ACCURACY COMPARISON OF DENTAL IMPLANTS OBTAINED BY DYNAMIC CAIS IN ALL-ON-4 EDENTULOUS AREA AMONG DIFFERENT TYPES OF BONE DENSITY: AN IN VITRO STUDY

Miss Jutasinee Pornpolsarun

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การเปรียบเทียบความแม่นยำของตำแหน่งรากฟันเทียมโดยวิธีใช้คอมพิวเตอร์ช่วยเหลือแบบพลวัตรในสันเหงือกว่าง ออล-ออน-โฟร์ ที่มีความหนาแน่นของกระดูกแตกต่างกัน: การศึกษาในห้องปฏิบัติการ

น.ส.จุฑาสินี พรพลศรัณย์

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By	Miss Jutasinee Pornpolsarun
Field of Study	Esthetic Restorative and Implant Dentistry
Thesis Advisor	Associate Professor ATIPHAN PIMKHAOKHAM, D.D.S., Ph.D.
Thesis Co Advisor	Associate Professor PRAVEJ SERICHETAPHONGSE, D.D.S., M.S. WAREERATN CHENGPRAPAKORN, D.D.S., Ph.D.

Accepted by the FACULTY OF DENTISTRY, Chulalongkorn University in Partial Fulfillment of the Requirement for the Master of Science

Dean of the FACULTY OF DENTISTRY
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Thesis Advisor
(Associate Professor ATIPHAN PIMKHAOKHAM, D.D.S., Ph.D.)

Thesis Co-Advisor
(Associate Professor PRAVEJ SERICHETAPHONGSE, D.D.S., M.S.)

Thesis Co-Advisor
(WAREERATN CHENGPRAPAKORN, D.D.S., Ph.D.)

External Examiner
(Assistant Professor CHAIMONGKOL PEAMPRING, D.D.S., Ph.D.)

จุฑาสินี พรพลศรัณย์ : การเปรียบเทียบความแม่นยำของตำแหน่งรากฟันเทียมโดยวิธีใช้คอมพิวเตอร์ช่วยเหลือแบบพลวัตรในสันเหงือกว่าง ออล-ออน-โฟร์ ที่มีความหนาแน่นของกระดูกแตกต่างกัน: การศึกษาในห้องปฏิบัติการ . (ACCURACY COMPARISON OF DENTAL IMPLANTS OBTAINED BY DYNAMIC CAIS IN ALL-ON-4 EDENTULOUS AREA AMONG DIFFERENT TYPES OF BONE DENSITY: AN IN VITRO STUDY) อ.ที่ปรึกษาหลัก : รศ. ดร.ทพ.อาทิพันธุ์ พิมพ์ขาวขำ, อ.ที่ปรึกษาร่วม : รศ. ทพ.ประเวศ เสรีเชษฐพงษ์,อ.ดร. ทญ.วรีย์รัตน์ เจิ่งประภากร

ที่มาและความสำคัญ: การประเมินวัดปริมาณและคุณภาพของสันกระดูกก่อนการฝังรากเทียมนั้นสำคัญเป็นอย่างมาก เนื่องจากคุณภาพของกระดูกนั้นสามารถส่งผลต่อความแม่นยำในการฝังรากเทียม ในปัจจุบันนี้การฝังรากเทียมด้วยระบบคอมพิวเตอร์ช่วยเหลือแบบพลวัตรได้แสดงผลถึงความแม่นยำในการฝังรากเทียมที่ดีขึ้น แต่ผลของความแม่นยำในการฝังรากเทียมด้วยระบบคอมพิวเตอร์ช่วยเหลือแบบพลวัตรในความหนาแน่นกระดูกที่แตกต่างกันนั้น ยังไม่มีผลลัพธ์ที่ชัดเจน ดังนั้นในการศึกษานี้มีเป้าหมายเพื่อทดสอบความแตกต่างของความแม่นยำในการฝังรากเทียมด้วยระบบคอมพิวเตอร์ช่วยเหลือแบบพลวัตรในความหนาแน่นของสันกระดูกที่แตกต่างกัน

วัตถุประสงค์: งานวิจัยนี้มีวัตถุประสงค์เพื่อเปรียบเทียบความแม่นยำของการฝังรากเทียมบริเวณสันเหงือกว่างที่มีการสูญเสียฟันทั้งปากในบริบทของความหนาแน่นของกระดูกที่แตกต่างกัน โดยวัดความคลาดเคลื่อนของตำแหน่งรากเทียมที่ฝังเปรียบเทียบกับตำแหน่งที่วางแผนไว้ก่อนการเริ่มการทดลอง การฝังรากเทียมโดยใช้ระบบคอมพิวเตอร์ช่วยเหลือแบบพลวัตร

