC NAVIGATION ON POSTERIOR MANDIBLE WITH TWO BONE DENSITIES

本論文係 Javier Edgardo Florian Samayoa（R10422025）在國立臺灣大學牙醫專業學院臨床牙醫研究所補綴學碩士班完成之碩士學位論文，於民國一百一十三年七月一日承下列考試委員審查通過及口試及格，特此證明

口試委員：

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中文摘要

實驗目的

電腦輔助人工植牙技術越來越受歡迎，因為根據義齒外型所制定的的手術計劃準確定位對於人工牙根的長期存活和美學中有重要作用。 本研究使用 X-Guide 和 Iris-100 作為動態導航，以及全導引手術導板作為靜態導航，將 30 度遠端傾斜的植體放置在下顎後區。此手術使用 Sawbones® 模型來模擬兩種不同的骨密度：具有一層皮質硬骨的中密度（30 pcf，1 mm）和無皮質骨的低密度（20 pcf，0 mm）。測量角度、平台和頂點偏差，以比較植體的位置精確度。本研究的目的是確定在這些條件下傾斜牙植體植入的最準確的導航方法。

實驗材料與方法

1. 實驗模型製備

使用患者的錐狀束電腦斷層掃描（CBCT）掃描和下顎模型的桌掃來製作實驗模型。本研究使用 3D 列印了一個完全無牙的下顎主模型。在主模型中的右下第二小臼齒區域創建了一個切除區域（16x7x20mm^3），用於放置人造骨塊。研究包括兩個變數：導航方法和骨密度。使用的三種導航方法是全導引手術導板（靜態導航）、X-Guide（動態導航）和 Iris-100（動態導航）。使用兩種類型的人造骨塊 (Sawbones®)：一種由 30pcf 海綿骨和 1mm 皮質層組成，另一種由 20pcf 海綿骨組成，不含皮質層。實驗組共分為 6 組，每組測試 20 個骨塊 (n=120)。每次測試前，將新的人造骨塊固定在主模型中以確保穩定性。

2. 實驗步驟

使用 3Shape Implant Studio 軟體規劃在右下第二小臼齒處以 30 度角向遠端傾斜的植體位置。 將數位資料匯出到 X-Guide 和 Iris-100 的專有軟體中。單一操作員依照植牙廠商建議的鑽骨流程在人造骨塊中鑽孔並放置 Nobel Parallel CC RP 植體 (4.3x13mm)。

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3. 植體位置準確度評估及統計分析

每次植體植入後，將植體掃描體固定在植體上並使用桌掃機（3Shape E4）進行掃描。使用計量軟體（Geomagic Control X）將掃描資料與初始手術計劃疊合。測量並分析計劃植體位置和植入植體位置之間的軸角、平台和頂點位置的偏差。採用 Kruskal-Wallis 檢定及 Wilcoxon 檢定進行統計分析，顯著水準設為 P<0.05。

實驗結果：

在按骨類型劃分的小組中，Iris-100 在尖端和角度偏差上有統計顯著差異，其中無皮質+20pcf 骨比 1mm 皮質+30pcf 骨組顯示出更準確的結果。 此外，平臺偏差上，導板在無皮質+20pcf 骨組中比 1mm 皮質+30pcf 骨組顯示出更高的準確性。 整體而言，按手術方法劃分，角度偏差在導板和 Iris-100 之間沒有顯著差異，但它們都比 X-Guide 更準確。 在尖端偏差上，導板比 Iris-100 更準確，而其他兩組之間沒有差異。 最後，在平臺偏差上，導板最準確，其次是 X-Guide，再次是 Iris-100，三組之間有統計差異。 在精確度分析中也得到了類似的結果，導板最精確，其次是 Iris-100，最後是 X-Guide，三組之間有顯著差異。

結論：

使用靜態導航和動態導航系統進行種植體植入的準確性在幾個變數中得到了證明，一般來說全導引手術導板組更準確，但所有導航系統的準確性都在可接受水準以上。 另一方面，除了在 Iris-100 的角度和尖端偏差以及導板的平臺偏差在較軟的骨頭中表現出更高的準確性外，骨類型差異對最終結果沒有影響。 還指出，三種不同方法的學習曲線陡峭，從研究開始到結束種植體準確性沒有太大差異。

關鍵詞：靜態導航，動態導航，傾斜種植體準確性，骨密度。

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Abstract

Objective

Computer-assisted implant placement is becoming increasingly popular because accurately positioning the dental implant according to a prosthetic-driven surgical plan is crucial for the long-term survival and aesthetics of the implant. This study used X-Guide and Iris-100 as dynamic navigation systems and 3D fully guided stents as static navigation to place a 30-degree distally tilted implant in the posterior mandibular area. The procedure was performed using Sawbones® models to simulate two different bone densities: medium density with a layer of cortical hard bone (30 pcf, 1 mm) and low density with no cortical bone (20 pcf, 0 mm). The angle, platform, and apex deviations were measured to compare the positional accuracy of the implants. The aim of this study was to determine the most accurate navigation method for tilted dental implant placement under these conditions.

Materials and methods

1. Preparation of experimental models

A patient's cone beam computed tomography (CBCT) scan and the laboratory scan of the mandibular cast were used to fabricate the experimental model. One fully edentulous master model was 3D printed for this study. A resection area (16x7x20mm^3) was created at the lower right area (tooth 45) for the artificial bone blocks in the master

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model. The study included two variables: navigation methods and bone densities. The three types of navigation methods used were fully guided stent (static navigation), X-Guide (dynamic navigation), and Iris-100 (dynamic navigation). Two types of artificial bone blocks (Sawbones®) were used: one consisting of 30 pcf cancellous bone with a 1 mm cortical layer and the other consisting of 20 pcf cancellous bone without a cortical layer. This resulted in a total of six groups, with 20 blocks tested in each group (n=120). Before each test, the new artificial bone block was fixed in the master model to ensure stability.

2. Procedure of experiment

3Shape Implant Studio was used to plan the distally-tilted implant position at a 30-degree angulation at tooth 45. A bone-supported surgical fully guided stent, held by three anchor pins, was designed and printed for static navigation. For dynamic navigation, the digital data was exported to proprietary software for X-Guide and Iris-100. A single operator drilled and placed the Nobel Parallel CC RP implant (4.3x13mm) in the artificial bone blocks, following the manufacturer's recommended protocol.

3. Evaluation of the accuracy of implant position and statistical analyses

The scan body was attached to the implant and scanned with a lab scanner (3Shape E4) after each implant placement. The scanned data was superimposed with the initial surgical plan using metrology software (Geomagic Control X). The deviations in axis

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angle, platform, and apex between the planned and placed implant positions were measured and analyzed. The Kruskal-Wallis test and Wilcoxon test were used for statistical analysis, with a significance level of $P < 0.05$.

Results

In the subdivision by bone type, there were statistically significant differences in the deviation of Iris-100 at the apex and angle. The no cortical bone group showed more accurate results compared to the cortical bone group. Additionally, the stent at platform deviation showed higher accuracy in the no cortical bone group compared to the cortical bone group. Overall, when divided by navigation methods, angle deviation showed no significant difference between the fully guided stent and Iris-100, but both were more accurate than X-Guide. For apex deviation, the fully guides stent was more accurate than Iris-100, with no difference between the other two groups. Lastly, for platform deviation, the fully guides stent was the most accurate, followed by X-Guide and then Iris-100, with statistical differences between the three groups. In the precision analysis, similar results were found, with the fully guides stent being the most precise, followed by Iris-100 and then X-Guide, showing significant differences between the three groups.

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Conclusion

The accuracy of implant placement using static and dynamic navigation systems was compared across several variables. Generally, the fully guided stent group was more accurate, but all navigation systems showed more than acceptable accuracy levels. On the other hand, bone type differences did not affect the final results, except for Iris-100 at angle and apex deviation, and the fully guided stent at platform deviation, which showed better accuracy with softer bone. It was also noted that despite the steep learning curve of the three different methods, there was no significant difference in implant accuracy from the beginning to the end of the study.

Keywords: static navigation, dynamic navigation, tilted implant accuracy, bone density.

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Chapter 1 Introduction

1.1 Preface

Nowadays, several different techniques for implant placement are being used every day in dental clinics. Computer-aided protocols provide patients with instant solutions to restore esthetics and function, such as immediate loading implants and more.[1]

Success in implant dentistry has several meanings: a stable implant, an esthetic prosthetic outcome, and functional occlusion translate into an implant position within bone levels that allow for bone integration, gingival contouring, and the correct angle for prosthetic restoration. Most of the time, this angle is perpendicular to the occlusal plane, allowing for a straight biting force. This marks the first change in the traditional protocol.

New ideas have arisen to avoid problems such as reduced bone height and cantilever distance while enabling simpler surgeries. From this, tilted implants were introduced as a solution, challenging all the normal standards of traditional implant surgery.

For several years, static fully guided surgery has been considered the gold standard in implant dentistry for its accuracy and simple protocol. As the gold standard, it has achieved a mean deviation of 0.74 mm and 0.85 mm at the platform and apex, respectively.

Later on, newer methods such as dynamic navigation have entered the field of dentistry, showing good results by being flexible and reliable within the minimum requirements for implant accuracy.

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However, aside from focusing on the technique itself, bone status has been shown to be very important. Softer bone tends to produce higher deviation of implants.[2] This deviation is not entirely dependent on the surgeon's experience during surgery but also on the surgical protocols, whether dynamic or static navigation.

1.2 Literature review

1.2.1 Implant accuracy

Dental implants need to be placed in optimal positions to ensure reliable long-term success. Therefore, the emphasis during surgery is on the anatomical features and properties of the subject, which include sufficient height and thickness of the bone wall. If there is not enough height during implantation, bone grafting is the first option to overcome the insufficient vertical bone volume. Bone density is also a major factor to consider during implant surgery. It has been stated that for unintentionally tilted implants, meaning those with angle deviation errors, there is higher marginal bone loss compared to implants with straight abutments.[3] This can also be related to certain properties of the implant body, such as the surface treatment that reacts with bone cells, as well as thread distribution and dimension, which can influence the body's response to the implant. Lastly, the implant-abutment connection has been shown to affect the interaction between bone and keratinized tissue.[3]

Another option proposed by implantologists is the use of intentionally tilted implants while using the surrounding bone as support. Implants must also be positioned accurately to support restorations that are esthetic and functional with adjacent and occluding dentition.

For these reasons, a minimum safety area has been established. The safety clearances given in the literature are between 0.5 to 1 mm horizontally and 1.2 to 1.7 mm vertically to any anatomic areas.[4] This is based on general results of implant

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position, with 1.44 degrees in angular deviation, 0.24 mm in entry deviation, and 0.40 mm in apex deviation.

It is important to note that mechanical properties also affect the final outcome. Within this group, strength refers to the actual resistance of the implant to fracture, which can ensure an easier solution by changing any of the prosthesis parts instead of redoing the implant surgery by removing and replacing the implant. Flexural strength gives the implant the ability to bend without a fatal crack in its body. Fatigue resistance is the implant's ability to withstand force over a long period while under pressure. Finally, biocompatibility ensures that the body accepts the implant without any adverse reactions or rejection. All of these factors are important.

