Effect of different static surgical guided systems on the accuracy of implant position in esthetic zone

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A Thesis Submitted in Partial Fulfillment of the Requirements
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ผลของระบบการฝังรากเทียมโดยวิธีคอมพิวเตอร์ช่วยแบบสถิตต่อความแม่นยำของตำแหน่งรากฟันเทียมบริเวณสวยงาม

น.ส.อริสสา อำนวยโชติทวี

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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อริสสา อำนวยโชติทวี : ผลของระบบการฝังรากเทียมโดยวิธีคอมพิวเตอร์ช่วยแบบสถิตต่อความแม่นยำของตำแหน่งรากฟันเทียมบริเวณสวยงาม. (Effect of different static surgical guided systems on the accuracy of implant position in esthetic zone) อ.ที่ปรึกษาหลัก : รศ. ทพ. ดร.อาทิพันธุ์ พิมพ์ขาวขำ, อ.ที่ปรึกษาร่วม : รศ. ทพ.ประเวศ เสรีเชษฐพงษ์

วัตถุประสงค์ เพื่อศึกษาผลของระบบคอมพิวเตอร์ช่วยแบบสถิตในการฝังรากเทียมบริเวณฟันหน้าต่อความแม่นยำของการฝังรากเทียม

วิธีการทดลอง ทำการฝังรากเทียมบริเวณฟันตัดหน้าบนซี่กลางด้านขวาในแบบจำลองขากรรไกรบนโดยใช้วิธีคอมพิวเตอร์ช่วยแบบสถิตทั้งสองระบบที่แตกต่างกัน ได้แก่ ระบบสตรอแมนน์ (Straumann®) และระบบแอสตร้าเทค (Astra Tech®) รากเทียมที่ใช้ทดลอง มีขนาดเส้นผ่านศูนย์กลาง 3.3 มิลลิเมตร ยาว 10 มิลลิเมตร และเส้นผ่านศูนย์กลาง 3.6 มิลลิเมตร ยาว 11 มิลลิเมตร สำหรับระบบที่หนึ่งและสองตามลำดับ การกรอกระดูกเพื่อเตรียมสำหรับการฝังรากเทียมจะถูกกรอตามวิธีการและขั้นตอนตามคำแนะนำของผู้ผลิต หลังจากทำการฝังรากเทียมแล้วเสร็จ จึงทำการทดสอบความแม่นยำในการฝังรากเทียม โดยการเปรียบเทียบตำแหน่งของรากเทียมที่วางแผนกับตำแหน่งของรากเทียมจริงที่ฝังแล้วเสร็จ ข้อมูลของทั้งสองกลุ่มจะถูกนำมาวิเคราะห์โดยการทดสอบสถิติด้วยวิธีแมน-วิทนีย์ยู เพื่อหาความแตกต่างของตัวแปรอิสระสองตัว (ระบบคอมพิวเตอร์ช่วยแบบสถิตทั้งสองแบบ) ที่ระดับนัยสำคัญ 0.05

ผลการทดลอง พบว่าค่าความคลาดเคลื่อนเชิงสามมิติที่ขอบบนของรากฟันเทียมระหว่างสองระบบมีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติ ($P < 0.05$) แต่ไม่พบความแตกต่างอย่างมีนัยสำคัญทางสถิติสำหรับค่าความคลาดเคลื่อนในแนวระนาบตั้งและแนวระนาบนอนที่ขอบบนของรากฟันเทียม รวมทั้งมุมเบี่ยงเบนของแนวแกนรากฟันเทียม

สรุป จากการศึกษาพบว่าระบบของคอมพิวเตอร์ช่วยแบบสถิตและความแม่นยำในการฝังรากฟันเทียมมีปฏิสัมพันธ์ต่อกัน เมื่อพิจารณาความค่าความคลาดเคลื่อนเชิงสามมิติบริเวณส่วนหัวของรากฟันเทียม แต่อย่างไรก็ตามการนำระบบคอมพิวเตอร์ช่วยแบบสถิตมาใช้ในการฝังรากเทียม สามารถช่วยเพิ่มความแม่นยำในการฝังรากเทียมในทุกระบบ

สาขาวิชา	ทันตกรรมบูรณะเพื่อความสวยงาม และทันตกรรมรากเทียม	ลายมือชื่อนิสิต ....
ปีการศึกษา	2563	ลายมือชื่อ อ.ที่ปรึกษาหลัก ....
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KEYWORD: Dental Implants, Static computer guided surgery, Accuracy

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Objectives To evaluate the effect of different surgical guided systems on the accuracy of single implant placement in the anterior zone.

Methods Twenty operators were divided into two groups by the system they performed in the experiment (Straumann Guided Surgery®; SG and Astra Tech Guide Surgery®; AG). One operator placed one implant on the right central incisor using a computer-guided template that had been planned with 3Shape Implant Studio® program. After the implant installation process was completed, all models were scanned and determined the placed implant position. The amount of coronal, horizontal, vertical, and angular deviation of planned and placed implant positions was statistically analyzed using the Mann-Whitney U test to investigate the influence of two different surgical guided systems.

Results The different guided surgery systems had no statistically significant effect on the accuracy of a single implant position except for the 3D coronal deviation. Moreover, the sleeve-on-drill concept resulted in a significantly greater coronal error when compared to the sleeve-in-sleeve concept ($P < 0.05$).

Conclusion Within the limitations of this study, the use of a step-by-step computer-guided surgery assists the operator to place an implant with reliable accuracy in any system. However, the different systems with different concepts had effects on the 3D deviation at implant platform.

Field of Study: Esthetic Restorative and Implant Dentistry

Academic Year: 2020

Student's Signature ....

Advisor's Signature ....

Co-advisor's Signature ....

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Arissa Amnuaychottawe

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Background and rationale

Nowadays, dental implants are one of the best alternative options for the replacement of missing teeth. It is widely accepted that dental implant therapy is a predictable treatment procedure for tooth substitution. The effectiveness of dental implant placement depends on the osseointegration, the function, and esthetic of the final restorations (1-3). The recent concept of prosthetic-driven implant placement has developed to enhance the esthetic result of the final prosthesis with proper mechanical and biological conditions (4).

Implant-supported restoration in the anterior esthetic zone is one of the most challenging procedures since the major consequence following an anterior tooth extraction is the resorption of the alveolar bone which compromises gingival tissue and esthetic outcome. The primary goal of implant therapy is the complete reconstruction of the tooth and gingival tissue. The accomplishment of an esthetic result of the implant restoration is contributed from several factors, including patient selection and smile line, tooth position, root position of the adjacent teeth, gingival biotype, tooth shape, the anatomy of bone, and dental implant position (5).

To achieve the proper implant position, the philosophy of three-dimensional (3D) implant placement has become a necessity. The objective of this concept is to highlight the risk of potential complications if implants are not correctly positioned in relation to the adjacent natural teeth. Chen and Buser Chen and Buser (6) defined the comfort and danger zones in three directions; mesiodistally, coronoapically, and orofacially (Figure 1).

In the past, the conventional method for implant placement, the freehand approach, is commonly used; however, in recent year, customized surgical templates have risen in popularity for transferring the virtual plan to the clinical situation since dental implant installation through the surgical guide allows a surpassing accuracy in comparison with freehand insertion or freehand final drilling (7).

Computer-aided implant surgery (CAIS) is the new technology using cone-beam computed tomography (CBCT) and computer-aided design/computer-assisted manufacture (CAD/CAM). Several advantages of this approach have been reported in previous studies. The benefit of the CAIS is to lessen postoperative discomfort as a consequence of flapless surgery. Moreover, the CAIS allows a shorten surgical time, decreases the crestal bone alteration, reduces the inflammation and bleeding (8-10). However, the disadvantages of this technique have also been reported. The important one is the limited access and visibility resulting from the flapless surgery approach or unfitness of the surgical template. Moreover, some authors revealed several complications occurred when a computer-aided implant surgery is used (11).

Definition of the accuracy in guided implant therapy is paralleling the virtual implant position in the planning software with the actual implant position in the patient's mouth (12). Documentation of the accuracy of computer-aided implant surgery is insufficient, and numerous factors are contributing to the accuracy. The possible causes of decreasing the accuracy of implant placement are errors that may arise during every step, for example, image capturing, data processing, and surgical template processing. Moreover, the position and the movement of the template during drilling, type of surgical template, flap approach, and operator’s experience also correlate to the accuracy (13-19). However, there are limited documents available reporting the effect of the different systems of static surgical guided surgery on the accuracy of computer-aided implant surgery. Thus, this study aimed to evaluate the effect of different static computer-guided systems on the accuracy of implant position.

Review literature

1. Three-dimensional (3D) implant placement in esthetic zone

The esthetic considerations are more critical than functional ones particularly in the situation involving a single anterior implant restoration because an axial loading is not as much as it is with posterior implant restoration. Implant position is significant to the final result and needs to be considered in all three dimensions (5).

Mesio-distal placement

In a mesiodistal dimension, implants should be placed 1.5 to 2 mm from adjacent teeth. The too-close positioning of implants to the adjacent tooth can lead to reduced interdental papilla height due to the resorption of interproximal bone and inadequate space for the soft tissues to develop. When the mesiodistal malposition of the implant is extreme and varies up to 2 to 3 mm from the ideal prosthetic position, it may induce a significant and permanent loss of hard and soft tissue support with extremely adverse esthetic outcomes (5, 6).

Apico-coronal placement

Apicocoronal positioning appears to be the most critical aspect. The implant should be placed 3 to 4 mm apical to the gingival margin of the contralateral tooth to provide the proper emergence profile of final restoration.

Errors in apico-coronal implant placement can have serious complications. An implant placed too coronally will not allow an adequate transitional zone from the implant shoulder to the restoration. The restoration will look short compared to the contralateral tooth. Besides, the metal implant shoulder can be visible and lead to an unpleasant esthetic outcome. On the other hand, an implant placement too apically produces an unnecessary amount of bone loss which results in an undesirable soft tissue contour. Also, this situation can cause persistent inflammation of the peri-implant mucosa due to the difficulty to maintain optimum plaque control (5, 6, 20).