วัสดุและวิธีการ: แบบจำลองฟันบนสันเหงือกว่างที่มีการสูญเสียฟันทั้งปากมีการบรรจุกระดูกเทียมตามความหนาแน่นบริเวณสันเหงือกว่างซี่ 16 12 22 26 ตามหลักการออล-ออน-โฟร์ จำนวน 16 ชิ้น รากเทียม 64 ตัว โดยจะแบ่งการทดลองออกเป็น 4 กลุ่มตามความหนาแน่นของสันกระดูกที่แตกต่างกันกลุ่มละ 4 ชิ้น โดยการทดลองจะมีการถ่ายภาพรังสีส่วนตัดอาศัยคอมพิวเตอร์แบบโคนบีมทั้งก่อนและหลังฝังรากเทียม จากนั้นเมื่อได้ภาพถ่ายรังสีมาแล้วนาภาพถ่ายรังสีเข้าสู่กระบวนการวางแผนการรักษาด้วยโปรแกรมทางคอมพิวเตอร์หลังจากนั้นทำการฝังรากเทียมตามที่วางแผนไว้ในแบบจำลองฟันบนโดยมีแบบจำลองฟันล่างทาหน้าที่เป็นคู่สบติดอยู่กับหัวจำลองเพื่อจำลองสถานการณ์เสมือนจริงของผู้ป่วยโดยมีทันตแพทย์ผู้ผ่าตัด 1 คนเป็นผู้ทำการฝังรากเทียม เมื่อเสร็จสิ้นการฝังรากเทียม แบบจำลองทั้งหมดจะถูกถ่ายภาพรังสีส่วนตัดอาศัยคอมพิวเตอร์แบบโคนบีม จากนั้นจะถูกนำเข้าซอฟต์แวร์เพื่อการวิเคราะห์ความคลาดเคลื่อนที่ตำแหน่งขอบบนของรากเทียม, ปลายรากเทียม และความคลาดเคลื่อนเชิงมุม

ผลการศึกษา: จากผลการทดลองของตัวอย่างรากเทียม 64 ตัว ผลรวมความคลาดเคลื่อนเฉลี่ยเชิงมุมคือ 2.60 ±1.04องศา ความคลาดเคลื่อนที่ตำแหน่งขอบบนของรากเทียมคือ 1.27±0.55 มม. และความคลาดเคลื่อนเฉลี่ยที่ตำแหน่งปลายรากเทียมคือ 1.25±0.62 มม. โดยไม่พบความแตกต่างอย่างมีนัยสาคัญทางสถิติระหว่างกลุ่มความหนาแน่นกระดูกที่แตกต่างกัน กลุ่มความหนาแน่นกระดูกที่น้อยที่สุด (D4) แสดงผลที่คลาดเคลื่อนของการฝังรากเทียมมากที่สุดในทุกหน่วยวัด นอกจากนั้นผลยังแสดงให้เห็นถึง ความสัมพันธ์เชิงลบ ระหว่าง ความหนาแน่นของกระดูก และ ความแม่นยำของการฝังรากเทียมในทุกหน่วยวัด

สรุปผลการศึกษา: ด้วยข้อจำกัดของการทดลองนี้ ความหนาแน่นของกระดูกที่แตกต่างกัน ไม่มีความสัมพันธ์กับความแม่นยำในการฝังรากเทียมบนสันเหงือกว่างทั้งปาก ด้วยเครื่องคอมพิวเตอร์นำทางเสมือนจริงอย่างมีนัยสำคัญ

สาขาวิชา	ทันตกรรมบูรณะเพื่อความสวยงามและทันตกรรมรากเทียม	ลายมือชื่อนิสิต ....
ปีการศึกษา	2564	ลายมือชื่อ อ.ที่ปรึกษาหลัก ....
		ลายมือชื่อ อ.ที่ปรึกษาร่วม ....
		ลายมือชื่อ อ.ที่ปรึกษาร่วม ....

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KEYWORD: Bone density, dynamic navigation system dental implant, All-On-4, Edentulism

Jutasinee Pornpolsarun : ACCURACY COMPARISON OF DENTAL IMPLANTS OBTAINED BY DYNAMIC CAIS IN ALL-ON-4 EDENTULOUS AREA AMONG DIFFERENT TYPES OF BONE DENSITY: AN IN VITRO STUDY . Advisor: Assoc. Prof. ATIPHAN PIMKHAOKHAM, D.D.S., Ph.D. Co-advisor: Assoc. Prof. PRAVEJ SERICHETAPHONGSE, D.D.S., M.S., WAREERATN CHENGPRAPAKORN, D.D.S., Ph.D.