1.2.2 All-on-Four

Difficulty in using the bone posterior to the inferior alveolar nerve without the addition of complicated surgical steps or healing periods through nerve transposition or even bone grafting procedures has led to the search for more viable solutions. At the beginning of the millennium, distally tilted implants were proposed for these situations, enabling the use of denser bone located in the anterior mandible and the replacement of posterior teeth without extended cantilevers. Later solutions, such as All-on-Four protocols, were created to fulfill the need for a fixed solution on fully edentulous arches. Another advantage of the All-on-Four protocol is that it requires fewer implants for the same total occluding surface. This is achieved by strategic imp lant placement, followed by four dental implants placed in the jawbone to maximize bone support and distribution of forces. Typically, two implants are positioned axially in the anterior region of the jawbone, while the remaining two implants are tilted distally towards the back of the mouth in the posterior region. This configuration optimizes bone utilization

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and minimizes the need for bone augmentation procedures[4]. The All-on-Four protocol is particularly advantageous in cases where there is limited bone volume or density, which often occurs with edentulous patients, as the tilted implants can engage denser and usually thicker bone in the anterior region of the jaw. This eliminates the need for extensive bone grafting procedures, streamlining the treatment process and reducing patient discomfort.

This protocol using only four implants has produced good short-term outcomes, with a survival rate of 98.2% and a marginal bone level of 0.6 mm at a 6-month follow-up. Previous studies using the Branemark System® Mk and Nobel Speedy™ implants of 10 to 18 mm located anterior to the foramen with angulation of 30 to 45 degrees have shown that implants fulfilled their intended function as support for reconstruction. Implants were stable when individually and manually tested, no signs of persistent infection were found, and no radiolucent areas around the implants were observed.

While the aesthetic outcomes were good, it was noted that 50% of implant failures occurred in the first 6 months of function, with a cumulative implant survival estimate of 95.4% at 7 years. Patzelt and colleagues reported a mean bone loss of 1.3 mm at 3 years. Duello reported cumulative success rates of 93% at 10 years. Fabbro, Ata-Ali, and colleagues reported no significant differences in failure rate and peri-implant bone loss between tilted and axial implants[6]. As mentioned before, peri-implantitis is one of the major complications related to this implant solution. It is related to the cleanliness of the operating area, sterilization of the instruments used, post-surgery care of the patient’s oral hygiene, and the tissue's reaction to the foreign body itself. Other disadvantages of the All-on-Four protocol include the high maintenance required to keep the gum healthy and prevent infections, the high cost of the surgery and final prosthesis, and long-term durability concerns[5].

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Generally, in most cases, tilted implants are used during All-on-Four planning. This method frees space between arches, where placing a Stent and drill tips risks the accuracy of the implant, or when the bone level is low and a large bone graft is to be avoided. Tilting an implant also allows the use of longer implants. If there is not enough available bone volume in the posterior maxilla, using tilted implants can decrease the need for bone augmentation, maintain a high success rate up to 96.6% (since 1999), enhance implant primary stability with longer implants, and shorten the cantilever of the prosthesis. Several studies have indicated that in cases without sufficient vertical bone in the posterior area, a dynamic navigation system can be used as a method of guidance to place tilted implants as accurately as axial implants, thereby preventing damage to any anatomical areas and reducing the need for bone grafts[6]. Lastly, another benefit is its lack of laboratory work and immediate planning.

In summary, the integration of tilted implants within the framework of All-on-Four protocols represents a significant advancement in implant dentistry, offering enhanced treatment options for patients with complex dental needs. Continued research and advancements in technology will further refine these techniques, ultimately improving patient outcomes and expanding access to comprehensive dental care.

1.2.3 Dynamic navigation

The dynamic system uses motion tracking technology to track the handpiece and the patient's jaw position. Radiopaque markers are attached to the patient's jaw while taking the CT scan, providing a symmetrical movement between the corresponding anatomy in the CT image and the surgical field. Any three-dimensional deviation of the drill and implant from the virtual plan can be seen in real-time, allowing for adjustments to the drilling depth and angle or implant position at any time during the surgery[7].

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Dynamic navigation can improve the precision of implant placement compared to freehand methods and pilot-drill surgery. However, it also has drawbacks, such as a steep learning curve and potential errors in the system that could affect the spatial relationship between the reference points and the patient.

In another meta-analysis, it was stated that the mean angular deviation with dynamic guidance was 1.6 degrees, with a platform deviation of 1.29 mm and an apex deviation of 1.33 mm[8].

1.2.4 Static navigation

The basis of static navigation relies on the use of a Stent or surgical guide. In the beginning, it was done by hand with acrylic or heated molding until better technologies arrived. Therefore, relatively new methods like 3D printing manufacturing have several advantages[9], such as low production costs, customization of treatment, reduced treatment time, and clinically acceptable precision. As a result, printed Stents have become more commonly used[10].

Both full-guided and half-guided static navigation significantly reduce the length of surgery, which decreases postoperative morbidity and ensures that the implant positions achieved are closer to the prosthetically ideal compared to those achieved by freehand surgery. For this reason, the Third EAO Consensus Conference stated that the mean system error should be less than 1.7 mm for horizontal deviation and 1 mm for vertical deviation[11].

The main inconvenience of the static navigation system is the inability to change the presurgical planning position during the surgery unless the surgical approach is changed to a freehand technique. Additionally, it was mentioned that irrigation and visibility are not direct, increasing the risk of overheating the bone[12].

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In another meta-analysis, it was stated that the mean angular deviation with dynamic guidance was 3.5 degrees, with a platform deviation of 1.3 mm and an apex deviation of 1.4 mm. Compared to the freehand traditional protocol, which achieved 9.9 degrees in angular deviation, 2.77 mm in platform deviation, and 2.91 mm in apex deviation[13].

1.2.5 Dynamic vs Static method

Nevertheless, several authors have shown good results in clinical studies and concluded that dynamic navigation systems are as effective as static navigation and significantly better than freehand implant placement. The main inconvenience of the static navigation system is the inability to change the presurgical planning position during the surgery unless the surgical approach is changed to the freehand technique, as mentioned before. For dynamic navigation, the primary drawbacks are the steep learning curve and the additional weight added to the handpiece.

To provide a more palpable comparison, various meta-analyses concluded that dynamic navigation showed an angular deviation of 4.1 degrees, a platform deviation of 1.03 mm, and an apex deviation of 1.04 mm. For static navigation, the angular deviation was 3.6 degrees, the platform deviation was 1.1 mm, and the apex deviation was 1.4 mm[14]. These results illustrate that both methods are comparable and can fulfill basic implant placement accurately, each with its own shortcomings and advantages.

1.2.6 Bone density and cortical bone relevance

Bone density and grey levels have been shown to be important factors in implant accuracy, whether using fully guided or half-guided Stents. In most previous studies, the correlation between bone density and angular deviation was negative, meaning that in the presence of lower density bone, the implant angular deviation tends to be higher.

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Conversely, when the bone density is higher and the cortical bone is thicker, the implant achieves greater stability and higher final accuracy.

It was also shown that in fully guided surgery with mucosa-supported, pin-anchored templates on edentulous jaws, implants tend to be placed deeper than planned at sites with lower bone density and more superficially at sites with higher bone density[15]. Conversely, other studies have concluded that there was no difference in accuracy depending on bone density as long as fully guided protocols were used. Some studies even showed that higher density bone resulted in more deviation due to its hardness. Interestingly, when multiple bone condition predictors were considered, bone density, bone width, and cortical bone thickness significantly influenced the accuracy of implant placement, with the first two factors showing more correlation[16].

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Chapter 2 Research Purpose

- To evaluate the accuracy of tilted implant position through Dynamic Navigation vs Static Navigation at posterior mandibular area.
- To evaluate accuracy of tilted implant position at posterior mandibular area with two different bone types and bone densities.

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Chapter 3 Materials and Methods

3.1 Research Hypothesis

- There is no significant difference in final tilted implant position accuracy in between dynamic vs static navigation at posterior mandibular area.
- There is no significant difference in final tilted implant position accuracy with different bone density.
-

3.2 Materials and Methods

A single operator used fully guided stent, Iris-100, and X-Guide equipment to place tilted implants in two different types of bone. Following the placement, a scan body was attached to the implant platform, and a desktop scanner was used to acquire implant position data <Figure 1>. Digital software then calculated the differences between the design file and the actual implant placement to statistically assess the implant accuracy with the three main variables <Figure 2>.

Pre-Surgery Preparation

Simulated Bone Block Preparation:

- Materials**:** Sawbones® (Pacific Research Laboratories Inc., Vashon, WA, USA) <Figure 3> were used to simulate human bone. Blocks with 1 mm cortical bone and a density of 30 pcf, as well as blocks without cortical bone and a density of 20 pcf, were prepared.

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- Density Specifications: The 30 pcf block (compressive strength 18 MPa) was analogous to Misch classification D1 bone (17 MPa), while the 20 pcf block (compressive strength 8.4 MPa) was similar to Misch classification D3 bone (9 MPa).
- Cutting and Dimensions: Using a MICRO bandsaw MBS 240/E by Proxxon (Luxembourg) <Figure 4>, blocks were cut into 16 mm (L) x 7 mm (W) x 20 mm (H) samples. Forty blocks per surgical method were prepared, totaling 120 bone block samples.

Experimental Model Design:

- 3Shape E4 lab scanner was used to scan the physical model of the patient, producing an STL file. Mesh-mixer (Autodesk) software was used to create the bone block spaces for implant placement with the following dimensions: 16.3 mm (L) x 7.3 mm (W) x 25 mm (H) <Figure 5>.
- High-temperature-resistant resin (TR250LV, Phrozen Tech Co Ltd, Taiwan) <Figure 6> was used to print the master models with a Phrozen Sonic XL 4K 3D printer <Figure 7>.

Grouping and Distribution:

- A total of 120 simulated bone blocks were randomly distributed among the three main groups, Stent, Iris-100 & X-Guide. The design of the experimental model allows each simulated bone block to be removed after the experiment was completed, replaced with the next simulated bone block for faster processing.

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Implant Position Design:

- Software: Implant Studio 3 Shape TRIOS Design Studio.
- Process: The CBCT DICOM file of the simulated patient and the STL file of the master model were used to design the implant in the area of tooth 45 with a 30-degree angulation. A Nobel Parallel Conical Connection implant (RP 4.3, length 13 mm) from Nobel Bio-Care (Switzerland) <Figure 8> was used.

Fully guided Stent plate preparation <Figure 9>:

- Design: A surgical fully guided stent was designed to cover the entire edentulous ridge, with three pins to secure it in place. The stent material used was DD guide dental implant guide plate material, produced using a Phrozen Sonic 4K printer (DD guide dental implant guide plate material, Yang Ming Digital Dental Materials, Taiwan) <Figure 10>.
- Components: A Nobel Bio-Care Guided Sleeve 4.3 metal sleeve guide was used for stent insertion and fixation, along with three buccal fixation pins.

Dynamic Navigation preparation <Figure 11>:

- Iris-100 Navigation System (IRIS-100 Navigation System, EPED Inc., Kaohsiung, Taiwan): The master model with the resin implant CBCT data was used to plan the implant position, following the same positioning as in the 3Shape planning, using the proprietary Iris-100 software.
- X-Guide System (X-Guide®, X-Nav Technologies, LLC, Lansdale, PA): The 3Shape software exported the same 3D digital plan with X-Guide markers. Data import and equipment calibration were completed before the surgery.

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Preoperative standard model preparation:

- The simulated bone block was embedded in the master model <Figure 11>, and the static surgical stent was placed. Beads printed on the master served as superficial locators for STL and CBCT superimposition during implant planning and for final comparison.