Facio-lingual placement

Placement in this aspect will vary depending on the mechanism of retention of final restoration (screw-retained versus cement-retained). Normally, the facial boundary of the implant shoulder is about 1.5 to 2 mm palatally to the point of emergence of the adjacent teeth. An insufficient amount of alveolar crest width may require bone augmentation before placement of an implant to avoid the undesirable consequences. Implants placed too palatal will often lead to a ridge-lap design of the implant crown and complicate the development of hygienic contours with subsequent long-term implications for peri-implant tissue. Moreover, increased dimensional of the crown on the palatal side may impact the tongue space. Generally, Implants are often mistakenly placed too facial. This error results in excessive facial bone resorption (5, 6).

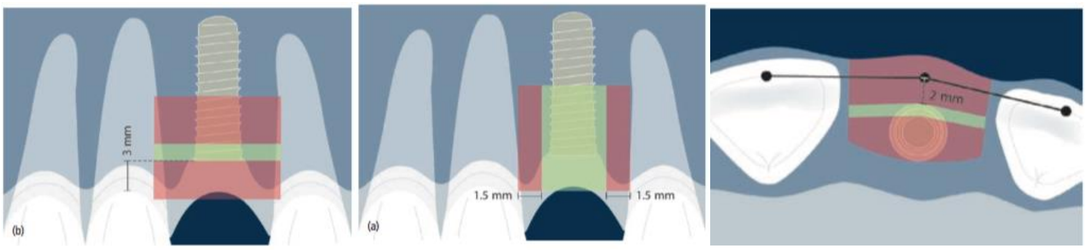


Figure 1 *The concept of comfort and danger zone for the implant position (21)*

2. Prevention of implant malposition

Implant malposition can be prevented by appropriate implant planning procedures. The correct three-dimensional position of implant placement is primarily influenced by the surgeon and the selection of a proper implant type. The diameter of the implant platform and the implant body is the most important. Oversized implants with a wide platform should be avoided in the esthetic region (6).

The insertion of implants in a correct three-dimensional position requires both surgical skill and clinical experience. The surgeon must possess the clinical skills and the competence to provide a surgical implant procedure with precision (6).

To accomplish a correct implant position, the use of a surgical guided template fabricated from an ideal wax-up can be helpful; however, the new trend of computer-assisted implant surgery has become popular among implant surgeons. These computer-assisted techniques can be divided into static surgical guided systems and dynamic navigation systems. Static surgical guided systems use a surgical template produced from a virtual plan of the implant position using computer software. A limitation of this technique is that the location of the implants cannot be modified unless the drilling is operated by a freehand approach (6).

3. Static computer-assisted implant surgery (static CAIS)

In the last decade, pre-operative three-dimensional planning has gained popularity. Computer-guided (static) surgery and computer-navigated (dynamic) surgery have been offered to transfer virtual planning to the clinical field. For a static computer-guided surgery, a surgical template is used to transfer the planned implant position to the surgical site. These guides are produced by computer-aided design/computer-assisted manufacture (CAD/CAM) technologies (12, 21).

The fabrication of a computer-generated guided stent begins with taking a cone-beam computed tomography (CBCT) with a radiographic template imitating the preoperative prosthetic design in the mouth as an imaging guide. Digital Imaging and Communications in Medicine (DICOM) files and CBCT images will be transferred to the implant planning software which is used to evaluate the bony structure in relation to the position of the teeth. From this information, the position and size of the dental implants were designed. After the digital plan is completed, the data will be transferred to a milling center to fabricate the stereolithographic surgical template using a CAD/CAM procedure. The surgeon will evaluate and adjust the surgical guide template to ensure proper seating on the cast and patient’s mouth.

The advantages of using a static CAIS include it provides an accurate implant placement and shorter surgical time. Also, in general, the use of static stents requires less invasive surgery which results in less patient discomfort and more patient satisfaction (22). Moreover, the static CAIS offers the predictability of the prosthetic outcome and allows for the production of the prosthesis before the surgery which is convenient for the immediate loading protocols (23).

However, the limitations of static CAIS are that the static guidance with surgical templates does not allow any changes at the time of surgery, and the deviations are observed between planning and post-operative outcome (12). The use of the surgical guide stent also limits access to irrigate the drill during osteotomy procedure with the potential for increased heat production. Furthermore, the use of static guides is impractical in the situation of limited mouth opening and when the implant is required at the second molar regions (22).

3.1 System of static CAIS

There are several static CAIS systems in the dental market. Each system has its component, concept, and treatment protocol. Some systems use a removable sleeve that is fixed to one template or inserted on the drill. Others apply a series of the template with increasing diameter sleeves. Some systems have indication lines on the drills, while others have drill stops to regulate the depth of drilling. After the implant osteotomy was completed, some systems allow the installation of the implant through the surgical guide, whereas other systems need to remove the template before implant placement (12).

Sleeve-in-Sleeve concept

This concept composes of the cylinder of the drill handle or the drill guide, and the metal sleeve fixed to the surgical template. The osteotomy preparation is performed by inserting the drill into the drill handle which is inserted into the metal sleeve on the surgical template. Some system has the depth marking on the drill and should be measured while drilling, whereas some system has the drill handle with different height and can control the drilling depth by itself. The implant system with this concept includes Straumann® guided surgery, Biohorizons® guided surgery, Zimmer® guided surgery, and Neoss® guided surgery.

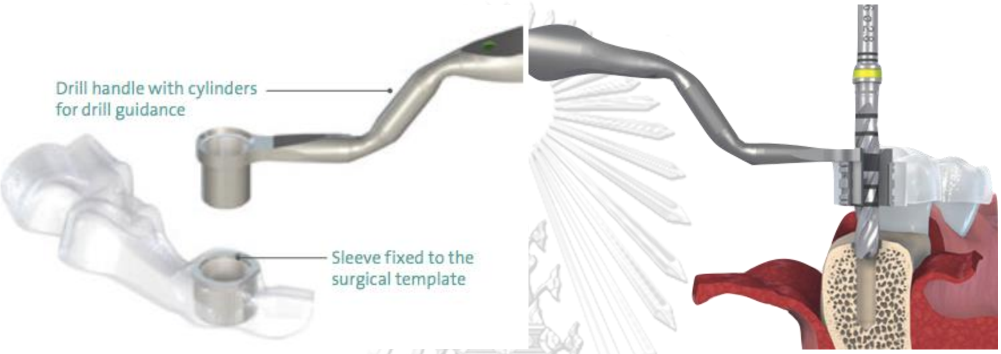


***Figure* 2** *The component of Straumann® guided system with the sleeve-in-sleeve concept*

Sleeve-on-Drill concept

This concept composes of the guide sleeve inserted into the drill. The positions of the guide sleeves are adapted to the planned implant length. Different osteotomy depths can be facilitated by one drill length. The guide sleeve position will be generated by the planning software according to the planned implant length and the manual modifications are not feasible. The implant system with this concept includes Astra Tech® guided surgery.

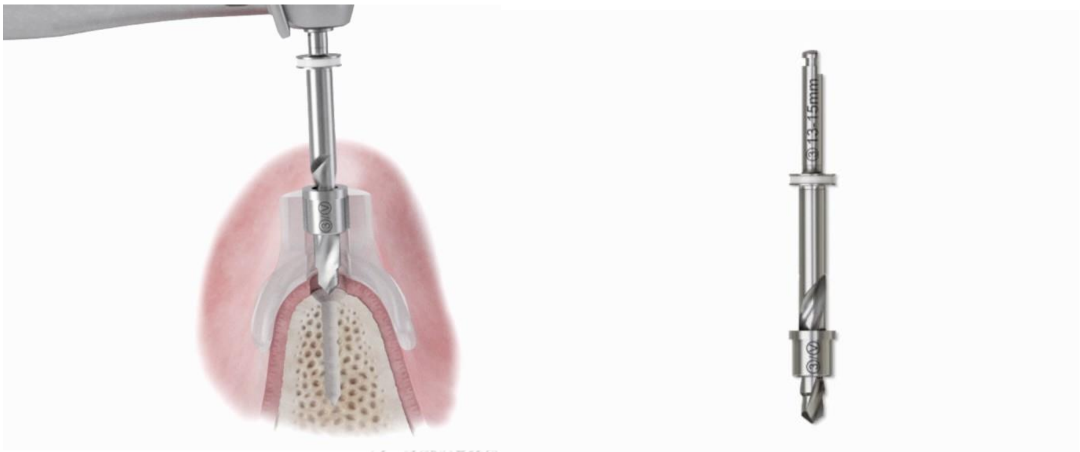


***Figure* 3** *The component of Astra Tech® guided system with the sleeve-on-drill concept*

3.2 Accuracy of static CAIS system

Several reviews of the scientific literature have been performed to evaluate the accuracy of stereolithographic surgical templates.

Tahmaseb and colleagues (24) assessed the literature on the accuracy of static computer-assisted implant surgery, a total of 40 studies were included in their study. A total of 2,238 implants that had been placed using a computer-guided surgery in 471 patients were collected for review. Meta-regression analysis was performed to summarize the accuracy of all studies. They summarized that the mean error at the entry point measured at the center of the implant was 1.3 mm, the mean error of apical position was 1.4 mm, the average angular deviation was 3.5 degrees, the average error in height at the entry point was 0.2 mm, and the average error in height at the apex was 0.5 mm.

Van Assche et al. (4) conducted 19 studies that focused on the accuracy of static CAIS and summarized the overall accuracy. They reported a mean error of 1.0 mm at the entry point, 1.4 mm at the apex, and a mean angular deviation of 4.2 degrees.

Zhou and others (13) systematically reviewed 14 clinical studies with a total of 1,513 implants. Meta-regression analysis presented a mean deviation of 1.25 mm at the entry point, 1.57 mm at the apex, and 4.1 degrees in angle.

Deeb and others studied the accuracy of single implant placement at the maxillary right central incisor using a static CAIS system (3shape Implant Studio). They found that the mean coronal deviation in mesiodistal direction between planned implants and placed implants was 0.28 mm and the deviation in the buccolingual direction was 0.49 mm. The mean angular deviation was 0.84 degrees in the mesiodistal direction and was 3.37 degrees in the buccolingual direction (25).