Background: Determination of available bone is particularly important in implant placement quality of bone can affect the accuracy implant placement. Currently, Dynamic navigation system illustrated the improvement of implant accuracy, The accuracy of implant placement using computer-assisted implant placement system (CAIS) is unknown. As a result, the goal of this study was to see how bone density affected implant placement accuracy with Dynamic CAIS.

Purpose: To determine the effect of different bone density in the accuracy of implant placement using dynamic navigation system

Materials and Methods: The study's overall design includes a single doctor planning each implant using a CBCT scan of a jaw model and performing a mock operation and implant delivery on a maxilla model while employing dynamic CAIS in various bone densities, all while following the All-on-4 protocol. To verify accuracy, the implant's placement and axis are compared to the implant plan. Oneway ANOVA and Welch test were used to determine differences between groups, and the Post Hoc test (Tukey HSD and Games-Howell) were used to determine differences within groups, The Pearson correlation coefficient was used to assess the relationship between each bone type and implant accuracy parameters. with 0.05 significant level.

Results: There were no significant differences were found between four groups of bone density in all parameters; The angular deviation(p=0.324), Implant 3D platform deviation (p=0.8933) and 3D apex deviation(p=0.61). However, the lowest bone density group(type4) illustrated the highest deviation for all implant deviation differences between groups, the result trend towards negative correlation between bone density and the accuracy of implant placement in angular deviation (P= 0.59) and apex deviation (P=0.55).

Conclusions: Within the limits of our investigation, the influence of bone condition on implant placement accuracy with dynamic computer-guided surgery is statistically unaffected

Field of Study:	Esthetic Restorative and Implant Dentistry	Student's Signature ....
Academic Year:	2021	Advisor's Signature ....
		Co-advisor's Signature ....
		Co-advisor's Signature ....

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Chapter I

I. Background and rationale

Currently, prosthetic has been a drive of implantations. With high technology and obvious long-lasting results, dental implants have become a popular alternative for those who suffer from tooth loss. In order to achieve the success of the functionality and aesthetic of the dental system, the implant must be placed in an accurate angle and a proper position according to an optimal treatment plan and good surgical procedure. The proper placement will result in dental restorations that align with surrounding anatomical structures functionally and aesthetically (1).

Implant-supported restoration is a favored treatment option for full mouth edentulous patients, despite their severe bone deficiency. This is because the better retention and the more comfortability of the implant compared to those of conventional removable dentures (2).

The “all-on-four” treatment concept was initiated by reason of the predictable result in atrophic jaws. The protocol utilizes two anterior straight implants and two posterior tilted implants. This technique allows an increased arch width to support the final fixed prosthesis and prevent perforation of the maxillary sinuses without regenerative procedures. Nevertheless, the surgical complications can still happen due to the limitations of the operator's experience and the patient's anatomical variations during implant surgery(3) (4, 5).

When performing conventional methods, the clinical outcomes often show unpredictable result that may lead to malposition of implants. This is followed by undesirable complications (6) as a result of two-dimensional patient’s anatomical data. Moreover, surgical guide stents fabricated on diagnostic casts do not display underlying critical anatomical structure and defect of bone (7) (8) also reported that anatomical structures that deviate from the norm can be reasons for greater inaccuracies in freehand technique (9) .

In recent years, the technology of computer-assisted implant placement system (CAIS) was introduced which can be categorized as either static or dynamic (1, 8). The literatures demonstrate that the majority number of implants are placed using the CAIS system provide superior accuracy over the freehand implant placement (10, 11).

While both static and dynamic image navigation are highly accurate, in terms of angular deviation, platform and apical positioning, dynamic navigated implant placement has been found to be similar precision to static implant placement(12-14). Nonetheless, dynamic navigation system has advantages over static. Firstly, Dynamic CAIS system tracks the patient and surgical instruments and presents real time position and guidance feedback at computer display. Then, the CT scan, implant plan and surgery can be conducted on the same day. The plans can also be altered during surgery when clinical situation dictates a change to avoid complications. Lastly, the accuracy can be verified at all times (15). Several studies on models (12, 15) (16) indicate that dynamic navigation systems have a mean entry deviation approximating 0.4 mm and mean angular deviation error approximating 4 degrees. These studies, simulating dynamic navigation, indicate very accurate implant placement.