Implant Placement Procedure:

- Equipment: The Surgical XT Plus dental handpiece by NSK Nakanishi, Japan <Figure 12>, along with a Mont Blanc 20:1 Push Button Dental Implant Handpiece <Figure 13>, was used for implant placement.
- Instruments: The Nobel Parallel Conical Connection surgery kit was used, following the manufacturer's guidelines. The sequence included various guided drills and a Nobel Parallel CC implant <Figure 14, Table 2>.

Post-Operative Procedure:

- The implant was connected to a scan body (Elos Accurate IO Nobel CC RP Single Abutment) <Figure 15>, and scanned using a 3 Shape E4 desktop scanner <Figure 16> to obtain the final scanned STL file <Figure 17 > used for data comparison.

Analysis of Implant Accuracy <Figure 24>:

- GeoMagic Control X 2020.1 software was used to calculate overlap and accuracy. The implant position was analyzed using the original planning file <Figure 18> as a reference. For setting reference variables, the center of the circular plane of the metal sleeve of the fully guided stent plate was used.

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From this center point, a measurement of 9 mm downward along the axis was taken to establish the implant platform level. From the platform level, a measurement of 13 mm downward was taken to establish the apex level <Figure 19>.

- For the sample data, the length of the scan body was 13 mm. From the top of the scan body along the axis, a measurement of 13 mm downward was taken to establish the platform level, and then a measurement of 13 mm downward from the platform was taken to establish the apex level.
- The reference points and axial directions analyzed from the implant samples were superimposed with the pre-operative design file <Figure 21> to calculate accuracy based on three measured values: (a) Platform deviation: the 3D difference in mm between the pre-operative design and the final implant position; (b) Apex deviation: the 3D difference in mm between the tip of the implant in the planned and final implant positions; (c) Angle deviation in degrees: the difference in the axis from the planned to the final implant position.

3.3 Statistical Analysis

1. The experimental raw data were stored in Microsoft Excel (V14.1), and SPSS (IBM SPSS Statistics V19.0) was used for analysis.

2. The Kruskal-Wallis test was used to compare the three main methods: Stent, Iris-100, and X-Guide. The Wilcoxon test was used for pairwise comparison of bone types: 1 mm cortical bone + 30 pcf and no cortical bone + 20 pcf, to evaluate whether there were significant differences among the three variables calculated after implant placement.

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3. When significant differences were found in the test results, post hoc multiple comparisons were used to detect which groups had significant differences.

4. The p value of all statistical analyzes was set at $p < 0.05$ to indicate statistical difference.

3.4 Experimental results

A. General results

The average mean deviation at *platform level* were:

Stent 0.54mm (±0.32)   Iris-100 0.89mm (±0.32)   X-Guide 0.75mm (±0.37)

The p-value was 0.001. Post hoc analysis established that Stent was the most accurate, followed by X-Guide and Iris-100, with significant differences among the groups.

The average mean deviation at *apex level* were:

Stent 0.76mm (±0.28)   Iris-100 1.12mm (±0.36)   X-Guide 0.84mm (±0.40)

the p-value was 0.001. Post hoc analysis established that Stent is more accurate than Iris-100, while X-Guide has no significant difference to any of the two other groups.

The average mean deviation at *angle level* were:

Stent 1.86º (±0.90)   Iris-100 1.74º (±0.86)   X-Guide 2.64º (±0.90)

The p-value was 0.001. Post hoc analysis established that Stent & Iris-100 are more accurate than X-Guide, but no difference between the two.

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B. Bone type analysis

i. Within all the samples of *1mm cortical + 30 pcf*, the results are as follow:

The average mean deviation at *platform level* were:

Stent 0.69mm (±0.16) Iris-100 0.90mm (±0.20) X-Guide 0.77mm (±0.32)

The p-value was 0.0053. Post hoc analysis established that Stent is the more accurate than Iris-100. X-Guide show no difference to any of the other two groups.

The average mean deviation at *apex level* were:

Stent 0.80mm (±0.30) Iris-100 1.32mm (±0.19) X-Guide 0.80mm (±0.36)

The p-value was 0.001. Post hoc analysis established that Stent & X-Guide are more accurate than Iris-100, but no significant difference between the two other groups.

The average mean deviation at *angle level* were:

Stent 1.78º (±0.78) Iris-100 2.13º (±0.78) X-Guide 2.43º (±0.99)

The p-value was 0.0638 with no significant difference within the 3 groups.

ii. Within all the samples of *No cortical + 20 pcf*, the results are as follow:

The average mean deviation at *platform level* by method were:

Stent 0.40mm (±0.19) Iris-100 0.87mm (±0.41) X-Guide 0.73mm (±0.42)

The p-value was 0.001. Post hoc analysis established that Stent is more accurate than Iris-100 & X-Guide. And these two last groups showed no difference in between.

The average mean deviation at *apex level* were:

Stent 0.68mm (±0.24) Iris-100 0.91mm (±0.38) X-Guide 0.88mm (±0.44)

The p-value was 0.2252 with no significant difference within the 3 groups.

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The average mean deviation at *angle level* were:

Stent 1.93º (±1.01)   Iris-100 1.36º (±0.77)   X-Guide 2.84º (±0.76)

The p-value was 0.001. Post hoc analysis established that X-Guide is the least accurate compared to Iris-100 & Stent. And these two last groups showed no difference in between.

C. Variable analysis

i. Within all the samples analyzing the *angle variable,* the results are as follow:

The average mean deviation at *Stent group*:

1mm C.B. + 30 pcf 1.78º (±0.78)   no C.B. + 20 pcf 1.93º (±1.01)

The p-value was 0.8392 with no significant difference within the groups.

The average mean deviation at *Iris-100 group*

1mm C.B. + 30 pcf 2.13º (±0.78)   no C.B. + 20 pcf 1.36º (±0.77)

The p-value was 0.0051 establishing that the second is more accurate.

The average mean deviation at *X-Guide group*

1mm C.B. + 30 pcf 2.43º (±0.99)   no C.B. + 20 pcf 2.84º (±0.76)

The p-value was 0.0601 with no significant difference within the groups.

ii. Within all the samples analyzing the *apex variable*, the results are as follow:

The average mean deviation at *Stent group:*

1mm C.B. + 30 pcf 0.80mm (±0.30)   no C.B. + 20 pcf 0.68mm (±0.24)

The p-value was 0.1298 with no significant difference within the groups.

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The average mean deviation at *Iris-100 group:*

1mm C.B. + 30 pcf 1.32mm (±0.19)   no C.B. + 20 pcf 0.91mm (±0.38)

The p-value was 0.0008 establishing that the second group is more accurate.

The average mean deviation at *X-Guide group:*

1mm C.B. + 30 pcf 0.80mm (±0.36)   no C.B. + 20 pcf 0.88mm (±0.44)

The p-value was 0.5075 with no significant difference within the groups.

iii. Within all the samples analyzing the *platform variable*, the results are:

The average mean deviation at *Stent group:*

1mm C.B. + 30 pcf 0.69mm (±0.16)   no C.B. + 20 pcf 0.40mm (±0.19)

The p-value was 0.0001 establishing that the second is more accurate.

The average mean deviation at *Iris-100 group:*

1mm C.B. + 30 pcf 0.90mm (±0.20)   no C.B. + 20 pcf 0.87mm (±0.41)

The p-value was 0.6949 showing no significant difference within the groups.

The average mean deviation at *X-Guide group:*

1mm C.B. + 30 pcf 0.77mm (±0.32)   no C.B. + 20 pcf 0.73mm (±0.42)

The p-value was 0.2616 with no significant difference within the groups.

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D. Technical progress analysis

Iris-100 group at angle deviation with 1mm cortical bone + 30pcf had a result of 2.67° (±0.71) during the first half of the samples, while the second half had a result of 1.59° (±0.36), with a p=0.0019 showing that the second half of the samples had an improvement in accuracy.

Same happened with Stent group at angle deviation with no cortical bone + 20 pcf at angle deviation, in which the first half of the samples had a mean deviation of 2.35° (±1.17) and 1.51° (±0.65) for the second half respectively, with a p=0.0452 showing that the second half of the samples showed an improvement in accuracy over time.

No other comparison within the same subgroups had any significance difference overtime. Meaning that the technical progress accuracy was consistent throughout the experiment.

E. Precision analysis

Between the three main groups in this study, the 2D platform precision was evaluated for precision levels. From the results it was stated that the more precise group was Stent with a mean deviation of 0.1660 mm and a SD of 0.1896 mm. Followed by Iris-100 groups which showed a higher mean deviation of 0.3188 mm and a SD of 0.3106 mm, and lastly X-Guide group with a mean deviation of 0.2638 mm and a SD of 0.3830. This gives a general idea of the performance of repetition within each method and their capabilities, while still been accepted as successful implant methods.

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Chapter 4 Discussion

The two initial hypothesis for this study are rejected due to finding statistical difference between the three different surgical methods and also having difference in accuracy based on the bone density and the presence of cortical bone.

1. Computer-aided implant planning combines CBCT and 3D model files letting the dentists plan the position of implants in a controlled and effective digital environment generating a 3D structure to study bone, prothesis and soft tissue. The relative position of the implant can be seen from any directions, after deciding its position the Stent file can be generated and printed and also a Dynamic guiding procedure can be generated as well. Accurately transferring the preoperative plan to the surgical process[17]. However, we strive to improve the accuracy and safety of surgery, speed up treatment, reduce costs, reduce the burden on patients, and obtain the best treatment possible.

2. This experiment focuses on the accuracy & precision of dental implants. The following discusses different factors that may affect the accuracy of this experiment.

2.1 The sawbones blocks were prepared using a bandsaw. Using a printed guide of the bone shape and size, this was trimmed to the exact dimension. Therefore, the error between each simulated bone block is minimal.

2.2 Three experimental models were used. They all used the same file from the same digital patient, the same 3D printer (Phrozen Sonic XL 4K), tray and printing material. After printing, they were stored properly. The mean deviation for each model was under 0.006mm (±0.018) so the errors are within normal limits[9].

2.3 The sawbones block was fixed in the previous empty planned space of the printed model and fixed with a metal pin from the buccal plate. Therefore, the height

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of the sawbones block in each experimental group is the same, and the error is very small without statistical significance, therefore it can be ignored.

2.4 Fully guided Stent was design as bone level, fixed with 3 metal pins fixing it in place. This is the traditional method used for edentulous patients in which the only anchorage point is the jaw bone. This one printed with the recommended settings. Herschdorfer L. on her study also stated that stereolithography is also an effective way to produce surgical Stents with no significance difference to other printing methods. Using the same Stent and same model reduce the error and it also can be ignored[10].

2.5 The dynamic navigation method was done by following the same initial planning, in which the calibration of tools was done with the assistance of a representative of the respective equipment brand. Using the same model and same planning for each implant. Reducing the number of errors possible from the operator.

2.6 The surgeon is the same operator who has minimal experience in dental implants. The operator is right-handed. Kivovics M. stated that during guided surgery, the operator error did not have any difference compared to more experienced one[18]. This can also be supported by the results on the present study in which only 2 of 18 subgroups showed significance difference from the initial samples to the final samples in accuracy. Also, the operation process follows the surgical guidelines of Nobel Parallel Conical connection surgery in Nobel BioCare Guided surgery. In Sittikornpaiboon P. Et al study was also stated that the sleeve on sleeve was the second most accurate compared to other guided methods preceded by sleeve on sleeve with locking system from Straumann[15]. But still not having significance difference between them. Therefore, the error in this part is ignored[19].