Valente and colleagues (23) studied the accuracy of implant placement using a static CAIS system (Simplant®, CSI Materialise) and found that the mean deviations of 89 implants placed in 28 patients were 1.4 ± 1.3 mm at the entry point, 1.6 ± 1.2 mm at the apex, 1.0 ± 1.0 mm for depth deviation and 7.9 ± 4.7 degrees for angle deviation.

Farley and others (26) compared the accuracy of 20 implants placed in 10 patients using static CAIS system (Implant Master software, iDent Imaging) and conventional method. The result showed that implants placed with CAD/CAM guides were closer to the planned positions than a conventional guide in all parameters examined. They reported the deviation of CAD/CAM guides of 1.45 ± 0.06 mm at the entry point, 1.82 ± 0.60 mm at the apex, and 3.68 ± 2.19 degrees for angle deviation.

Schneider and colleagues (27) calculated the mean deviation from 8 articles that reached the inclusion criteria. They reported a mean deviation of 1.07 mm at the implant platform and 1.63 mm at the implant apex.

D'haese and colleagues (28) revealed the mean coronal deviations of 1.04 mm (0.20 - 1.45 mm), mean apical deviations of 1.64 mm (0.95 - 2.99 mm), and mean angular deviation of 3.54 degrees (0.17° - 7.90°).

Table 1 The overall accuracy revealed from previous studies.

Study	Implant (N)	Coronal deviation (mm)	Apex deviation (mm)	Depth deviation (mm)	Angular deviation (degree)
Tahmaseb et al.	2,238	1.3	1.4	0.2 (entry) 0.5 (apex)	3.5
Van Assche et al.	1,688	1.0	1.4	-	4.2
Zhou et al.	1,513	1.25	1.57	0.64 (entry) 1.24 (apex)	4.1
Deeb et al.	10	0.28 (M-D) 0.49 (B-L)	-	-	0.84 (M-D) 3.37 (B-L)
Valente et al.	89	1.4 ±1.3	1.6 ±1.2	1.0 ±1.0	7.9 ± 4.7
Faley et al.	20	1.45 ± 0.06	1.82 ± 0.60	-	3.68 ± 2.19
Schneider et al.	-	1.07	1.63	-	-
D'haese et al.	-	1.04	1.64	-	3.54

3.3 Factors that influence the accuracy of static CAIS system

Effect of Age factors

A systematic review by Zhou et al. (13) demonstrated the data on patient's ages from 11 studies. They categorized three age groups; Group 1 composed of patients with 40-50 years old from four studies (n=493 implants); Group 2 consisted of 50-60 years old patient conducted from five studies (n=648 implants); and Group 3 was patients with 60 or older from two studies (n=104 implants). The mean platform deviation for the three age groups was 1.21 mm, 1.23 mm, and 1.03 mm, respectively. The mean deviation at the apex was 1.47 mm for the 40- to 50-year group, 1.64 mm for the 50- to 60-year group, and 1.27 mm for the 60 years or older group, and the mean error of angle was 4.15° degrees for 40 to 50 age group, 4.32° degrees for 50 to 60 age group and 4.43° degrees for the older age group. They concluded that no significant difference was found between age groups for angular deviation, deviation at the entry point, and deviation at the apex.

Effect of Guide Position (maxilla/mandible)

Behneke et al. (7) studied a total of 132 implants placed in 52 partially edentulous patients using static guide stents. The result showed a significant difference between maxilla and mandible for the linear deviation at the apex, but not for the linear deviation at the implant platform and the error angle. Besides, they discovered a greater amount of maxillary deviations between the planned and placed implant positions. This may be a result of the lower bone density of the maxilla than the compact mandibular bone.

From the meta-analysis study of Zhou et al. (13), Four studies with a total of 274 implants were included for criticizing the accuracy of guided surgery executed on the maxilla or mandible. They summarized that there are statistically significant differences in the mean error of angle between the implants that placed in maxillary and mandible, whereas no statistical significance was found between the maxilla and mandible when considered the coronal accuracy and the apical error.

Effect of Flap Approach (Open flap/Flapless)

According to a systematic review by Zhou and others (13), A total of 190 implants from three studies compared the effect of flap approach on the accuracy of guided surgery. Guided surgery with a flapless approach indicated a statistically significantly greater reduction in angle deviation and coronal deviation. For the apical deviation, the outcome revealed no statistically significant difference between flap and flapless groups; nevertheless, the global analysis reported that the open-flap group had significantly less accuracy than the flapless group.

Influence of Guide Type (Totally Guide vs. Partially Guide)

According to a systematic review by Zhou et al. (13), there are only two studies that evaluated 215 implants reported data comparison of totally and partially guided surgery protocols. The results of the prospective study reported that the angular deviation was significantly greater in the partially guided surgery group, whereas the retrospective study showed no statistical difference. Moreover, the meta-analysis showed statistically greater accuracy in the fully guided surgery group than the partially guided surgery group when angle deviation is considered. For the deviation at the entry point and apex, the partially guided surgery group showed significantly greater error than the fully guided surgery group.

Effect of the Guide Fixation

Zhou et al. (13) measured the influence of guide fixation on the accuracy. A total of 123 implants from two retrospective studies were recruited. Based on the use of the fixation screw, the significant differences were demonstrated only in the error of the angle parameter. However, no statistical differences were observed between fixed and unfixed guides for coronal deviation and apical deviation parameters.

Effect of mechanical components of a surgical template (Metal sleeve/drill key)

Schneider and colleagues (29) compared the tolerance of surgical instruments of the surgical guided stents manufactured by the 3D printing method without metal sleeves to conventional templates with metal sleeves. They experimented by recording the lateral movement of drill tips, which is caused by tolerance between the sleeve and drill key and between the drill key and the drill. From the results of this study, they concluded that the lateral movements of the drill were significantly decreased by using a smaller sleeve diameter template, a shorter drill, and a higher drill key. According to the study of Van Assche and Quirynen (30), they also found that increasing the height of the drill key will minimize inaccuracy.

In another recent experimental study, El Kholy and others (31) measured the impact of drilling distance, guided sleeve height, and guided key height on the accuracy of static CAIS. They found that the less drilling distance was, the more accuracy we observed. Reducing the drill distance under the sleeve can be made by using shorter sleeve height or shorter implants.

Koop and colleagues (32) tested the degree of deviation during the drilling procedure. They stated that the apical and coronal deviation enlarged if the distance of the sleeve from the bone was increased. They also reported that the apical deviation, coronal deviation, and angular deviation reduced with enhancing sleeve heights.

Effect of Operator’s skill (experienced/inexperienced)

There are multiple scientific reports have been examined the accuracy of stereolithographic surgical templates. Hinckfuss et al. (15) measured the effect of surgical template design, operator’s level of experience, and size of the edentulous area on the accuracy. They concluded that the surgeon’s experience statistically significantly affects the accuracy of implant placement; furthermore, they found that an error angle in the bucco-lingual aspect was smaller in the experienced group. These results coincide with those of a study conducted by Cushen and Turkilmaz (17). These authors determined the effect of surgeon’s experience on the accuracy of implant position with bone support stereolithographic surgical template and reported a statistically significant difference between surgeons with and without experience groups for angular and horizontal deviation at implant platform and apex.

On the other hand, Cassetta and Bellardini (18) analyzed the accuracy of implant position performed by experienced and inexperienced surgeons. The results revealed a statistically significant difference when considered the positioning error, whereas no statistically significant differences were found when considered the coronal, apical, and angular deviations.

The study of Rungcharassaeng et al. (19) which had evaluated the effect of the operator’s experience on the accuracy of implant placement using a computer-guided surgery protocol. This study was executed by ten experienced and ten inexperienced surgeons. They reported that there were no significant differences in the angular and linear deviations between the two groups (P>.01); nevertheless, they found that the amount of depth deviation at the implant platform and the implant apex was about twice in the inexperienced operators compared to experienced operators.

According to the study of Park and others (33) which investigated the accuracy of a surgical template regarding the different levels of operator experience and site of implant placement. Implants were placed in a model with and without the surgical guide by two experienced surgeons and two inexperienced surgeons. They concluded that no significant differences were found in all deviation parameters between experienced and inexperienced surgeons when using the surgical guide surgery.

4. Accuracy analysis

There are several methods to assess the preciseness of 3D computer-guided implant surgery. The position of the placed implant can be accomplished by using postoperative CT images after implant surgery was done or indirectly valuating from the scan abutment attached to the inserted implants. Accuracy of implant placement is obtained by determining the quantity of displacement using reference points to quantify the degree of displacement between the planned and placed position (3).

4.1 Pre- and Post-Operative CT Comparison

To measure the error between the actual and planned position of implants, two pieces of three-dimensional images need to be superimposed on an identical plane (Figure 4). In partial edentulous cases, there is a necessity to mark the reference points of both preoperative and postoperative CT data. For the complete edentulous patients, specific reference markers are necessary for superimposition.

According to the review by Pyo and colleagues (3), the benefit of this method is that it can perform immediately after implant positioning; nonetheless, the titanium implant established the radiographic artifacts and caused unclearness of the radiographic outline of the implant, which results in the overall expansion of the implant contour.

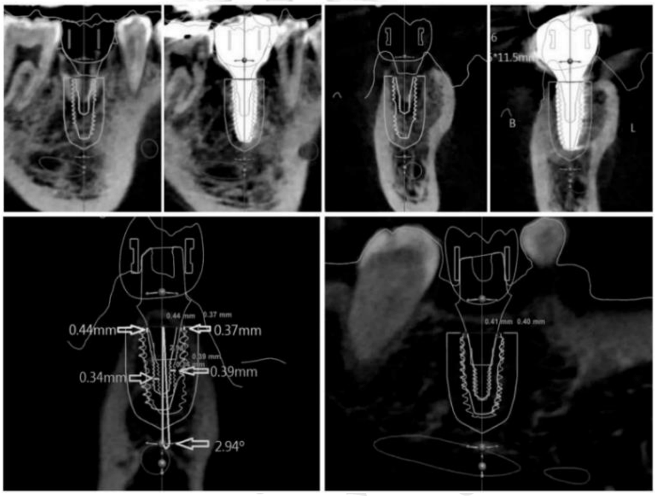


***Figure* 4** *The displacement measurement using the superimposition process of the planned position and the placed position* (3).