Determination of available bone is particularly important in implant placement as the quality of bone can reflect the long-term success of implant placement, especially the position and stability. Besides, it also assists in predicting healing process and prosthetics loading. Previous studies illustrate that bone structure affects the accuracy of implant, for example there were higher discrepancies between planning and implant placement in maxilla than those in mandible (1, 17) (18). However, the influence of bone density on the accuracy of dynamic CAIS still remain controversial up to now. The literature evidence regarding the influence of recipient bone quality on the accuracy of static CAIS is limited. Some researches demonstrated a statistically significant negative correlation between bone density and the accuracy of static CAIS (19-21). Nonetheless, the research evidence regarding the influence of recipient bone quality on the accuracy of dynamic CAIS is still inadequate.

Therefore, the aim of this study was to analyze the influence of bone density on the accuracy of implant position using dynamic CAIS system (navigation system), with special focus on using All-on-4 protocol in edentulous areas.

Chapter II

Review literature

1 Surgical complications from malposition of implant placement implant placement

The majority of surgical problems occur during the implantation. Surgical complications, such as perforation into the maxillary sinus, damage to the inferior alveolar nerve, intraoral hemorrhage, wound dehiscence, postoperative pain, lack of primary implant stability, sinus lift sequelae, neurosensory disturbances, injuries to adjacent teeth, tissue emphysema, and aspiration or ingestion of surgical instruments, can occur despite careful planning. It's easier to get the appropriate treatment if you're aware of potential problems and can avoid them. Similarly, practitioners who place dental implants must be able to detect and treat unpredictable complications. (22).

1.1 Damage to adjacent tooth

An adjacent tooth can become non-vital if an implant is placed incorrectly and strikes or impinges on an adjacent tooth's blood supply, or if the bone is overheated during the osteotomy (Fig 1). If this happens, the tooth will require endodontic treatment, an apicoectomy, or extraction. Furthermore, if a periapical lesion develops as a result of devitalization and encroaches on the implant, it may contaminate the implant and lead to its loss.

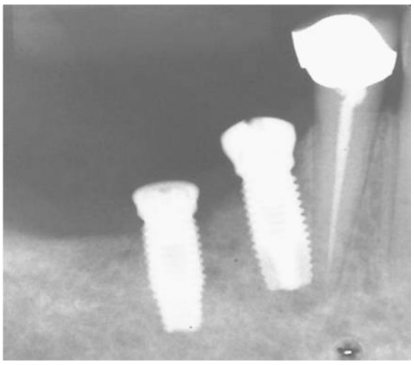


Figure 1 Malposed implant hitting adjacent tooth
(Copied from reference No. #20)

1.2 Nerve Injury

Following implant therapy, neurosensory abnormalities may happen. Nerve transection, ripping, or laceration can result from intrusion into the inferior alveolar or mental canal during osteotomy development. The insertion of an implant might potentially cause bone compression on the nerve.

1.3 Neurological sequelae of nerve injury

Following a nerve damage, the patient may experience paresthesia (numbness, burning, and prickling), hypoesthesia (reduced feeling), hyperesthesia (increased sensitivity), dysesthesia (painful sensation), or anesthesia (complete loss of feeling of the teeth, the surrounding skin, and mucosa).

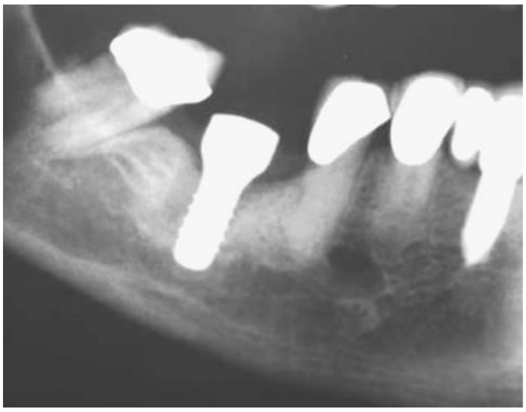


Figure 2 Dental implant penetrating into the inferior alveolar canal.

(Copied from reference No. #20)

1.4 Incidence of neurosensory dysfunction

The frequency of sensory changes after implant placement differed between studies due to a variety of factors, including osteotomy sites, surgical methods, study design, sensitivity of evaluation tools, and the outcome variables utilized to link sensory problems.

1.5 Penetration Into Maxillary Sinus or Nasal Fossa

If there is enough bone length to install a stable implant, accidental penetration into the maxillary sinus or nasal cavity with the twist drill is a minor issue. A few millimeters of implant insertion into the sinus or nasal cavity is typically well tolerated. In these cases, however, an antibiotic and a decongestant should be prescribed.