2.7 During the operation, the Stent is fixed by the surgeon's left hand to prevent the Stent from moving and shifting[20-22]. It can be thought that this method of fixation

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assistance definitely causes errors, and part of the error in experimental results comes from the stability of the Stent during surgery. However, if you want to eliminate this error, Stent and model had to be printed in one piece, eliminating the joint error between them, but this is not a real scenario and also makes the procedure of replacing the saw bone more complicated. The method chosen in this experiment was to print the Stent and the model separately, which is closer to the real clinical situation, also in which the drilling protocols are all as followed by the recommended manufacture and established by previous different drilling protocols and methods ensuring primary stability[23-25].

2.8 Then the implant is connected to the scan body and scanned. Using GeoMagic Control X 2020.1. the analysis of the data was acquired. During the analysis process, it is necessary to locate the boundaries of the scan body, and then the software will use it accordingly to find the implant platform, apex and angle. The process is done manually by the operator within the software. This inevitably will produce some errors. This part of the operation is also performed by the same operator, and the error can be ignored.

Meng T. Zhang X. conducted a retrospective for dynamic navigation intentionally tilted implants. The results showed that the average implant platform level was 1.3mm, the average implant apex difference was 1.1mm, and the average implant angle difference was 3.1°. In which within his study compared to not intentionally tilted implants it had no difference[17].

Jorba A. et al on his meta analysis and systematic review stated that platform deviation was 0.75mm, angle deviation was 1.09mm and angular deviation was 2.84°. which is similar to the results on the present study[19]. Also supported from Jorba A. study, static method showed the highest accuracy levels and X-Guide showed a higher accuracy than Iris-100. On the present study X-Guide did have higher accuracy than Iris-100 in platform and apex deviation with significant difference, but fall short during

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angle deviation in which Iris-100 had higher accuracy than X-Guide. But at the same time both of them falling behind Stent. However, it is important to stress that a 2-mm safety margin should always be applied, because deviations of slightly over 1 mm were registered on some occasions.

Kivovics M. also stated that there is a significant negative correlation between bone density and implant accuracy, in which a harder bone will have better accuracy[18]. This conclusion can be refuted from the present study in which 3 of the 9 subgroups showed a higher accuracy with lower density bone sample and the other 6 subgroups had no significant difference in accuracy[26]. This was also stated from Putra R. et al in his study in which bone density and cortical bone showed a negative correlation to accuracy, in which harder bone and cortical bone will have lower accuracy compared to softer bone and no cortical bone, same as we saw in the present study.

Yimarj P. also stated that the difference between static vs dynamic method is comparable with no significance difference[27]. The results of his study are for static group platform deviation1.04mm, apex deviation 1.54mm and angle deviation of 4.08°, compared to dynamic in which platform deviation was 1.24mm, apex deviation 1.58mm and angle deviation of 3.78°. These results are similar to the ones stated in the present study in which Stent group had a platform deviation of 0.54mm, apex deviation 0.76mm and angel deviation of 1.86°, and dynamic methods from Iris-100 had platform deviation of 0.89mm, apex deviation of 1.12mm and angle deviation of 1.74°, followed by X-Guide with a platform deviation of 0.75mm, an apex deviation of 0.86mm and an angle deviation of 2.64°. This following the norm from Yimarj P. study and similar meta-analysis[28].

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The research results of dynamic and static guidance accuracy by scholars such as Dong W. the difference between the average implant platform level of Stent is 1.22 mm, the difference between the average implant apex is 1.33 mm, and the average implant angle difference is 4.34°[14]. These results are better than those of Zhou et al[12]. The difference in the research results of Dong W. and other scholars is larger. Compared to the results in the present study we can see a higher level in accuracy.

From the precision distribution of implant 2D <Figure22>, we can see that the offsets in Stent, and the offset distribution in X-Guide and Iris-100 groups are more dispersed[29]. However, because the Stent has a metal sleeve The ring limits the movement range of the implant bone drill, and the overall offset error does not deviate too much from the planned implant placement point <Figure23>. The same way the distance between the implant position and the opposing occlusion was recorded in which from the bone sample to the tooth 15 it had a space of 38mm, after placing the static surgical Stent the distance was reduced to 30mm of clearance. This made the positioning of the drill into the guide even more difficult and stress the anchor pins during placement and removing the drills from the Stent. This cannot be stated for the dynamic navigation methods (X-Guide & Iris-100), which they are not limited to any physical guide but only to their proprietary fiducial markers which do not obstruct the drill position. Yimarj P. also stated in his study that platform deviation was more prone to be lingualized and apex deviation more to the distal side[27]. This happened more in the dynamic methods compared to static one, but without any significance difference. In the present study the same can be tell from the precision results, in which Stent group showed to be the one with more homogeneous area of implantation[30]. Followed by Iris-100 and last X-Guide. From there we can tell that in platform level, Stent group showed a general deviation towards lingual side, Iris-100 had a buccal deviation and X-Guide

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had a disto-lingual deviation <Figure22>. These results might also be extrapolated to axial implants seen that the technique is the most important and not the angle itself as seen in previous studies[31].

There was no significant difference in the deviation direction of the implant implantation point whether on the buccal, palatal, proximal, or distal sides. This may be because the number of samples participating in the experiment was not large enough to make significant differences during this experiment.

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Chapter 5 Conclusion

1. When using a fully guided stent for tilted implant placement, the accuracy of dental implants position will still be affected by the bone hardness.

2. There are significant differences in the deviation acquired at implant platform, implant apex & implant angle, between the three different methods of navigation, and between the two bone types, in which Stent method is the more accurate between the three groups.

3, Dynamic navigation methods, in this case Iris-100 and X-Guide showed comparable results to the gold standard fully guided Stent, being suitable for tilted implant surgery within clinical acceptance results.

4. Within precision analysis, the most precise is Stent followed be Iris-100 and last was X-Guide, in which at platform level it showed the one with the most amount of inconsistency during the implantation.

5. The accuracy levels were improved after half of the samples were done in two groups, meaning that for a novice practitioner, Stent and Iris-100 had a benefit after having a short training period. X-Guide did not benefit from it.

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Chapter 6 Limitations and Future Prospects

1. This experiment is conducted with simulated bone block. The density of the selected bone block is similar to that of sponge bone. Such simulated bone block is different from some clinical situations. If a bone block with a bone density similar to that of cortical bone is selected, A bone block with an outer layer and an inner layer of spongy bone will be closer to the actual clinical encounter, and the thickness of the cortical bone can be changed to simulate bones of various hardness. In the future, experiment with several modules of different hardness of the saw bone should be taken in consideration to expand the results and significance difference.

2. The greater the inclination of the implant angle, the greater the difference between the implant root tip and the implant axial direction. In the future, when facing tilted implant protocols, the fully guided Stent should be firmly secure, and with dynamic navigation systems the initial round bur should be prevented from slipping due to high angle and less stability while drilling.

3. The method of using the static surgical guide plate to guide the dental implant drill to the implant is very suitable for dental implant beginners, and the surgery can be completed according to the surgical plan. Same can be said for dynamic navigation system which beginners with enough understanding of 3D space location will perform within the limits of an accurate implantation. However, the operator must fully understand the concept, advantages and disadvantages of the fully guided stent in order to obtain the same surgical results as planned in advance.

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From the results of this experiment, is stated that the accuracy of the fully guided stent might be affected by the software planning, the design of the fully guided stent, the method of generating the guide plate, the stability of the guide plate wearing, and the stability of the bone where the drill needle is implanted. Various factors such as flatness, mouth opening, and familiarity with the surgical process can affect the final outcome. The same is explained during dynamic navigation protocol in which even more errors can be established by moving the fiducial markers, re-adjusting the handpiece marker, moving of the patients, light source not being bright enough for the camera to properly locate the markers and else.

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Appendix

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Figure 1. Methodology Flow chart

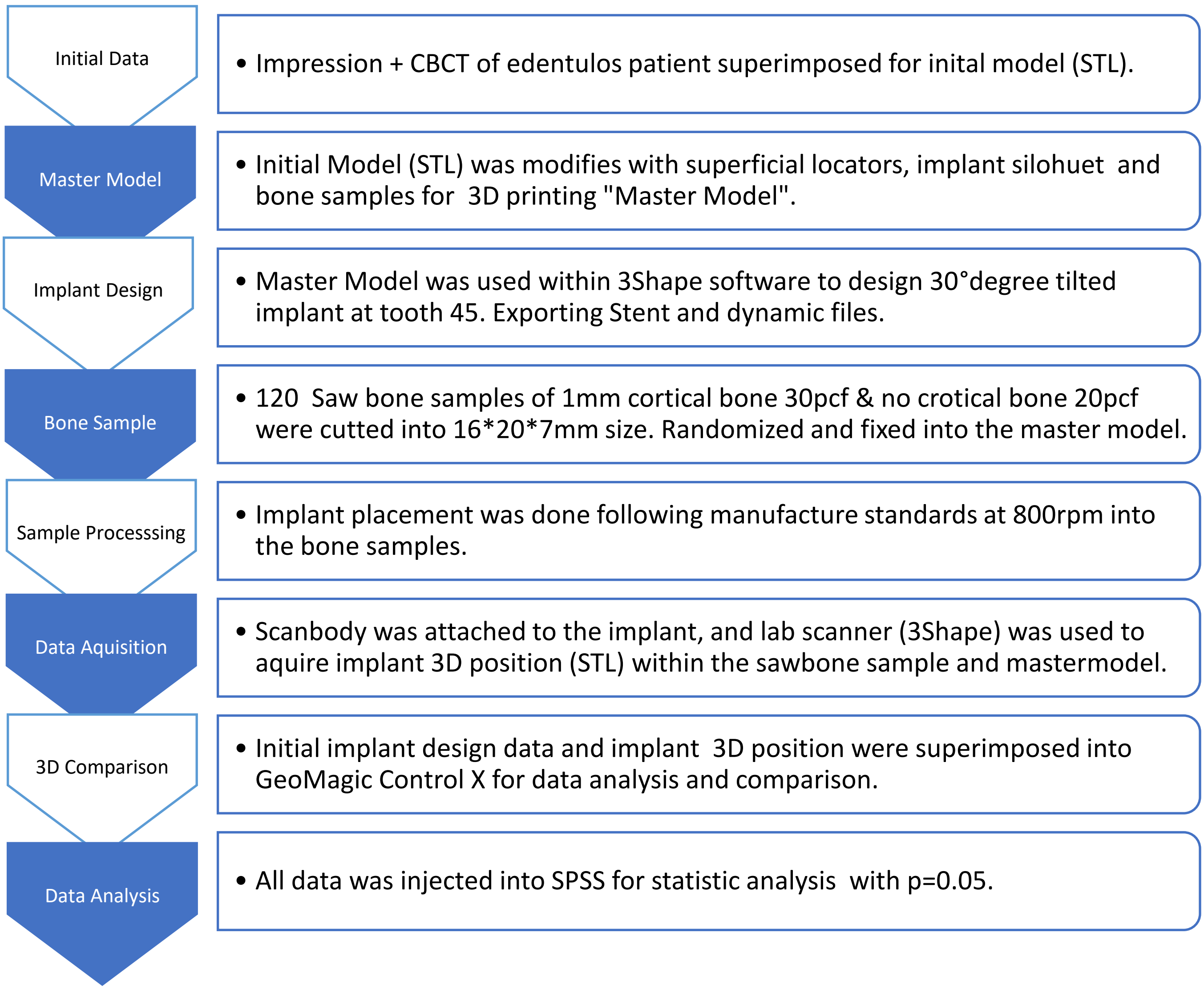

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Figure 2. Analysis of implant accuracy variables:

a. Platform deviation in “mm”

b. Apex deviation in “mm”

c. Angle deviation in “°”

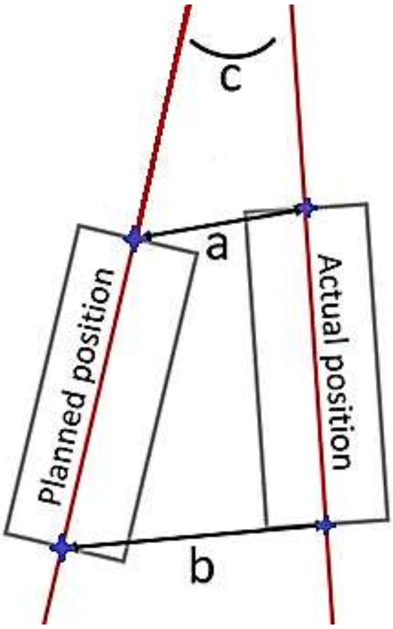

Figure 3. Simulated Bone Block

Solid rigid polyurethane foam block, saw bone®.