4.2 Pre- and Post-Operative Model Comparison

This method measures the implant position by taking an impression directly or by scanning through the scan body that is attached to the implant instantly after the implant surgery. Thus, the patient does not need to take an additional CT radiograph after the implant surgery was done. To apply this process, the impression coping or scan body should be correctly connected to the implant because it may cause a critical error in the implant position (3).

An implant scan body can be used to determine the placed position with an intraoral scanner. This method defines the position of the actual implant by paring the scan body outline and the virtual connecting of the implant fixture. When the scan body is located, the implant fixture position can be explored by the data in the library image (Figure 5) (3).

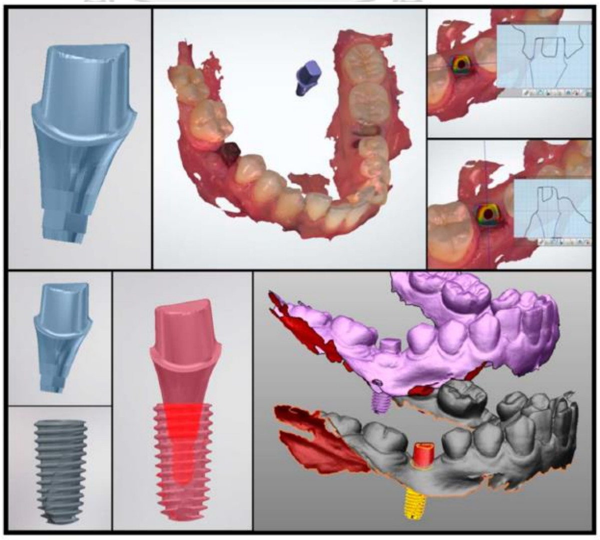


***Figure* 5** *Accuracy analysis using model comparison method* (3)

4.3 Displacement Measurement

According to the previous systematic reviews, standard parameters were used in general (Figure 6):

(1) Linear deviations at the implant platform (mm)

(2) Linear deviations at the implant apex (mm)

(3) Angular deviation (degree)

(4) Vertical deviation in height at the implant platform (mm)

(5) Vertical deviation in height at the implant apex (mm)

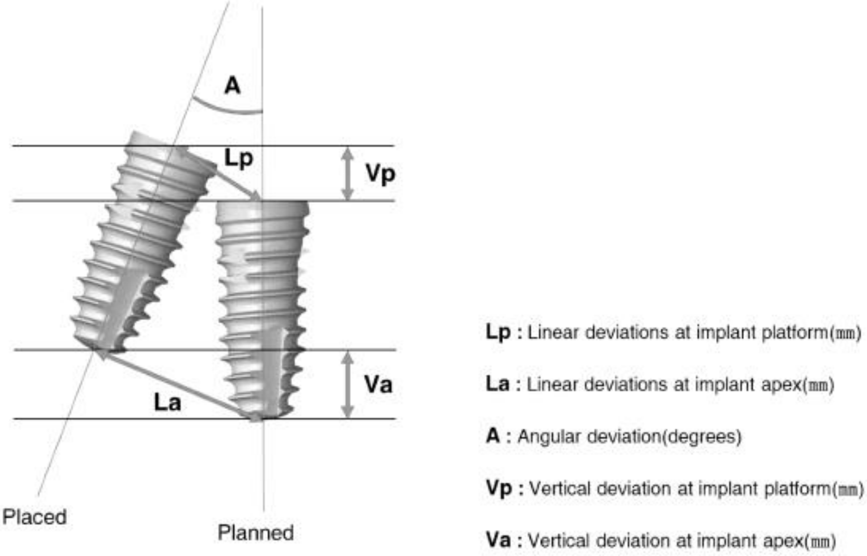


***Figure* 6** *The parameters used to displacement measuring in general* (3)

For the deviations at the entry point and apex, the most common method is to measure the deviations between the planned and actual position as the distance, while some studies reported as two individual vectors with a horizontal and vertical distance. About the error angle, previous studies mostly reported a degree of deviation. For the deviation in height or depth deviation, there was often reported as a negative number if the implant was not inserted as deeply as the planned position.

Research questions

Does the different system of surgical guide affect the accuracy of implant position in a single space missing in the anterior region?

Research objectives

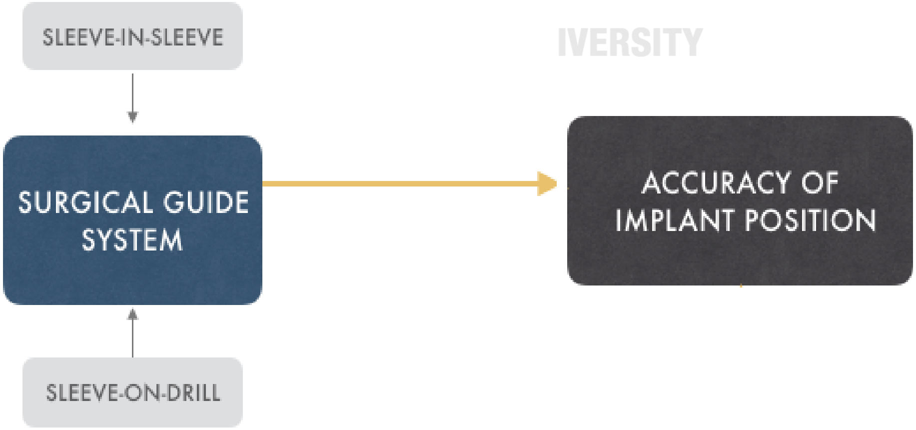
To evaluate the effect of different surgical guide systems on the accuracy of single implant placement using a step-by-step computer guide surgery.

Statement of hypothesis

H_0: No significant difference would be found between the different static surgical guided systems in the accuracy of inserted implants using a static computer-guided surgery.

H_1: The significant difference would be found between the different static surgical guided systems in the accuracy of inserted implants using a static computer-guided surgery.

Conceptual framework

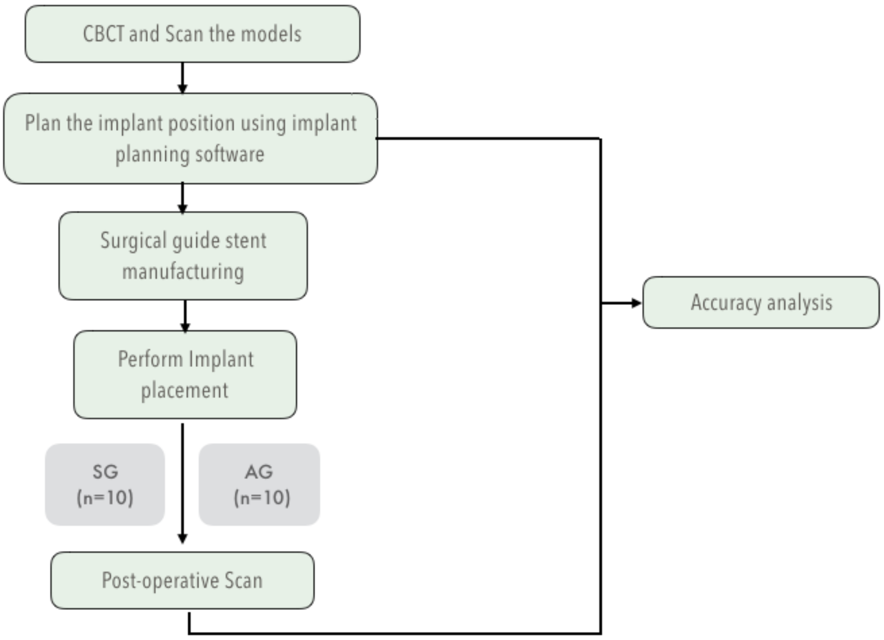


Type of study

Experimental study

Research methodology

1. Diagram of the study design



2. Materials

Polyurethane models

Maxillary bony dentate models of custom polyurethane models with a single missing space at the right central incisor were used for the study models. D3 bone type was used for representing the anterior maxillary region. All models had no bone defect such as bone dehiscence, fenestration, and vertical or horizontal bone loss (Figure 7).

***Figure* 7** *The maxillary model with a single space missing at the upper right central incisor.*

Implants and static guided systems

Two implant systems with different static guided concepts were used in this study: (1) Straumann Guided Surgery® (SG; Straumann, Switzerland) with Bone Level Taper implant 3.3, 10 mm REF 021.3310; and (2) Astra Tech Guided Surgery® EV (AG; ASTRA TECH Implant System®, Sweden) with OsseoSpeed™ EV conical implant 3.6, 11 mm REF 25224. The implants were placed using the drilling technique and insertion protocols following each system.