1.6 Complications Associated With Sinus Elevation

Perforation of the Schneiderian membrane during elevation is the most prevalent complication. If a rupture in the membrane develops around the border of the osteotomy and reengagement is problematic, the condition can be handled by spreading the osteotomy outline several millimeters beyond the window and reestablishing contact with the membrane.

2. Prosthetic Complications from malposition of implant placement

Proper implant position as well as optimum volume of hard and soft tissue support is the important factor for successful treatment. As a consequence, the significance of bone to support the soft tissues was understood as a necessity to achieve esthetic outcomes in the anterior maxilla. In addition, the importance of a correct three-dimensional (3D) implant placement was also recognized, from which the term “restoration-driven implant placement” was derived the concept of “comfort” and “danger” zones for the position of implants in relation to the adjacent natural teeth (23) (24).

Implant malposition problems could be prevented by volumetric implant planning procedures, Implant insertion in a correct 3D position is only one important prerequisite for successful aesthetic outcomes. The other prerequisite is to rebuild a sufficient volume of peri-implant tissues on the facial aspect of the implant to achieve a pleasing aesthetic result. In aesthetic areas, the majority of implants require a contour augmentation on the facial aspects, since a facial atrophy is most often present in healed sites, bone modeling activities will lead to the resorption and flattening of the facial contour in post extraction sites, and the facial bone wall provides support of the peri-implant mucosa. In addition, the clinician must also demonstrate proper judgment of the clinical situation.

In the nutshell, malposition of implant placement can exaggerated compromise the long- term success rate. Thus, to overcome the problem of malposition implant delivered, there are several methods including well treatment plan and using CAIS program to help provide accurately implant position planning.

3. Computer-assisted implant surgery (CAIS)

The conventional approaches included a freehand approach and the utilization of a surgical guide stent. For treatment planning, traditional dental panoramic tomography and plain film tomography are commonly employed since they do not give three-dimensional data. Traditional surgical templates can help guide the drill's entrance location into the bone, but they can't provide accurate 3-dimensional guidance. When it comes to planning the optimal implant position on radiographs, radiographic templates that replicate the prosthetic set-up are frequently used. During implant placement, the same templates might be applied as a prosthetic reference. However, the third dimension of the patient's anatomy is absent with this type of preoperative planning. As a result, the templates are made without regard for the underlying anatomical structure on the diagnostic stone cast. Hence, when conventional procedures are utilized, the clinical outcome is frequently unexpected, with implant implantation malposition and other problems. (25) (26).

To solve the limitations of the freehand technique and the traditional surgical guide stent method, computer-assisted surgery (CAIS) was developed (Fortin, Coudert et al. 1995). Important advancements in this discipline include the invention of cone-beam computed tomography (CBCT) and 3D implant design software. Garber and Belser (1995) (Somogyi-Ganss, Holmes et al. 2015) (Ruppin, Popovic et al. 2008) (Somogyi-Ganss, Holmes et al. 2015) (Ruppin, Popovic et al. 2008) (Edelmann, Hosseini et al. 2016).

Three-dimensional (3D) imaging is a fundamental feature of CAIS systems, allowing for precise diagnosis and improved virtual planning, both of which are required pre-conditions for achieving good esthetical and long-term implant outcomes. Since the development of cone-beam CT (CBCT) technology, 3D diagnosis has become widely used in dentistry procedures, with the added benefit of much lower patient radiation exposure as compared to medical CT diagnosis. In pre-surgical dental implant planning, actual investigations reveal identical diagnostic values for CBCT and medical CT data sets. Different CAIS systems take use of the benefits of superior 3D diagnosis and software-based planning by precisely translating virtual implant placements to anatomical patient sites. The accurate transfer of 3D dental implant design is especially significant for flapless surgery techniques, preparing prosthesis for immediate loading before surgery, reducing the danger of harming critical anatomical structures, and eliminating manual placement mistake. Different techniques to computer-assisted implant planning have been available since 1997. Real-time tracking systems, also known as dynamic or active systems, and static surgical drill templates, commonly known as passive systems

3.1 Static computer assisted system

The static CAIS system, also known as computer-guided surgery, combines CBCT and 3D implant planning software with computer-aided design and manufacturing (CAD/CAM) technology. The virtual implant is designed digitally using the 3D image reconstruction from CBCT, and the relationship between the virtual implant position and the radiography template may be utilized to build a stereolithographic surgical template that fits closely with the bone or tooth surface. (15). Taking a cone-beam CT scan (CBCT) with the patient wearing a radiographic template replicating the preoperative prosthetic design in the mouth as an imaging guide is the first step in creating a computer-generated guide. The implant planning program requires the uploading of the CBCT Digital Imaging and Communications in Medicine (DICOM) file. Obtain the CT data and save it to your PC. In the surgical software, convert the CT data to display the planned location of the teeth in respect to the bone. Through the combining of separate data, analyze the osseous tissues in relation to the location of the teeth using 3-D implant design software. Evaluate and plan the placements and sizes of the dental implants based on this information. (11) (27) (28). After the plan is finalized, send the data to a milling center to produce the stereolithography surgical template with the implant placement sleeves using a CAD/CAM method. Examine and alter the surgical template to ensure correct cast and patient fitting. (29).