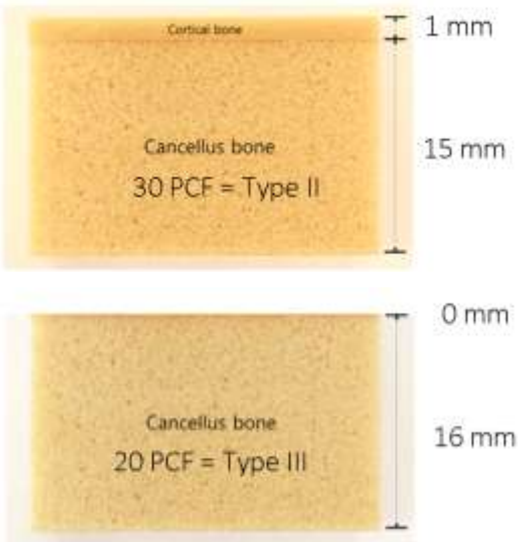

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Figure 4. MICRO bandsaw

MBS 240/E by Proxxon Luxemburg and bone block sample:16x7x20mm3.

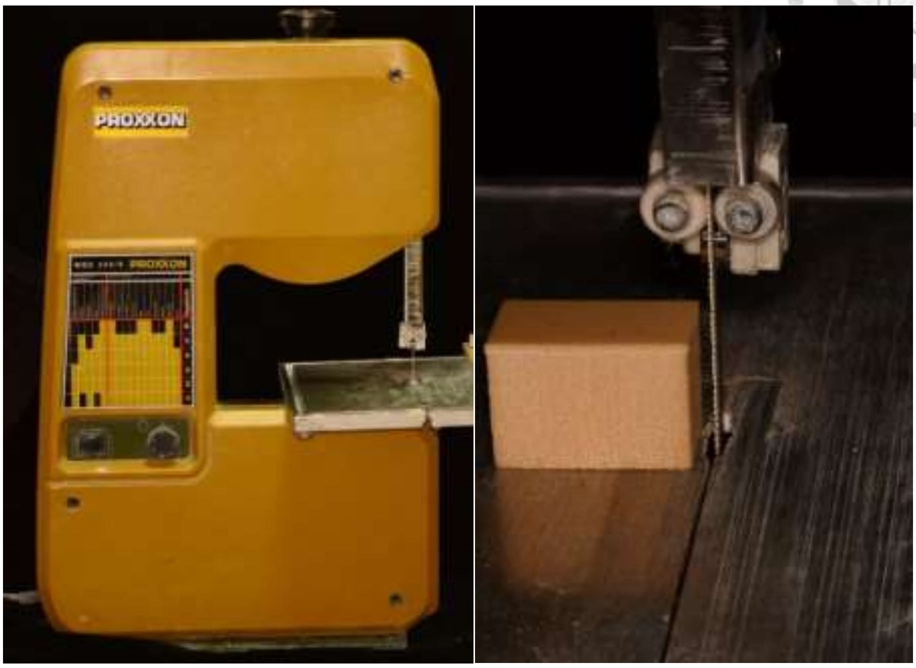

Figure 5. Master Model

Left: master model STL; Right: Physical Master model.

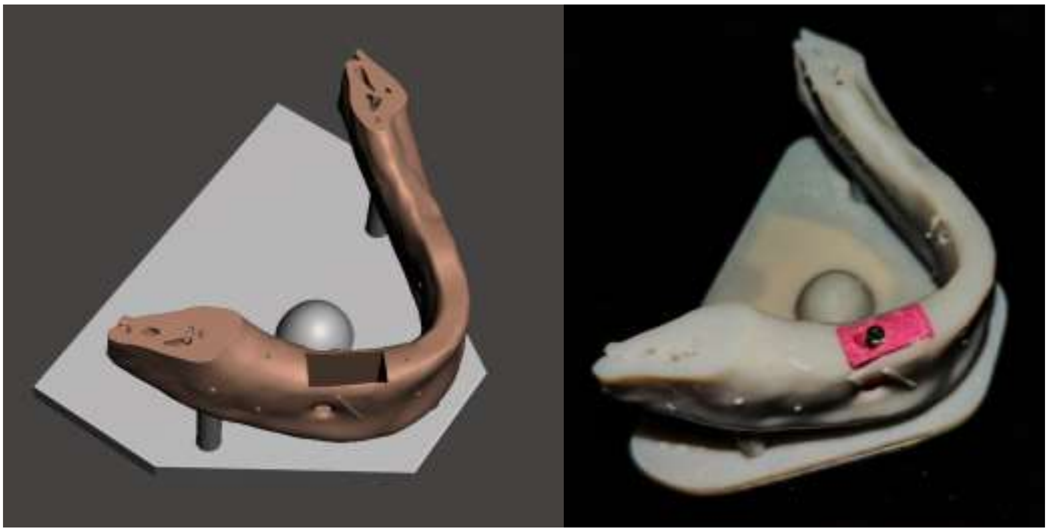

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Figure 6. Light-cured Resin

The material used for the master model, high temperature resin (TR250LV,Phrozen).

Figure 7. 3D Printer

Phrozen Sonic XL 4K 3D printer.

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Figure 8. Implant Design

3 Shape TRIOS Design Studio, Implant planning.

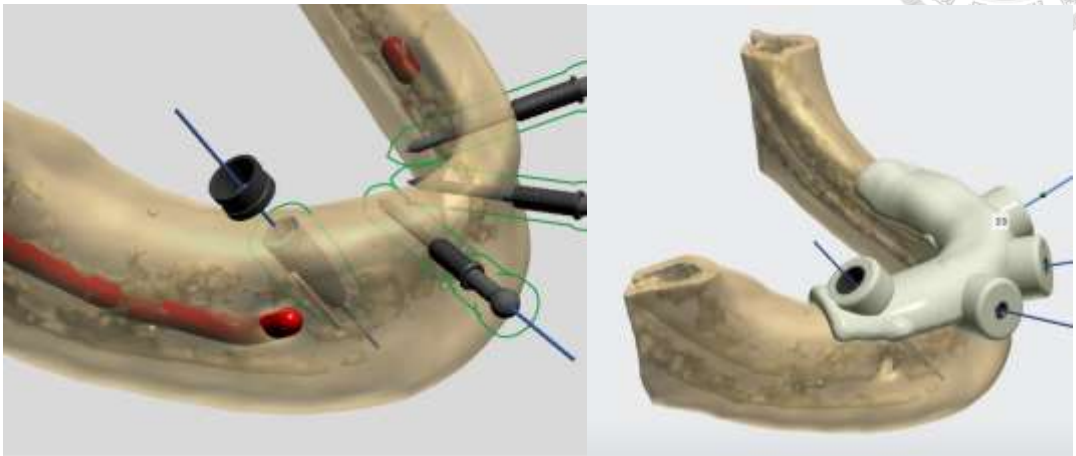


Figure 9. 3D Model

Design of fully guided stent.

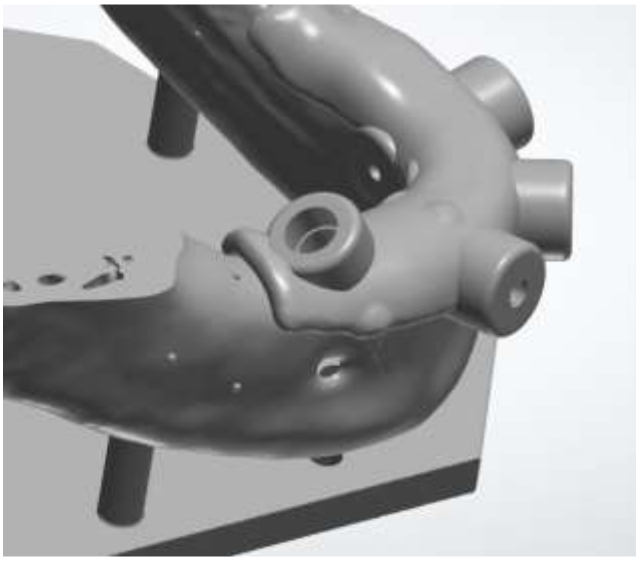


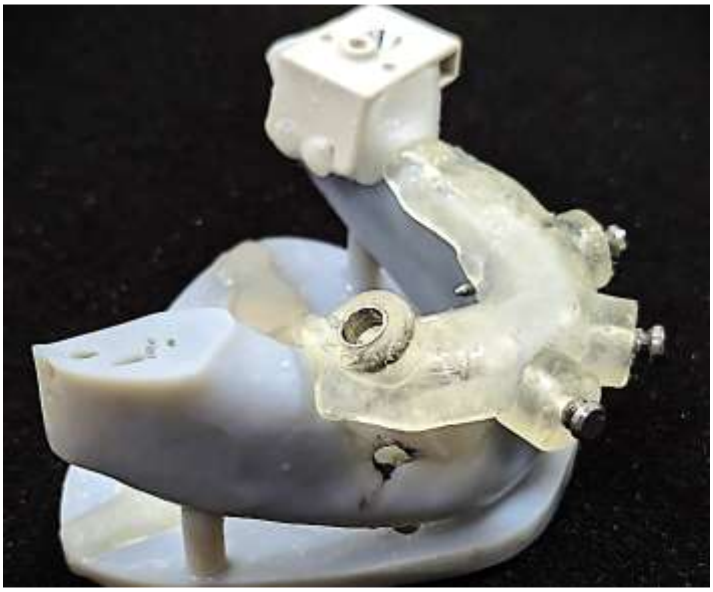
Figure 10. Printing Resin

Yang Ming Optical Dental Implant Guide Plate Printing Resin, DD guide.

Figure 11. Implantation Preparation

Model preparation before surgery for each group.

Stent



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X-Guide.

Iris-100.