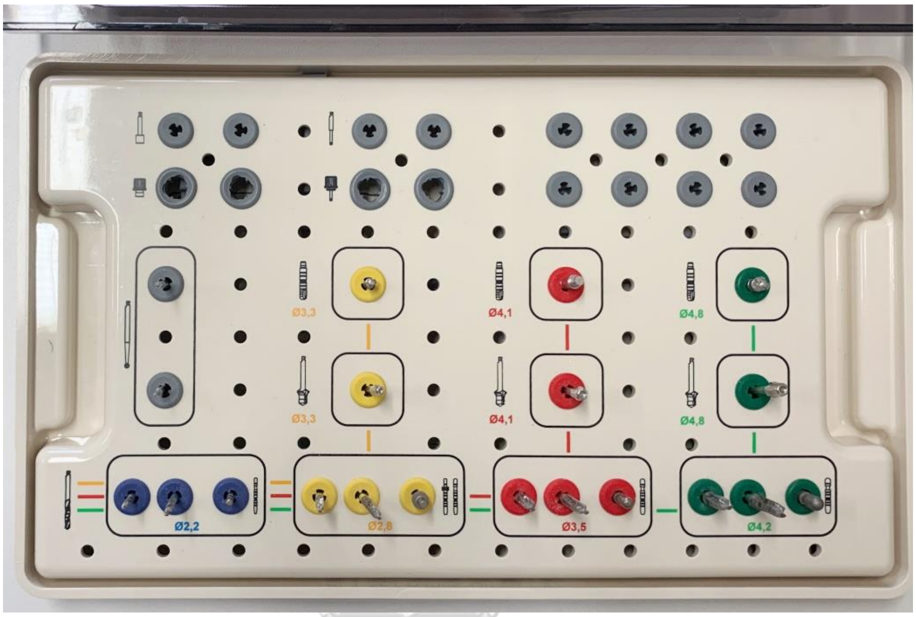


Figure *8 Straumann Guided Surgery*$^{®}$ *(SG) cassette used in this study.*

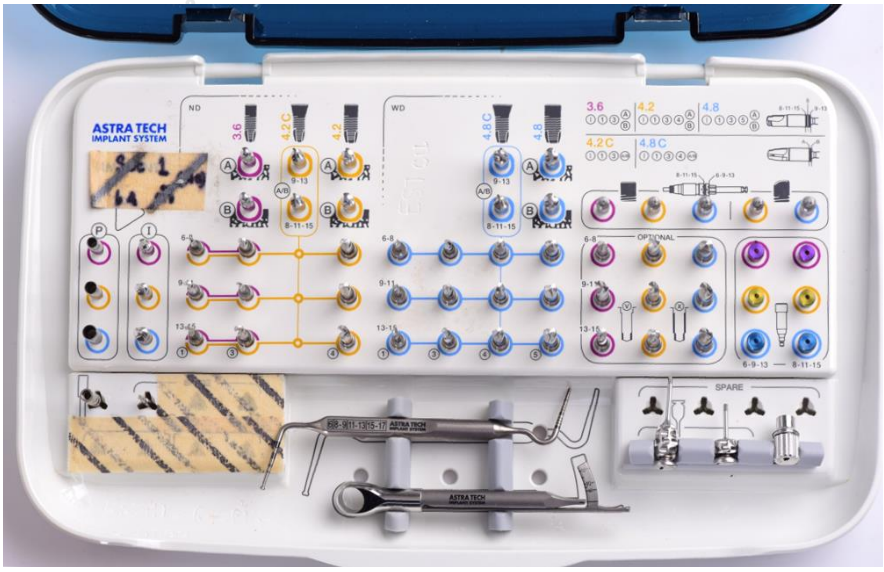


Figure *9 Astra Tech Guided Surgery*$^{®}$ *EV (AG) cassette used in this study.*

Surgical guided template

After dental implants were completely planned, the digital drill guides with a sleeve were designed, and this information was sent to a dental laboratory for surgical template fabrication.

3. Methods

3.1 Sample size calculation

The sample size was calculated using means and standard deviations obtained from a previous study (19). The calculation was performed using *G*Power version 3.1.9.3 Program* based on 5% Type I Error, 80% study power. The sample size from the calculation was ten subjects in each group.

Twenty experienced surgeons were recruited from the dentists who graduated from Esthetic Restorative and Implant Dentistry Program and had placed more than twenty implants with no less than three years of experience. A total of twenty participants were randomly divided into two groups by the system they performed in the experiment. Ten operators placed Straumann® Bone Level Taper implant 3.3, 10 mm with Straumann Guided Surgery® (SG). Another ten operators placed OsseoSpeed™ EV conical implant 3.6, 11 mm with Astra Tech Guided Surgery® (AG).

3.2 Intervention

3.2.1 Model preparation and surgery planning

All maxillary bony dentate models were scanned by standard cone-beam computed tomography (CBCT) with a 3D I-CAD machine (Imaging Science International LLC. Hatfield, PA, USA), and were scanned by 3Shape Trios® intraoral scanner (3shape A/S, Copenhagen, Denmark).

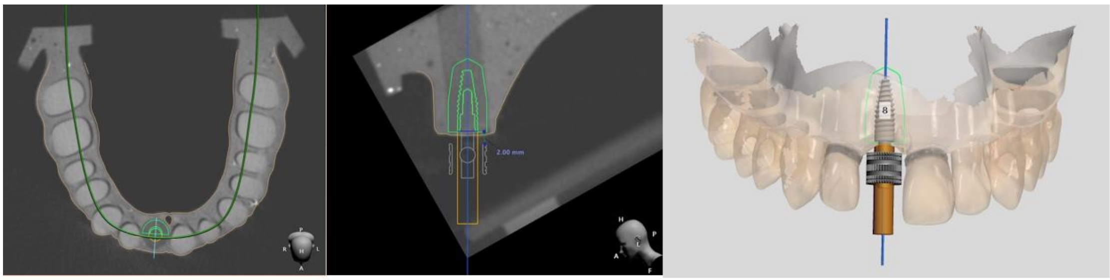


***Figure* 10** *Planning of implant position with 3Shape Implant Studio® software*

All scan data was transferred to the 3Shape Implant Studio® program (3shape A/S, Copenhagen, Denmark) which was used to designate the position of the virtual implant. The planned implants were Straumann® Bone Level Taper 3.3, 10 mm (Straumann®, Switzerland) and the OsseoSpeed™ EV conical implant 3.6, 11 mm (Astra Tech Implant System™, Sweden).

The surgical drilling protocols of the SG group were created with 2 mm sleeve height which is the distance below the sleeve to the implant platform, 3 mm key length (the height of the drill key), and the removable metal sleeve was 5 mm in length (Figure 12).

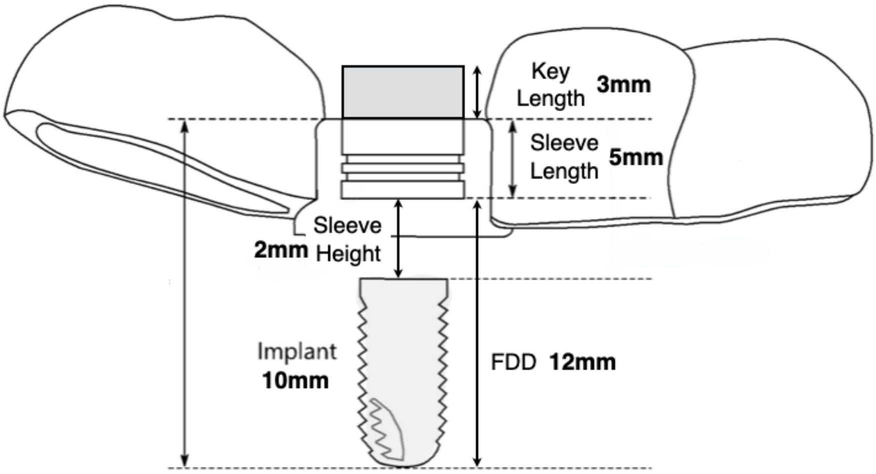


***Figure* 11** *Drilling protocol of Straumann Guided Surgery® (SG) used in this study.*

The surgical drilling protocols of the AG group were automatically produced corresponding to the implant length and unable to modify. For the implant length of 11 mm, the prolongation, which is the distance from the inferior border of the metal sleeve to the implant shoulder, was 6 mm. The sleeves, fixed on the drill and the removable one, were 4 mm in height (Figure 13).

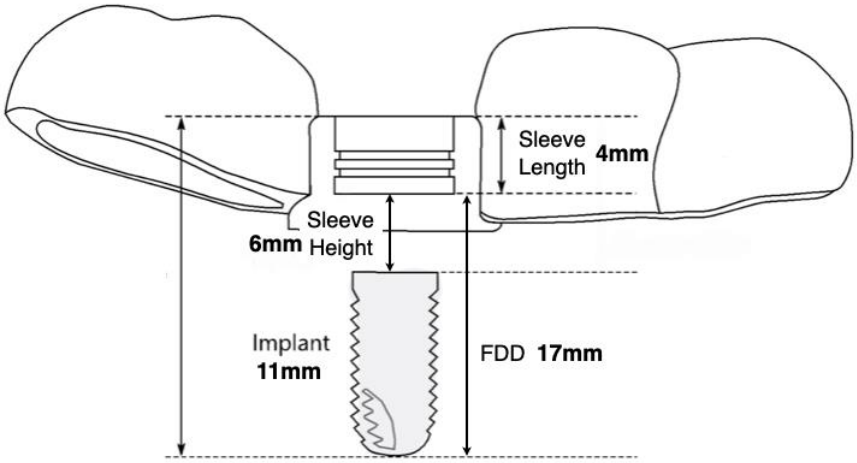


Figure 12 *Drilling protocol of Astra Tech Guided Surgery® (AG) used in this study.*

The optimal position of the implant was adjusted manually by one dentist. After finished the plan, the digital drill guides with a sleeve were designed, and all the information was sent to a dental laboratory for surgical template fabrication.

3.2.2 Drilling procedure

Before the surgical procedure starts, the fit of each surgical guide was verified via inspection windows and was adjusted manually. Fully guided placement systems were used in the present study (Figure 14). All maxillary models were fixed into a dental manikin head to simulate the clinical situation. One surgeon performed one implant placement. A step-by-step computer-guided surgery was explained to each operator. The osteotomy site preparation was operated as the manufacturer’s recommendation for each implant system. An In-and-out motion was done during drilling until the depth of the drill reached the reference line depending on systems.

***Figure* 13** *The surgical guided template fabricated from the planned implant*

Drilling sequences for Straumann® BLT 3.3, 10 mm REF 021.3310 (Straumann®, Switzerland)

- Pilot drill with 2.2 mm diameter (REF 026.0001) was used for the initial bone preparation inserted up to 10 mm depth with a maximum of 800 rpm.
- BLT drill with 2.8 mm diameter (REF 026.2200) was inserted up to 10 mm depth with a maximum of 800 rpm.
- Profile drill with 3.3 mm diameter (REF 026.0003) was used to create the shape of the coronal part with a maximum of 800 rpm.