The advantages of this procedure, for the completely edentulous arch, include 1) shorter surgery times, 2) shorter treatment times, 3) less invasive, flapless surgery and, therefore, less chance of swelling, less pain, and faster initial healing times, 4) placement of a prefabricated definitive or provisional prosthesis, and 5) use of the fixed prosthesis immediately (11). The CAD/CAM surgical template used can easily transfer the planned positions from the software to the patient with the use of the surgical instrumentation and protocol. Because of the design of the surgical instrumentation, the osteotomy site preparation is more precise and, therefore, there is a greater possibility of having a more stable implant.

A limitation of this procedure, particularly for the partially edentulous patient, is inter-arch space for the surgical instrumentation. Surgical drills have an added 10 mm in length, and, therefore, may be difficult to place in patients with minimal opening or those needing implant placement in the second molar position (27). In addition, CT-generated guided implant surgery requires several preoperative steps , according to such a complex treatment planning sequence with many potential sources of error, necessitate time delays and additional cost to the patient (17) also the use of the CT planning software requires training to gain proficiency with the planning software, creates a workflow barrier for the use of static CT-generated guides (30). Intraoperative disadvantages of CT-generated guides are the inability to prevent deviation of drill movements if the sleeves are not the same diameter as the drill, inability to change implant position or surgical plan as needed, limits the ability to irrigate the drill during the osteotomy with the potential for increased heat production. Moreover clinician will require the appropriate surgical kit that coordinate to the implant and CT-generated guide system (12).

3.2 Dynamic computer-assisted implant system / Navigation system

Watzinger et al. (Watzinger, Birkfellner et al. 1999) introduced the dynamic CAIS system or navigation system in 1999 as a technique that provides direct observation of the implant bur on a computer display in real time, based on information obtained from the patient's computed tomography. Optical technologies are used in dynamic navigation systems for dental implant placement to track the patient and the hand piece and display pictures on a monitor (Nijmeh, Goodger et al. 2005). (Bouchard, Magill et al. 2012). Passive or active tracking arrays are used in the optical systems. Tracking arrays are used in passive systems to reflect light generated by a light source back to the stereo cameras. Stereo cameras track light emitted by active system arrays. (Figure3).

Mounting the fiducial markers to the arch is the first step in the dynamic navigation procedure. A clip with four metallic fiducial markers is attached to the patient's arch in a region that will not be surgically treated. If an esthetic plan is being employed, radiopaque teeth can be used as an imaging guide in the mouth to enable for virtual implant location afterwards. With the clip in place, the CBCT scan should be performed. After that, the clip can be removed and preserved for further use during surgery. The DICOM data set is loaded into the navigation system’s computer. A virtual implant is placed then. The software is simple and requires minimal computer experience by the clinician. The implants are generically generated using the platform diameter, apical diameter, and length in 0.1mm increments. The implant can be oriented as needed.

The clip with the fiducial markers is applied to an array during surgery. The operator should register the clip with the associated array and the handpiece with similar arrays to the navigation system. Local anesthetic and small incisions can be used, with minimal flap reflection. The clip array should be fixed tightly on the arch. During the preparation procedure, the drill lengths should have been registered. The surgeon then places the patient and arrays in such a way that they have a straight line of sight to the overhead cameras (12).

The precision, timeliness, and capacity to adjust the implant size, system, and position throughout the surgical operation are all advantages of the dynamic navigation approach. In comparison to free-hand techniques, it also necessitates less intrusive flap reflection and leads in less trauma to the surgeon since the surgeon's posture is better, with less back and neck bending. Dynamic navigation enables for implant placement in a patient who has difficulties opening their mouth or requires an implant at a difficult-to-access second molar location by depending on the navigation screen to guide the drills without direct visibility in the patient's mouth. (12) (31) (9) (28)

Figure 3 Line drawings depicting the emitted light from the blue lights in the overhead array, which are then reflected back to the 2 cameras in the overhead array. The 3-dimensional graphics are then displayed on the navigation screen.
(Copied from reference No. #27)