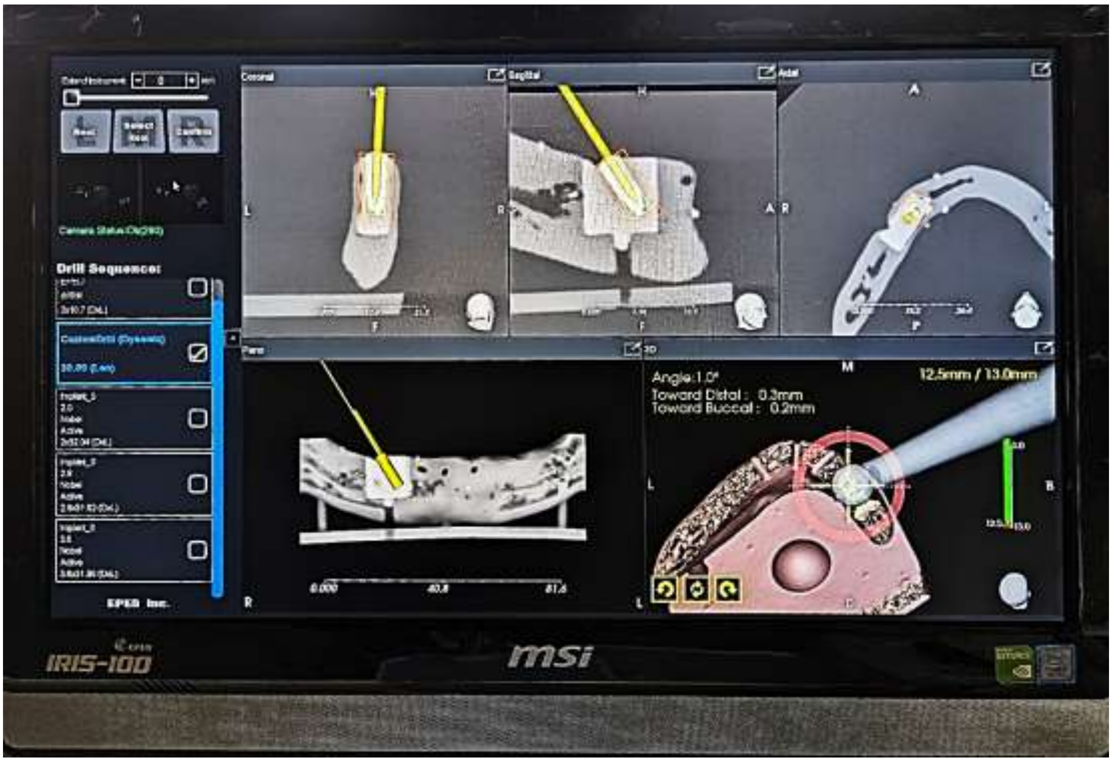

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Figure 12. Implant Motor

NSK Dental Implant Motor (Surgical XT Plus machine).

Figure 13. Hand Piece

Mont Blanc 20:1 Push Button Dental Implant Handpiece Low Speed Contra angle.

Figure 14. Drill Order

Nobel BioCare Guided surgery recommended instructions.

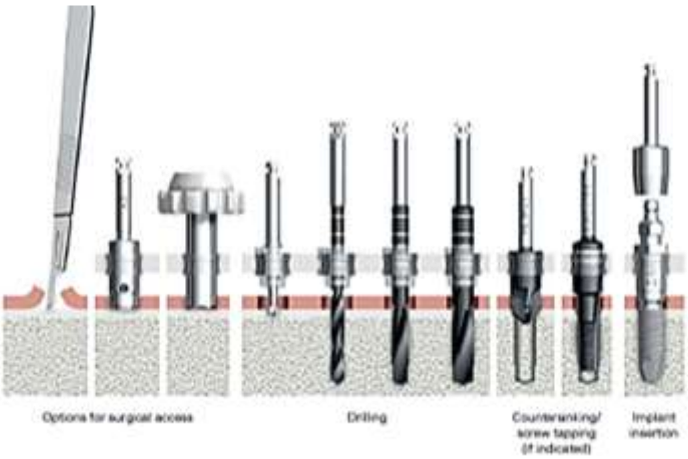

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Figure 15. Scan body

Elos Accurate IO Nobel CC RP Single Abt

Figure 16. Desktop Scanner

3 Shape E4

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Figure 17. STL File

Sample scanned STL file for comparison

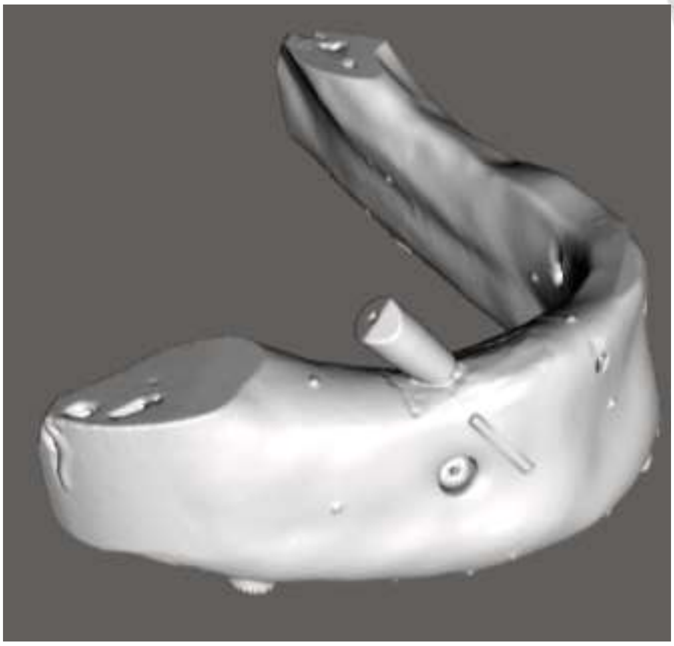

Figure 18. Stent Parameters

Analysis method for implant position and its measrument.

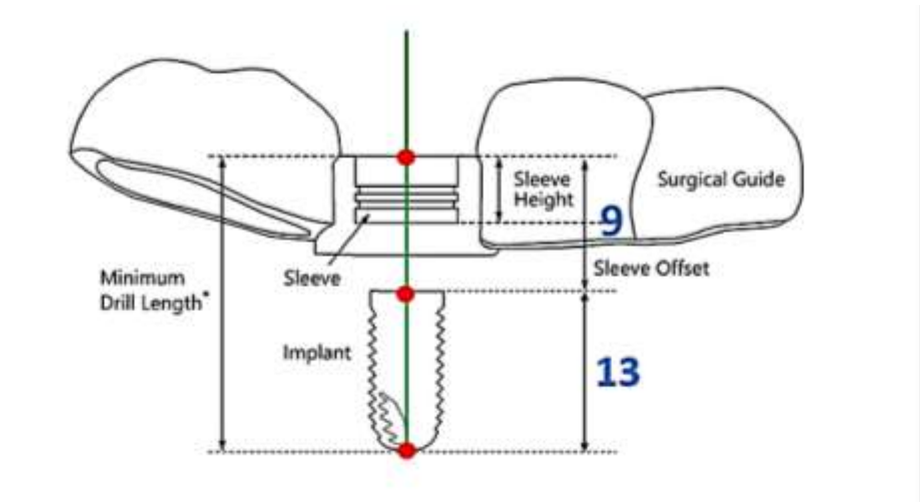

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Figure 19. GeoMagic Model

Superimposition of Master Model (Blue) and Sample (Gray).

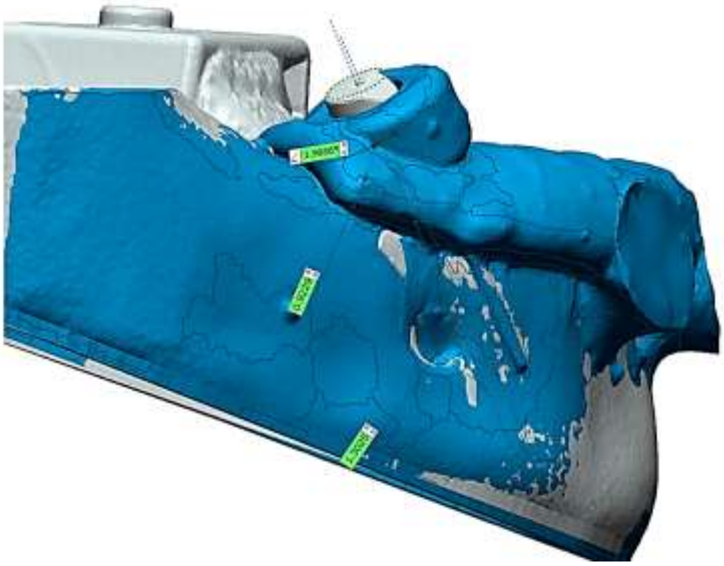

Figure 20. Variable Analysis

Geo Magic Control X 2020.1 analysis software for superimposition and accuracy calculations.

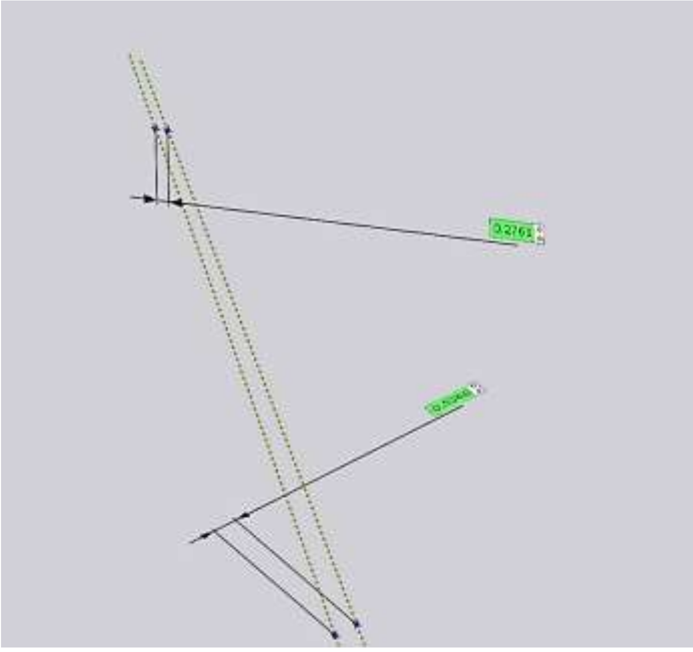

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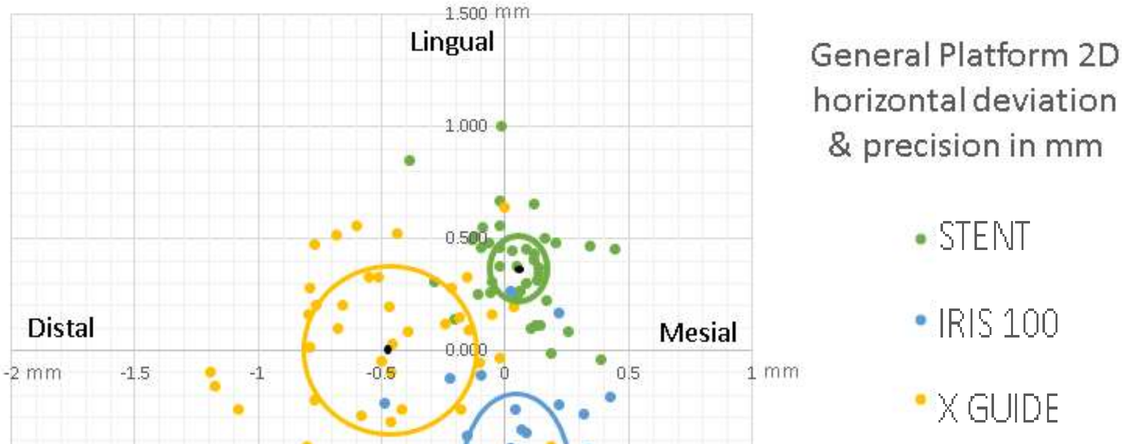
Figure 21. Platform Precision

Distribution of implant platform on the buccal-lingual & mesio-distal deviation in mm, with precision assessment with in the sample groups.



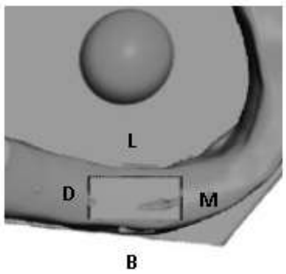


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Figure 22. Apex Precision

Distribution of implant platform and apex on the buccal-lingual & mesio-distal deviation.