Drilling sequences for OsseoSpeed™ EV 3.6, 11 mm REF 25224 (AstraTech Implant System™, Sweden)

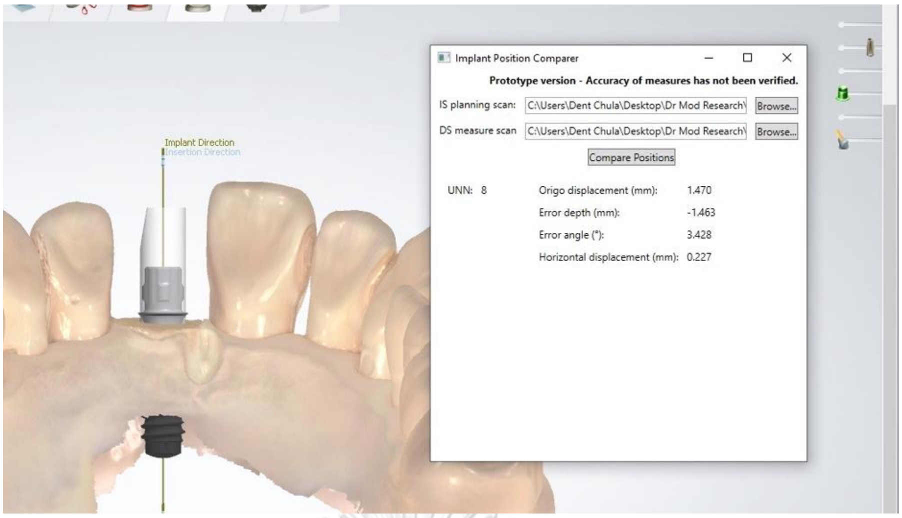
- Twist drill EV with 1.9 mm diameter (REF 25163) was used for the initial bone preparation inserted up to 11 mm depth with a maximum of 800 rpm.
- Step drill EV with 1.9/2.5 mm diameter (REF 25165) was inserted up to 11 mm depth with a maximum of 800 rpm.

- Step drill EV with 2.5/3.1 mm diameter (REF 25169) was inserted up to 11 mm depth with a maximum of 800 rpm.
- Cortical drill with 3.1/3.6 mm diameter (REF 25195) was used to create the shape of the coronal part with a maximum of 800 rpm.

3.2.3 Implant insertion

After the osteotomy site preparation was completed in all blocks. Implants were inserted with an electronic surgical device until they reached the crestal bone level. The insertion torque for the implant is to a maximum of 35 Ncm.

After the implant installation process was done, the scan body was connected to the implant fixture. Then, the postoperative model scans were taken for all models with 3Shape Trios® intraoral scanner. The STL files of the placed implant were exported and superimposed with the STL files of the planned position. The measurement of all parameters was automatically calculated by the 3Shape® Implant position comparer tool (3shape A/S, Copenhagen, Denmark).



Prototype version - Accuracy of measures has not been verified.

IS planning scan: C:\Users\Dent Chula\Desktop\Dr Mod Research\

DS measure scan C:\Users\Dent Chula\Desktop\Dr Mod Research\

UNN: 8

Origo displacement (mm): 1.470
Error depth (mm): -1.463
Error angle (°): 3.428
Horizontal displacement (mm): 0.227

***Figure* 14** *Measurement of implant position by 3Shape® Implant Position Comparer Tool*

3.3 Data collection and analysis

Four parameters which were used for outcome measurement were as follows: (1) coronal deviation (mm); (2) horizontal deviation (mm); (3) depth deviation (mm); and (4) angular deviation (degree) (Figure 16). The coronal deviation is calculated as the three-dimensional distance between the centers of the planned and placed implant platforms. The horizontal deviation is defined as the distance between the center of the implant platform of the horizontal axis. Depth deviation is the distance of the longitudinal axis between coronal centers of the planned and placed implants. The angular deviation is measured as the angle between the virtual and actual implant axis.

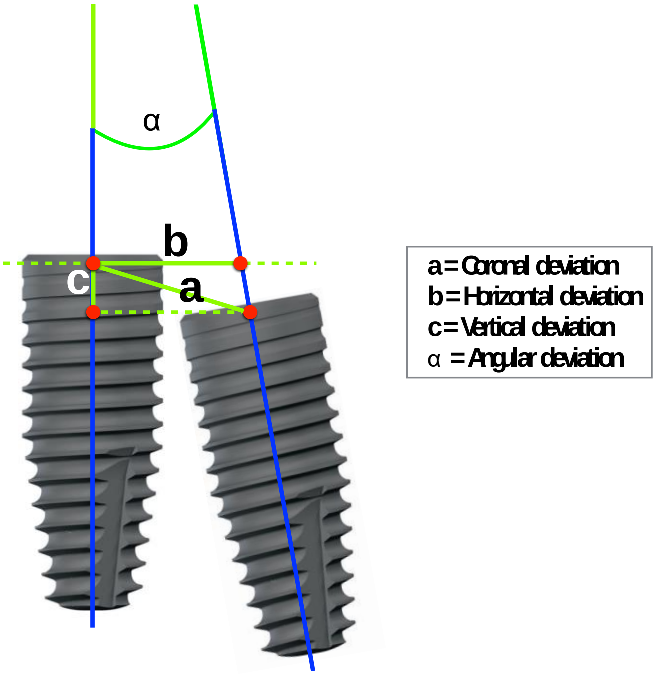


Figure *15 Measurement of deviation parameters: coronal (a), horizontal (b), vertical (c), and angular deviations (α)*

Measurement data was gathered and entered to IBM SPSS Statistics software (version22 software SPSS Inc., Chicago, IL). Mean differences between the planned and actual position were compared between the SG and the AG groups using an independent *t*-test or Mann-Whitney U test. P-value < 0.05 was considered statistically significant.

Ethical consideration

There was no ethical consideration as this study was done in the laboratory setting.

Expected benefit

The advantage of this study was to verify the reliability of each surgical guide system in the dental market. Moreover, the results of this study will be useful for the clinician to select the proper surgical guided system with reliable treatment outcomes.

Limitation

The limitations of this investigation were that it was an in vitro study executed under the controlled condition without limit mouth opening situation and tissue interruption by patient’s tongue and cheek which may consequently underestimate an error. Besides, this study did not consider and compare the time spent in the implant placement process between two groups. Further investigation may examine the time of the implant installation. Another limitation was that this study was performed by a limited number of participants; therefore, these experimental results might not be able to refer to the clinical situation. Further in vitro investigations with a larger number of clinicians, multiple implant fixation, and placement at the posterior region are recommended to confirm the results.

Results

A total of twenty participants were divided into two groups; Group 1 consisted of operators who placed Straumann® Guided system (SG), and Group 2 included operators who placed Astra Tech® Guided system (AG). The mean, standard deviation, minimum, and maximum of all parameters of each group are shown in Table 2.

Table 2 Accuracy of all parameters measured for all groups.

Parameters	Group 1 SG				Group 2 AG			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Coronal deviation (mm)	0.63	0.20	0.32	0.87	0.80	0.10	0.64	0.94
Horizontal deviation (mm)	0.20	0.15	0.01	0.50	0.30	0.12	0.07	0.42
Depth deviation (mm)	-0.53	0.26	-0.14	-0.86	-0.69	0.23	-0.28	-1.0
Angular deviation (degree)	1.59	0.37	1.00	2.21	1.80	0.41	0.98	2.55

* AG, Astra Tech® Guide; SG, Straumann® Guide

For the SG group, the mean error of coronal deviation was 0.63 ± 0.20 mm, horizontal deviation was 0.20 ± 0.15 mm, depth deviation was -0.53 ± 0.26 mm, and angle deviation was 1.59 ± 0.37 degrees. For the AG group, the mean error of coronal deviation was 0.80 ± 0.10 mm, horizontal deviation was 0.30 ± 0.12 mm, depth deviation was -0.69 ± 0.23 mm, and angle deviation was 1.80 ± 0.41 degrees. The comparison of mean and standard deviations between SG and AG groups are shown in Table 3 and Figure 16-19.