3.2.1 Accuracy of dynamic CAIS system

1. Several clinical studies reported the accuracy of implant placement with dynamic CAIS system. Mean entry deviation was 1.0 – 1.67 mm, mean apex deviation was 0.56 – 2.51 mm and mean angular deviation was 2.64 – 6.4 degrees

Study	System	Implant (N)	Error entry(mm)	Error apex (mm)	Error angle (degree)
Block et al (2016)	X-guide vs Freehand	80 20	1.37 ± 0.55 1.67 ± 0.43	1.56 ± 0.69 2.51 ± 0.86	3.62 ± 2.73 7.69 ± 4.92
Robert W. et al (2016)	X-guide	40	Max 0.58 ± 0.18 Mand 0.49 ± 0.16	Max 0.63 ±0.17 Mand0.48 ±0.13	1.26 ± 0.66
Wagner et al (2003)	VISIT	32	La 0.8 ± 0.5 Li 1.0 ± 0.7	La 1.1 ± 0.9 Li 1.3 ± 0.9	6.4 ± 3.6
Vercruyssen et al(2014)	Robodent	14	0.7 ± 0.5	0.9 ± 0.7	2.8 ± 2.2
Kim et al (2015)	Anatomage	110	0.41 ± 0.12	0.56 ± 0.14	2.64± 1.31
Chiu et al (2006)	IGI	80	0.43 ± 0.56	1.24 ± 0.28	4 ± 3.5

Table 1 Mean deviation of each studies using dynamic CAIS to delivered implant on vary site of both arches

According to Robert W. et al (1) they had performed the laboratory study involves 1 surgeon experienced with dynamic navigation placing implants in models under clinical simulation using a dynamic navigation system (X-Guide, X-Nav Technologies, LLC, Lansdale, Pa) based on optical triangulation tracking. Virtual implants were placed into planned sites using the navigation system computer. Post–implant placement cone-beam scans were taken. These scans were mesh overlaid with the virtual plan and used to determine deviations from the virtual plan. The primary outcome variables were platform and angular deviations comparing the actual placement to the virtual plan. The angular accuracy of implants delivered using the tested device was 1.26 for edentulous case types measured relative to the preoperative implant plan. Three-dimensional positional accuracy was 0.38 for edentate, measured from the implant apex (Table1)

Block et al (12) compared the accuracy of implant position between using dynamic CAS system (X-Guide, X–Nav Technologies) and freehand approach in 100 patients with single tooth gap. They concluded that the accuracy of navigation system was superior compared to freehand approach. Using navigation system, mean entry error, apex error and angle error was 1.37 ± 0.55 mm, 1.56 ± 0.69 mm and 3.62 ± 2.73 degrees respectively while in freehand was 2.51 ± 0.86 mm, 1.67 ± 0.43 mm and 7.69 ± 4.92 degrees respectively (Table1).

Kim et al. (32) have evaluated the accuracy of navigational system in partial edentulous models. The mean positional deviations between the planned and placed implants in 110 implant surgeries were 0.41 ± 0.12 mm at the center point of the platform and 0.56 ± 0.14 mm at the center point of the apex. The mean angular deviation was 2.64± 1.31 for the long axis of the implant.

Wagner et al (33) studied the accuracy of implant placement using novel dynamic navigation system (VISIT navigation system, University of Vienna, Vienna, Austria) in 5 partially edentulous patient after microvascular bony reconstruction due to tumor surgery. They reported the mean deviation at base and tip of 32 implants in lingual and vestibular direction is 1.1 mm (0 – 3.5 mm) and the mean angle deviation is 6.4 ± 3.6 degrees (0.4 – 17.4 degrees). The mean deviation in lingual and vestibular direction was larger at the tip if implants (1.3 ± 0.9 mm in lingual, 1.1 ± 0.9 mm in vestibular direction at the tip vs 1.0 ± 0.7 mm in lingual, 0.8 ± 0.5 mm in vestibular direction at the base). They concluded that sufficient accuracy in placing oral implants can be performed in patients with difficult anatomical situations (Table1).

Some laboratory studies compared the accuracy of implant placement between using several methods. Somogyi Gnass et al. (31) compare the accuracy of implant site preparation in mandibular models between using a novel dynamic CAS system (Claron Technology Inc., Toronto, ON, Canada), three commercial static CAS systems: Simplant (Materialize Dental, Leuven, Belgium), Straumann Guided Surgery (Institute Straumann AG, Basel, Switzerland), Nobel Clinician, (Nobel Biocare AG, Zurich, Switzerland) and conventional laboratory guide stent. They reported that average error from both dynamic and static CAS system are less than 2 mm and 5 degrees whereas average error from using conventional guide stent is less than 3 mm and 9 degrees. The dynamic and static CAS system provide superior accuracy for implant site preparation.