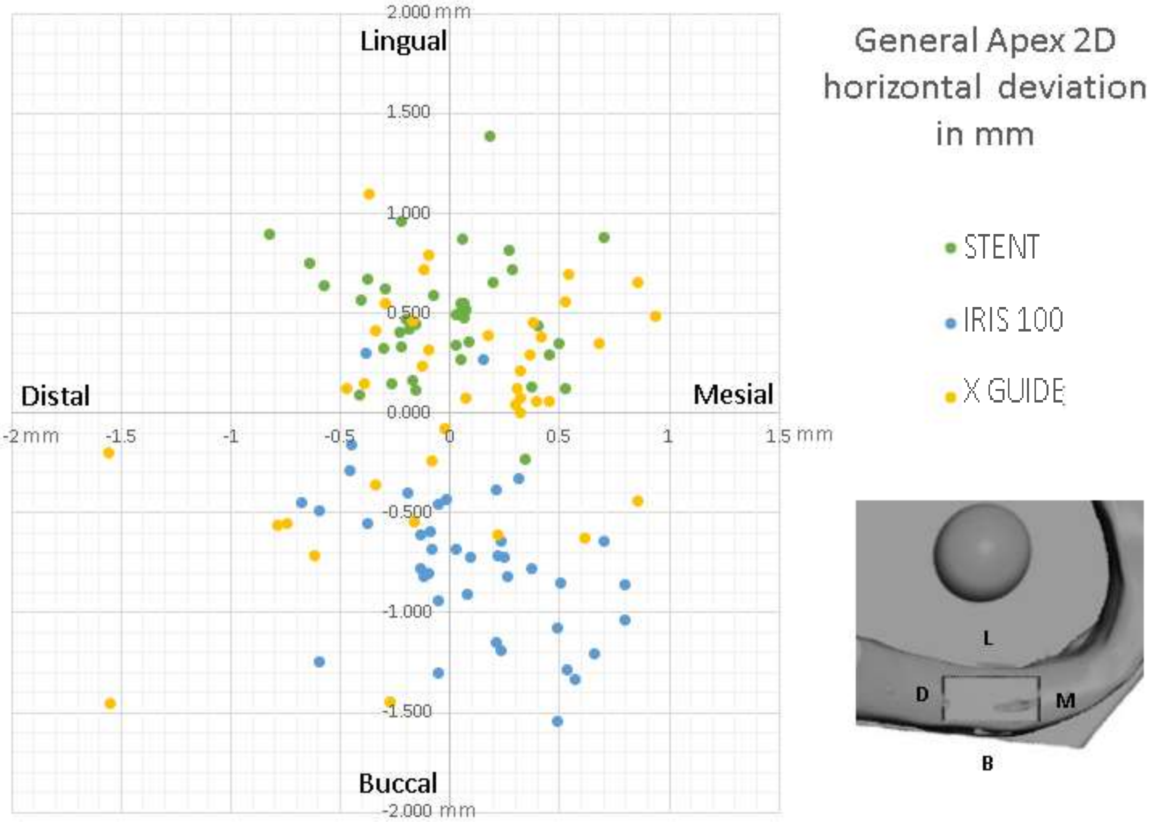

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Figure 23. Platform Offset

The offset of the implant platform point is concentrated near center area

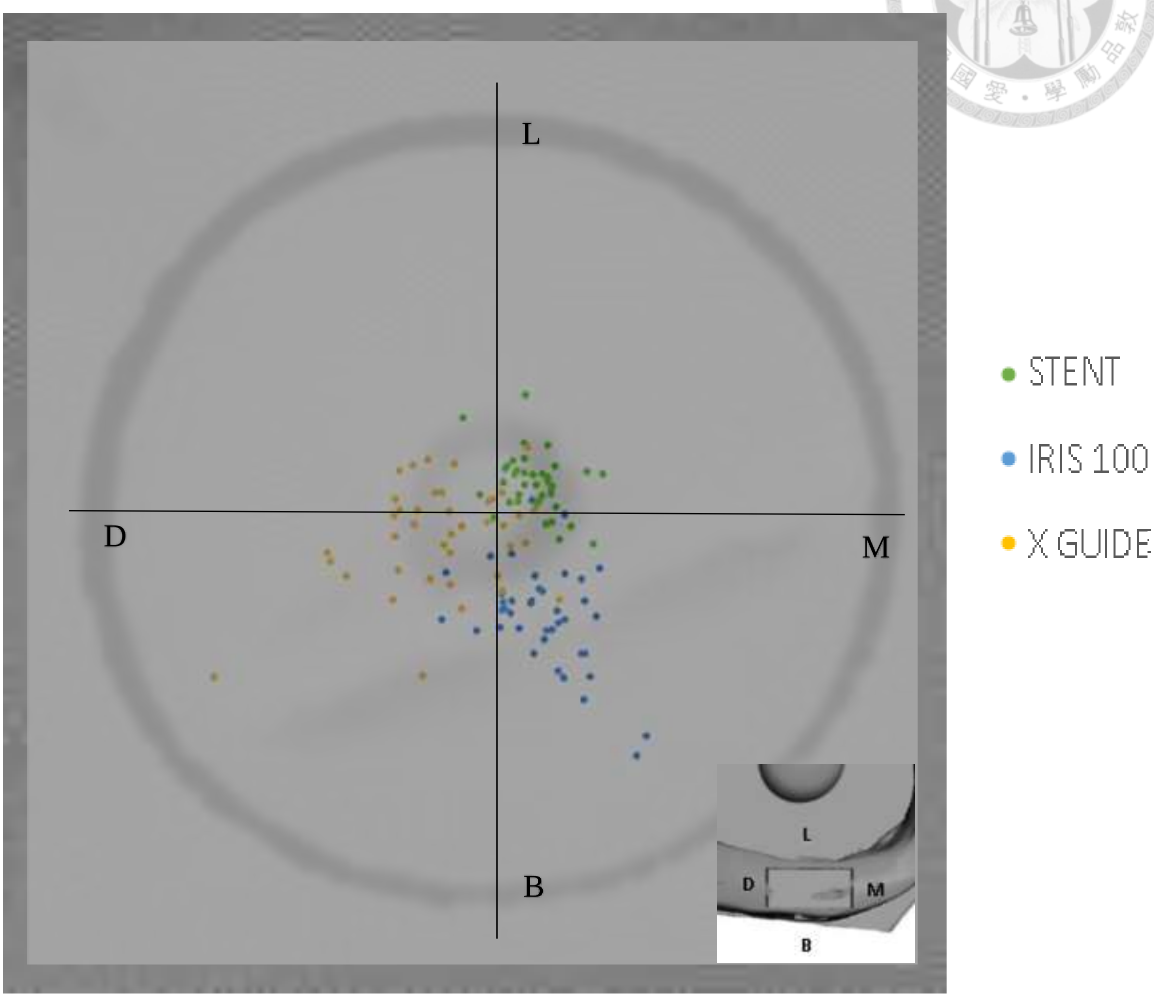

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Figure 24. Summary Bar Graph

Bar Graph of Total statistical results of the three main groups and its variables.

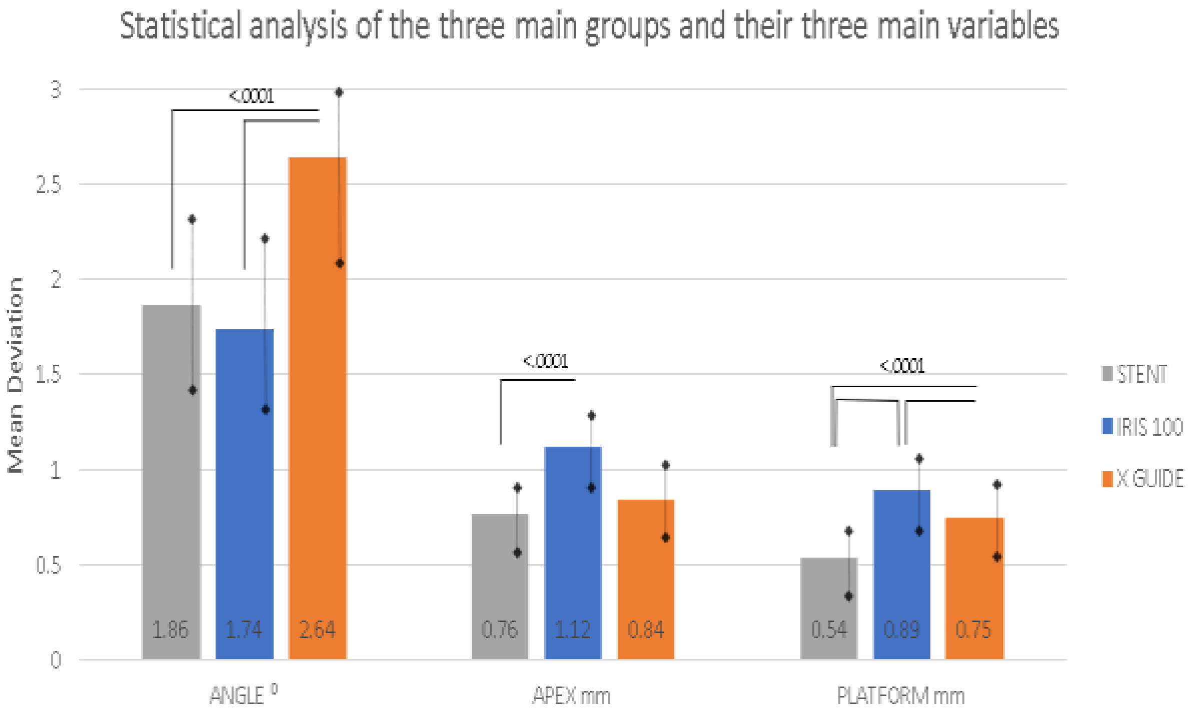

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Table 1. Saw Bone Mechanical Properties

DENSITY			COMPRESSIVE		TENSILE		SHEAR	
(PCF)	(g/cc)	Volume Fraction	Strength (MPa)	Modulus (MPa)	Strength (MPa)	Modulus (MPa)	Strength (MPa)	Modulus (MPa)
ASTM D1622			ASTM D1621		ASTM D638		ASTM C273	
5*	0.08	0.07	0.60	16	1.0	32	0.59	7.1
8	0.13	0.11	1.5	38	1.3	56	1.2	13.7
10*	0.16	0.14	2.2	58	2.1	86	1.6	19
12*	0.19	0.16	3.2	81	2.5	112	2.1	24
15*	0.24	0.20	4.9	123	3.7	173	2.8	33
20*	0.32	0.27	8.4	210	5.6	284	4.3	49
25*	0.40	0.34	12.9	317	8.8	399	5.9	68
30*	0.48	0.41	18	445	12	592	7.6	87
35*	0.56	0.47	24.4	592	15.6	713	9.4	108
40*	0.64	0.54	31	759	19	1000	11	130
50*	0.80	0.68	48	1148	27	1469	16	178

Note: The mechanical properties of Saw bone® used in this experiment are the same as those of human spongy bone. Source: (SawBone, USA, sawbones.com)

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Table 2. Drilling Protocol

Drilling protocols according to bone quality*

Platform	Ø Implant	Soft bone Type IV	Medium bone Type II–III	Dense bone Type I
NP	3.75mm	2.0 [2.4/2.8]	2.0 2.4/2.8 Guided Counterbore 3.75 [Guided Screw Tap 3.75]	2.0 2.4/2.8 2.8/3.2 Guided Counterbore 3.75 Guided Screw Tap 3.75
RP	4.3mm	2.0 2.4/2.8 [3.2/3.6]	2.0 2.4/2.8 3.2/3.6 Guided Counterbore 4.3 [Guided Screw Tap 4.3]	2.0 2.4/2.8 3.2/3.6 Guided Counterbore 4.3 Guided Screw Tap 4.3
RP	5.0mm	2.0 2.4/2.8 3.2/3.6 [3.8/4.2]	2.0 2.4/2.8 3.2/3.6 3.8/4.2 Guided Counterbore 5.0 [Guided Screw Tap 5.0]	2.0 2.4/2.8 3.2/3.6 3.8/4.2 Guided Counterbore 5.0 Guided Screw Tap 5.0
WP	5.5mm	2.0 2.4/2.8 3.2/3.6 4.2/4.6 [4.2/5.0]	2.0 2.4/2.8 3.2/3.6 4.2/5.0 Guided Counterbore 5.5 [Guided Screw Tap 5.5]	2.0 2.4/2.8 3.2/3.6 4.2/5.0 Guided Counterbore 5.5 Guided Screw Tap 5.5

All data in mm. Drills within square brackets [--] are optional.