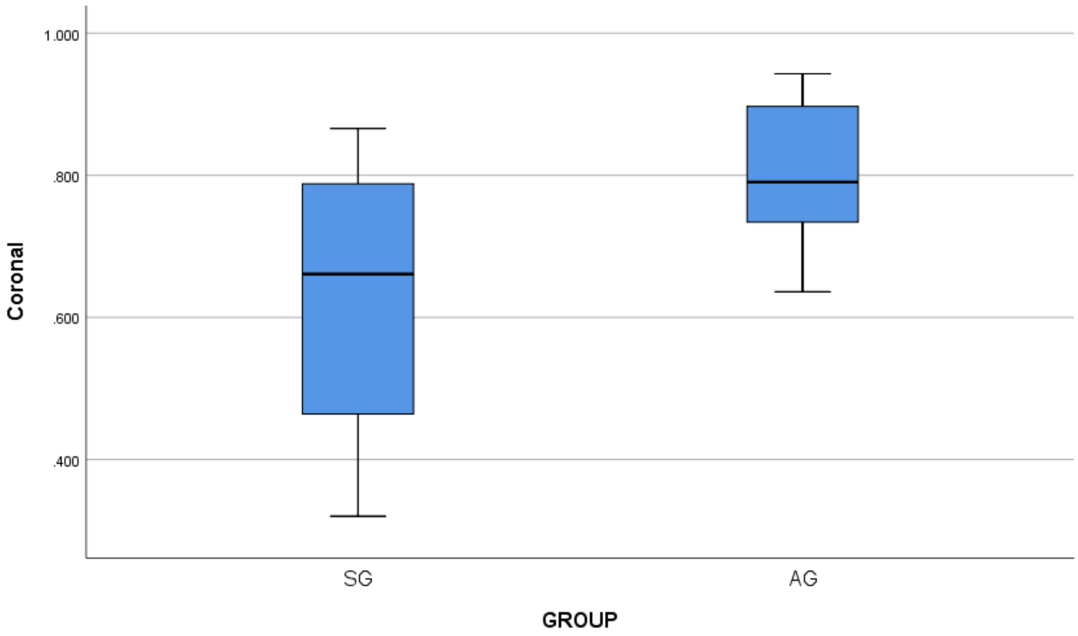


Figure 16 Boxplot graph for coronal deviation

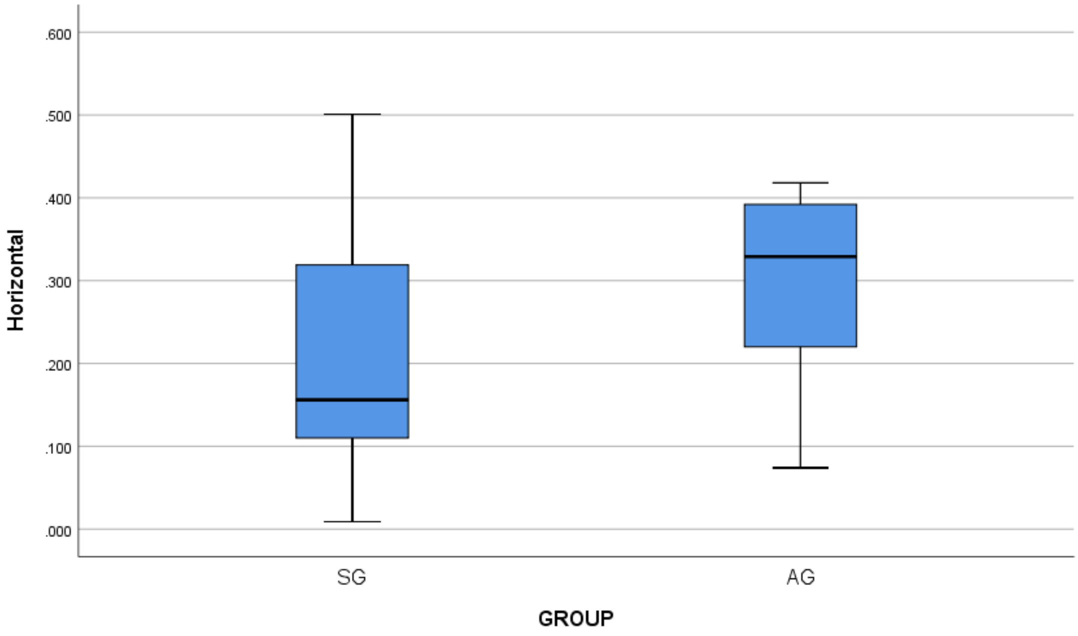


Figure 17 Boxplot graph for horizontal deviation

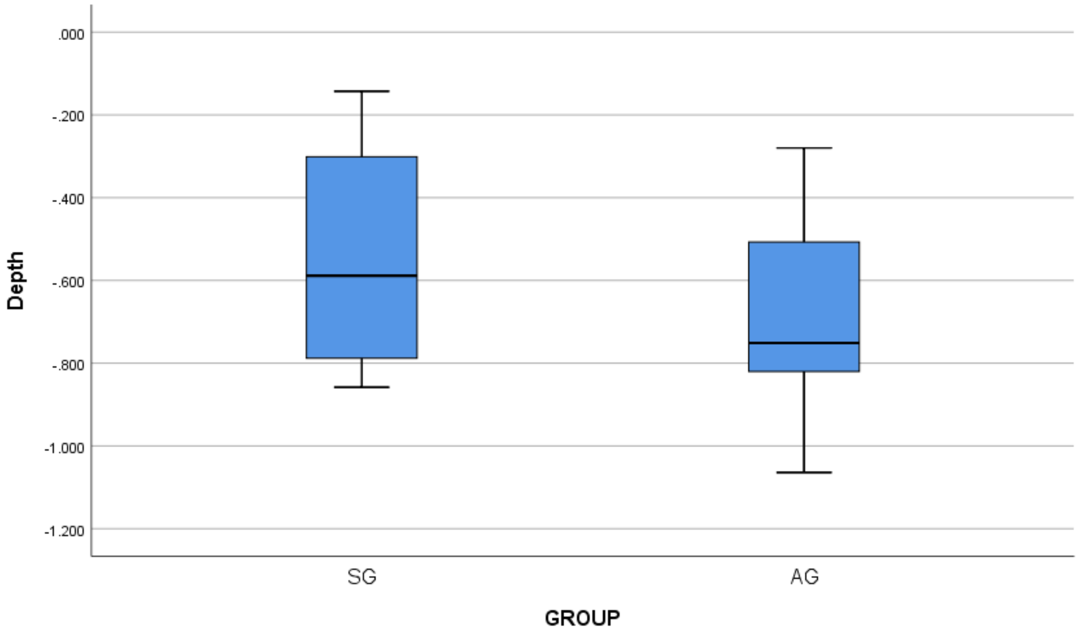


Figure 18 Boxplot graph for depth deviation

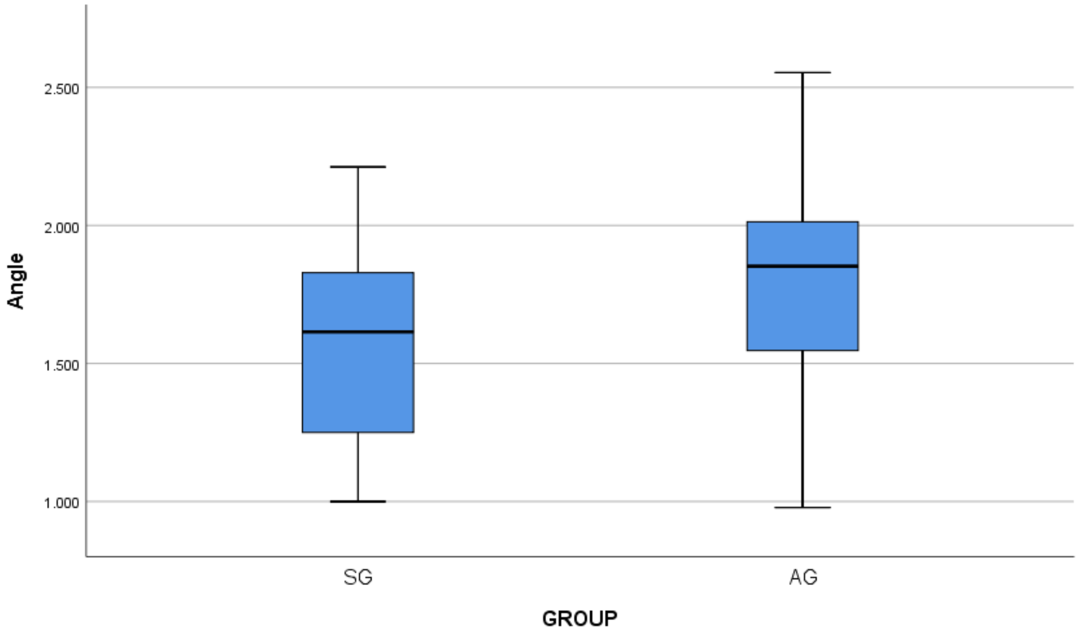


Figure 19 Boxplot graph for angular deviation

Table 3 Accuracy of all parameters compared between SG and AG group

	Group 1 SG		Group 2 AG		
Parameters	Mean	SD	Mean	SD	P
Coronal deviation (mm)	0.63	0.20	0.80	0.10	**.034***
Horizontal deviation (mm)	0.20	0.15	0.30	0.12	.583
Depth deviation (mm)	-0.53	0.26	-0.69	0.23	.625
Angular deviation (degree)	1.59	0.37	1.80	0.41	.932

*AG, Astra Tech® Guide; SG, Straumann® Guide

The statistical analysis was performed with SPSS software (IBM Corp., NY, USA). All data were analyzed and compared using a Mann-Whitney U test. The results revealed a statistically significant difference when coronal (P = 0.034) was considered (P<.05). On the other hand, the statistical analysis showed no statistically significant differences when horizontal (P = 0.583), vertical (P = 0.625), and angular (P = 0.932) deviations were considered (P>.05: Table 3).

Discussion

The results of this in vitro investigation reject the agreement of the null hypothesis. The different systems of static surgical guided surgery would affect the accuracy of single implant position. There are several pieces of literature investigating the influence of surgical guided system and its component on the accuracy of implant installation.

Schneider and others (29) investigated the tolerance of surgical instruments of the Straumann Guide® and the Facilitate Guide® systems. The results revealed that the lateral movement of the drills were significantly decreased with reduced sleeve diameter, shorter drill, and higher drill key.

Another study by Van Assche and Quirynen (30) which also studied the tolerance of two surgical guide systems; Nobel Guide® (NobelBiocare) and Facilitate Guide® (AstraTech). They found that the deviation was influenced by the guiding system, the implant length, and the sleeve height.

Table 4 *The comparison of the surgery protocols used in this study.*

System	Implant length	Sleeve height	FDD	Sleeve diameter	Sleeve length	Drill key height	Guiding tube length
SG	10.0	2.0	12.0	5.0	5.0	3.0	8.0
AG	11.0	6.0	17.0	5.2	4.0	-	4.0

AG, Astra Tech® Guide; SG, Straumann® Guide

Two static surgical guided systems which were chosen in this investigation were Straumann Guide Surgery® (SG), and Astra Tech Guide Surgery® (AG). The SG represents the system using the sleeve-in-sleeve concept, while the AG owns the sleeve-on-drill concept. From the results of this study, the mean deviation of AG group had slightly greater than that of SG group in all parameters, even though that differences had no statistically significant except for the 3D deviation at platform.

The free-drilling-distance (FDD), the distance from the bottom of the metal-guided sleeve to the tip of the drill, was the sum of the sleeve height and the implant length. According to the surgery protocols of this experiment, the SG group used 3.3 x 10 mm bone level taper implants, 2 mm sleeve height, 3 mm key height, and 5 mm sleeve length. Thus, the FDD from the calculation was 12 mm. On the other hand, the AG group used 11 mm implant length, 6 mm sleeve height, 4 mm sleeve length, and no use of the drill key, therefore the FDD of the AG group was 17 mm.

Another reason that may involve the deviation values is the drill guiding tube which supports the stability of the surgical drill during drilling. The more immovable the drill is, the more accuracy of implant placement gains. The SG group had an 8 mm drill guiding channel computed from 3 mm key height and 5 mm sleeve length, while the AG group had only 4 mm sleeve length without any drill key.