Note: Nobel Parallel Conical Connection Guided Surgery drilling protocol.
Source: (Nobel BioCare, Zurich, nobelbiocare.com)

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Table 3 Raw Results

	Stent							IRIS							X GUIDE					
	CORTICAL BONE			NO CORTICAL BONE				CORTICAL BONE			NO CORTICAL BONE				CORTICAL BONE			NO CORTICAL BONE		
	ANGLE °	APEX mm	PLAT. mm	ANGLE °	APEX mm	PLAT. mm		ANGLE °	APEX mm	PLAT. mm	ANGLE °	APEX mm	PLAT. mm		ANGLE °	APEX mm	PLAT. mm	ANGLE °	APEX mm	PLAT. mm
1	1.934	0.6196	0.4211	5.1836	1.1256	0.2846	1	3.7619	1.2944	0.4487	2.3636	1.4843	0.9608	1	3.1957	0.6233	0.5216	2.5187	0.519	0.4915
2	0.6613	0.9397	0.9041	1.6481	0.8922	0.6749	2	3.823	1.6833	0.8648	0.5274	0.5595	0.5243	2	3.8181	0.831	0.7447	3.9543	0.9696	1.2062
3	1.5122	0.335	0.6393	2.0625	0.5251	0.1778	3	2.3436	1.3434	0.8679	2.6457	0.8329	1.1691	3	2.7609	0.5585	0.7404	2.9008	2.148	2.1067
4	1.6616	0.9376	0.7833	2.886	0.7312	0.255	4	2.4122	1.507	1.0229	0.6037	0.3165	0.3054	4	3.2169	0.4924	0.8458	3.5714	0.9028	0.6441
5	4.0939	1.2463	0.5571	1.6427	0.548	0.3985	5	1.5374	0.9525	0.6549	0.6628	0.6826	0.7173	5	2.6648	0.7969	0.8926	1.866	0.4474	0.5079
6	1.3557	0.8602	0.6805	2.5574	0.9353	0.3998	6	3.0126	1.4449	0.7638	0.3691	0.5245	0.5965	6	2.0554	1.0035	1.1316	0.5269	0.6505	0.6621
7	1.4569	0.861	0.6349	1.0269	0.5354	0.3469	7	2.6043	1.3572	0.8746	1.2353	0.6795	0.692	7	2.1041	1.5205	1.4568	3.6058	1.081	0.2006
8	1.3188	0.8014	0.7946	2.0607	0.541	0.1746	8	2.0648	1.2594	0.8254	2.444	1.2018	1.6598	8	1.7876	0.4299	0.8289	2.9686	0.9095	0.675
9	2.5154	0.7833	0.7999	1.5139	0.7724	0.434	9	2.551	1.4602	1.005	1.934	0.5368	0.2761	9	1.6964	1.6244	1.2994	2.7668	1.2034	0.4836
10	2.057	0.6953	0.5004	2.9008	1.0366	0.5578	10	2.551	1.4227	0.9481	0.791	0.7484	0.5923	10	4.6859	1.1152	0.1248	3.4165	0.9145	0.93
11	0.1962	0.3823	0.4241	0.8574	0.5514	0.3874	11	1.545	1.2121	0.9031	0.9913	0.8259	0.6272	11	2.1395	0.365	0.178	3.2454	0.5363	0.3629
12	2.3582	1.2132	0.7902	1.4771	0.795	0.4789	12	1.247	1.0398	0.8242	2.359	0.6781	0.2531	12	2.2532	0.4916	0.5949	2.7459	1.3	0.903
13	1.2719	0.8871	0.6789	1.1934	0.5793	0.3089	13	1.6806	1.4063	1.1004	0.6028	0.9538	0.9943	13	2.2244	0.6272	0.69	2.1787	0.5259	0.8046
14	2.0556	1.0102	0.6488	0.6362	0.2372	0.2664	14	1.9686	1.3025	0.9229	1.1542	1.6554	1.5926	14	1.492	0.6969	0.9065	3.0282	1.6387	1.213
15	1.8681	0.4213	0.5522	2.2654	0.8935	0.4236	15	1.3649	1.5072	1.3263	0.5046	1.2127	1.1803	15	2.2966	1.2053	0.7622	2.445	0.6021	0.6533
16	1.9859	1.4687	1.0519	1.2455	0.5858	0.3055	16	1.2213	1.2574	0.997	2.4386	1.0786	1.2323	16	1.7259	0.4774	0.6005	2.6686	0.7756	0.5651
17	1.3968	0.6242	0.6494	1.1899	0.5615	0.2939	17	1.317	1.3112	1.037	1.5579	0.9648	1.0448	17	2.9902	0.8889	0.6264	2.4943	0.2515	0.4945
18	1.7069	0.541	0.6573	2.7375	0.8493	1.0109	18	2.3248	1.4487	1.0585	1.2174	0.472	0.7329	18	3.8745	0.5583	0.6969	3.6027	0.7659	0.7616
19	1.8323	0.7794	0.8506	1.5343	0.195	0.2832	19	1.4079	1.3714	1.1059	0.9206	1.5165	1.3623	19	0.7157	1.1682	1.1091	2.9921	0.7667	0.587
20	2.4312	1.1981	0.8002	1.9914	0.8018	0.4796	20	1.8287	0.907	0.5159	1.8029	1.2874	0.9342	20	0.9472	0.5717	0.5996	3.3951	0.747	0.3547

Note: Table of Raw data by method of implantation of the total of samples. Source: (Personal Data)

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Table 4. Bone Hardness Analysis

1mm Cortical + 30pcf					
	STENT	IRIS 100	X GUIDE	p value	post hoc
ANGLE º	1.78 (0.78)	2.13 (0.78)	2.43 (0.99)	**0.0638**	
APEX mm	0.80 (0.30)*	1.32 (0.19)*,**	0.80 (0.36)**	**<.0001**	iris>stent,iris>xguide
PLATFORM mm	0.69 (0.16)*	0.90 (0.20)*	0.77 (0.32)	**0.0053**	iris>stent

No cortical + 20pcf					
	STENT	IRIS 100	X GUIDE	p value	post hoc
ANGLE º	1.93 (1.01)**	1.36 (0.77)*	2.84 (0.76)*,**	**<.0001**	x guide>stent,x guide>iris
APEX mm	0.68 (0.24)	0.91 (0.38)	0.88 (0.44)	**0.2252**	
PLATFORM mm	0.40 (0.19)*,**	0.87 (0.41)*	0.73 (0.42)**	**<.0001**	iris>stent,x guide>stent

Total					
	STENT	IRIS 100	X GUIDE	p value	post hoc
ANGLE º	1.86 (0.90)**	1.74 (0.86)*	2.64 (0.90)*,**	**<.0001**	x guide>stent,x guide>iris
APEX mm	0.76 (0.28)*	1.12 (0.36)*	0.84 (0.40)	**<.0001**	iris>stent
PLATFORM mm	0.54 (0.23)*	0.89 (0.32)*	0.75 (0.37)*	**<.0001**	iris>stent, iris> xguide >stent

*Kruskal-Wallis test;

Note: Kruskal Wallis statistical analysis of three main variables, based on bone hardness and method of implantation. Source: (Personal Data)

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Table 5. Variable Analysis

ANGLE º			
	1mm cortical + 30pcf	No cortical + 20 pcf	p value
STENT	1.78 (0.78)	1.93 (1.01)	0.8392
IRIS 100	2.13 (0.78)*	1.36 (0.77)*	0.0051
X GUIDE	2.43 (0.99)	2.84 (0.76)	0.0601
APEX DEVIATION mm			
	1mm cortical + 30pcf	No cortical + 20 pcf	p value
STENT	0.80 (0.30)	0.68 (0.24)	0.1298
IRIS 100	1.32 (0.19)*	0.91 (0.38)*	0.0008
X GUIDE	0.80 (0.36)	0.88 (0.44)	0.5075
PLATFORM DEVIATION mm			
	1mm cortical + 30pcf	No cortical + 20 pcf	p value
STENT	0.69 (0.16)*	0.40 (0.19)*	<.0001
IRIS 100	0.90 (0.20)	0.87 (0.41)	0.6949
X GUIDE	0.77 (0.32)	0.73 (0.42)	0.2616

*Wilcoxon Sum Rank test;

Note. Wilcoxon statistical analysis of the three main surgical groups, based on the main variables. Source: (Personal Data)

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Table 6. Learning Curve Analysis

	1mm Cortical, 30 Pcf Bone				No Cortical, 20 Pcf Bone		
	Angle °				Angle °		
	1~10	11~20	p value		1~10	11~20	p value
Stent	1.86 (±0.93)	1.71 (±0.65)	0.9097	Stent	2.35 (±1.17)*	1.51 (±0.65)*	0.0452
Iris 100	2.67 (±0.71)*	1.59 (±0.36)*	0.0019	Iris 100	1.36 (±0.90)	1.35 (±0.67)	0.9012
X Guide	2.80 (±0.96)	2.07 (±0.93)	0.1859	X Guide	2.81 (±1.01)	2.88 (±0.45)	0.6776
	Apex mm				Apex mm		
	1~10	11~20	p value		1~10	11~20	p value
Stent	0.81 (±0.24)	0.85 (±0.37)	0.9097	Stent	0.76 (±0.23)	0.60 (±0.24)	0.5205
Iris 100	1.37 (±0.19)	1.28 (±0.18)	0.273	Iris 100	0.76 (±0.35)	1.06 (±0.37)	0.0757
X Guide	0.90 (±0.42)	0.71 (±0.29)	0.3447	X Guide	0.97 (±0.48)	0.79 (±0.40)	0.3075
	Platform mm				Platform mm		
	1~10	11~20	p value		1~10	11~20	p value
Stent	0.67 (±0.15)	0.71 (±0.17)	0.5708	Stent	0.37 (±0.16)	0.42 (±0.22)	0.6776
Iris 100	0.83 (±0.17)	0.98 (±0.21)	0.0539	Iris 100	0.75 (±0.42)	1.00 (±0.39)	0.1212
X Guide	0.86 (±0.38)	0.68 (±0.24)	0.162	X Guide	0.79 (±0.54)	0.67 (±0.26)	0.9097

Note: Technical progression of the operator after half of the sample were performed.

Source: (Personal Data)

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