Choi and others (34) evaluated the length of surgical guided channel and found that the angular deviation was significantly controlled by the guiding tube; nonetheless, their studies did not investigate other deviation parameters.

From that dissimilarity in the FDD and the drill guiding channel between the sleeve-in-sleeve and the sleeve-on-drill concept may relate to the different amount of deviation that occurred. As reported in the previous study, Kholy et al. (31) suggested that in order to enhance the accuracy of static computer guided surgery, the free drilling distance under the sleeve should be minimized by using shorter sleeve heights or shorter implants, whereas the guided key height above the sleeve should be maximized.

Regarding the diameter of metal sleeve, the SG group has less diameter compared to the AG group. This dissimilarity might influence the deviation of implant placement. From the study by Schneider and others (29), they concluded the smaller sleeve diameter had less lateral movement of the drill.

All things considered, these findings cannot conclude that the sleeve-on-drill concept presents inferior accuracy compared to the sleeve-in-sleeve concept because the accuracy of the static CAIS is multifactorial. Many other factors relate to the outcome of the implant installation. From the conclusion of numerous previous studies, all guide surgery systems offer reliable treatment outcomes and increases the accuracy in comparison with a free-hand approach. In other words, surgeons have independence in choosing any of the guided surgery systems; however, it is suggested to choose the lowest amount of FDD and the highest amount of the guiding channel length as long as possible. The surgical drilling protocol should be considered and adjusted by the surgeon case by case. The FDD should be as less as possible, and the drill guiding tube should be maximized within the capability of access and the surgery site.

Clinical reports previously revealed the learning curve. There is still an ambiguous conclusion about the chronological changes of surgeons on the report of gaining of placement skills. Vasak, Watzak (35) found the effect of the learning curve, while another study by Valente, Schiroli (23) did not found a clear learning curve except for angle deviation and depth deviation; therefore, this study used one operator to place one implant to eliminate the influence of the learning curve.

The amount of depth deviation found in this study in both systems were the negative value which means the placed implant position were shallower than the planned implant position. Too shallow implant placement can be prevented by planning the implant deeper approximately 0.5 mm from the desired depth.

Conclusion

Within the limitations of this study, the different systems with different concepts affected only the 3D coronal deviation. The SG group, representing Sleeve-in-Sleeve concept, showed better accuracy when compared to the AG group which is the Sleeve-on-Drill concept. Overall, the use of a step-by-step computer guided surgery assists the operator to place an implant with reliable accuracy in any system.

REFERENCES

1. Margonar R, Queiroz TP, Luvizuto ER, Betoni-Junior W, Zocal EA. Mandibular rehabilitation using immediate implant loading after computer-guided surgery. Journal of Craniofacial Surgery. 2012;23(2):e129-32.

2. Motta M, Monsano R, Velloso GR, de Oliveira Silva JC, Luvizuto ER, Margonar R, et al. Guided Surgery in Esthetic Region. The Journal of craniofacial surgery. 2016;27(3):e262-5.

3. Pyo S-W, Lim Y-J, Koo K-T, Lee J. Methods Used to Assess the 3D Accuracy of Dental Implant Positions in Computer-Guided Implant Placement: A Review. J Clin Med. 2019;8(1):54.

4. Van Assche N, Vercruyssen M, Coucke W, Teughels W, Jacobs R, Quirynen M. Accuracy of computer-aided implant placement. Clinical oral implants research. 2012;23 Suppl 6:112-23.

5. Jivraj S, Chee W. Treatment planning of implants in the aesthetic zone. British Dental Journal. 2006;201(2):77-89.

6. Chen ST, Buser D. Esthetic complications due to implant malpositions: etiology, prevention, and treatment2015 2019/03/27.

7. Behneke A, Burwinkel M, Behneke N. Factors influencing transfer accuracy of cone beam CT-derived template-based implant placement. Clin Oral Implants Res. 2012;23(4):416-23.

8. Becker W, Goldstein M, Becker BE, Sennerby L. Minimally Invasive Flapless Implant Surgery: A Prospective Multicenter Study. Clin Implant Dent Relat Res. 2005;7(s1):s21-s7.

9. Beretta M, Poli PP, Maiorana C. Accuracy of computer-aided template-guided oral implant placement: a prospective clinical study. Journal of periodontal & implant science. 2014;44(4):184-93.

10. Van de Wiele G, Teughels W, Vercruyssen M, Coucke W, Temmerman A, Quirynen M. The accuracy of guided surgery via mucosa-supported stereolithographic surgical templates in the hands of surgeons with little experience. Clin Oral Implants Res. 2015;26(12):1489-94.

11. Hultin M, Svensson KG, Trulsson M. Clinical advantages of computer-guided implant placement: a systematic review. Clin Oral Implants Res. 2012;23 Suppl 6:124-35.

12. Vercruyssen M, Cox C, Coucke W, Naert I, Jacobs R, Quirynen M. A randomized clinical trial comparing guided implant surgery (bone- or mucosa-supported) with mental navigation or the use of a pilot-drill template. Journal of Clinical Periodontology. 2014;41(7):717-23.

13. Zhou W, Liu Z, Song L, Kuo CL, Shafer DM. Clinical Factors Affecting the Accuracy of Guided Implant Surgery-A Systematic Review and Meta-analysis. The journal of evidence-based dental practice. 2018;18(1):28-40.

14. Albrektsson T. A multicenter report on osseointegrated oral implants. Journal of Prosthetic Dentistry. 1988;60(1):75-84.

15. Hinckfuss S, Conrad HJ, Lin L, Lunos S, Seong WJ. Effect of surgical guide design and surgeon's experience on the accuracy of implant placement. The Journal of oral implantology. 2012;38(4):311-23.

16. Preiskel HW, Tsolka P. Treatment outcomes in implant therapy: the influence of surgical and prosthodontic experience. The International journal of prosthodontics. 1995;8(3):273-9.

17. Cushen SE, Turkyilmaz I. Impact of operator experience on the accuracy of implant placement with stereolithographic surgical templates: an in vitro study. J Prosthet Dent. 2013;109(4):248-54.

18. Cassetta M, Bellardini M. How much does experience in guided implant surgery play a role in accuracy? A randomized controlled pilot study. International journal of oral and maxillofacial surgery. 2017;46(7):922-30.

19. Rungcharassaeng K, Caruso JM, Kan JY, Schutyser F, Boumans T. Accuracy of computer-guided surgery: A comparison of operator experience. J Prosthet Dent. 2015;114(3):407-13.

20. Buser D, Martin W, Belser UC. Optimizing esthetics for implant restorations in the anterior maxilla: anatomic and surgical considerations. International Journal of Oral & Maxillofacial Implants. 2004;19(7).

21. Jung RE, Schneider D, Ganeles J, Wismeijer D, Zwahlen M, Hammerle CH, et al. Computer technology applications in surgical implant dentistry: a systematic review. The International journal of oral & maxillofacial implants. 2009;24 Suppl:92-109.

22. Block MS, Emery RW. Static or Dynamic Navigation for Implant Placement—Choosing the Method of Guidance. J Oral Maxillofac Surg. 2016;74(2):269-77.

23. Valente F, Schiroli G, Sbrenna A. Accuracy of computer-aided oral implant surgery: a clinical and radiographic study. The International journal of oral & maxillofacial implants. 2009;24(2):234-42.

24. Tahmaseb A, Wu V, Wismeijer D, Coucke W, Evans C. The accuracy of static computer-aided implant surgery: A systematic review and meta-analysis. Clinical oral implants research. 2018;29 Suppl 16:416-35.

25. Deeb GR, Allen RK, Hall VP, Whitley D, 3rd, Laskin DM, Bencharit S. How Accurate Are Implant Surgical Guides Produced With Desktop Stereolithographic 3-Dimentional Printers? Journal of Oral and Maxillofacial Surgery. 2017;75(12):2559.e1-.e8.

26. Farley NE, Kennedy K, McGlumphy EA, Clelland NL. Split-mouth comparison of the accuracy of computer-generated and conventional surgical guides. The International Journal of Oral and Maxillofacial Implants. 2013;28(2):563-72.

27. Schneider D, Marquardt P, Zwahlen M, Jung RE. A systematic review on the accuracy and the clinical outcome of computer-guided template-based implant dentistry. Clinical oral implants research. 2009;20 Suppl 4:73-86.

28. D'Haese J, Van De Velde T, Komiyama A, Hultin M, De Bruyn H. Accuracy and complications using computer-designed stereolithographic surgical guides for oral rehabilitation by means of dental implants: a review of the literature. Clinical Implant Dentistry and Related Research. 2012;14(3):321-35.

29. Schneider D, Schober F, Grohmann P, Hammerle CHF, Jung RE. In-vitro evaluation of the tolerance of surgical instruments in templates for computer-assisted guided implantology produced by 3-D printing. Clinical oral implants research. 2015;26(3):320-5.

30. Van Assche N, Quirynen M. Tolerance within a surgical guide. Clinical oral implants research. 2010;21(4):455-8.

31. El Kholy K, Janner SFM, Schimmel M, Buser D. The influence of guided sleeve height, drilling distance, and drilling key length on the accuracy of static Computer-Assisted Implant Surgery. Clin Implant Dent Relat Res. 2019;21(1):101-7.

32. Koop R, Vercruyssen M, Vermeulen K, Quirynen M. Tolerance within the sleeve inserts of different surgical guides for guided implant surgery. Clin Oral Implants Res. 2013;24(6):630-4.

33. Park SJ, Leesungbok R, Cui T, Lee SW, Ahn SJ. Reliability of a CAD/CAM Surgical Guide for Implant Placement: An In Vitro Comparison of Surgeons' Experience Levels and Implant Sites. The International journal of prosthodontics. 2017;30(4):367-169.

34. Choi M, Romberg E, Driscoll CF. Effects of varied dimensions of surgical guides on implant angulations. J Prosthet Dent. 2004;92(5):463-9.

35. Vasak C, Watzak G, Gahleitner A, Strbac G, Schemper M, Zechner W. Computed tomography-based evaluation of template (NobelGuide™)-guided implant positions: a prospective radiological study. Clin Oral Implants Res. 2011;22(10):1157-63.

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