3.2.2Factors influence the accuracy of dynamic CAIS system

When utilizing a navigation system, there are a few aspects that affect the accurate transmission of virtual planning to the surgical site. Human error, picture resolution, and registration mistake are some of these variables.

Accuracy of the registration

The registration technique, which is the matching of the coordinated points between the patient jaw and the CT image, is critical to the proper transfer of virtual planning to the surgical site. Errors that occur throughout the registration process are also included. The mistake in identifying the fiducial points via measurement hardware, known as (i)fiducial localization error (FLE), is assessed by the measuring probe locating two fiducial markers on the patient's jaw. The registration procedure computes (ii)fiducial registration error (FRE), which is the root-mean square distance between comparable fiducial points after registration. The critical and direct measure of registration error is (iii)target registration error (TRE), which is the distance between corresponding points other than the fiducial points after registration. After registration, TRE is calculated by converting the locations of specified spots on the jaw to CT-space and comparing them to the corresponding places on the original picture.

Experience of the surgeon

According to the study of Block et al. (12), they studied the accuracy of implant placement in 80 patients using navigation system. 3 surgeons are included in this study. One surgeon had prior experience with dynamic navigation system while the other two had no prior dynamic navigation experience. The result showed that implant placed by experienced surgeon had minimal deviation and flat learning curve while the other two showed more deviation for the first 10 and second 10 cases, and then their learning curve flattened. They concluded that the proficiency from using navigation system is obtained by the 20th surgical procedure.

Accuracy of the image acquisition

CBCT has many advantages like significantly lower radiation exposure, reasonably short scanning times, compact design together with adequate accuracy compared with MSCT as mentioned before.

In conclusion, there are no significant different in accuracy in position of implant placement using dynamic CAIS among different bone types according to the previous studies.

II.4 Accuracy analysis

The displacement of the actual implant location from the virtual planning position is used to determine the accuracy of implant placement utilizing computer-assisted surgery. Implant planning software automatically superimposes postoperative CBCT scan image data on the virtual planning picture. On both picture sets, a mathematical algorithm was used to compute the positional and angular variation between the planned and actual implant position. (17). Several measuring parameters were used in the previous systematic reviews for the comparison of these positions (26) (34) (11) (35).

- deviation at the entry point of the implant (mm), measured at the center of the implant
- deviation at the apex of the implant (mm), measured at the center of the implant
- deviation of the axis of the implant (degree)
- deviation in height/depth of the implant (mm)

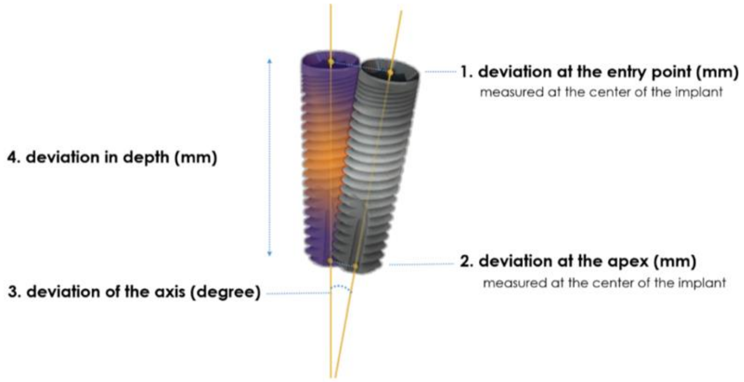


Figure 4 illustrates the different parameters for describing the deviations.
(Copied from reference No. #7)

For the first two parameters, the most common method was to measure deviation between the planned and actual point by one distance in 3D while some studies reported by two individual vectors with a buccolingual (x-axis) and mesiodistal (y-axis) distance. For deviation of the axis, the comparison was less complicated, since every study reported by degrees of deviation. For the deviation in height/depth, there was often reported as a negative number if the implant was not inserted as deeply as planned.

The advantages of applying a static or dynamic CAIS system to enable accurate implant positioning are identical. In addition, as compared to traditional approaches, the CAIS system provides a superior outcome in terms of implant placement precision. Furthermore, the CAIS system's virtual implant planning ensures proper implant angulation and depth for esthetic conditions, as well as allowing prosthetic and surgical collaboration with accurate planning to deliver high-quality patient-specific results (30).

5 Bone classification

There are many bone quality assessment studies which generally categorized the bone quality into four groups according to the proportion and structure of compact and trabecular bone tissue (36). In 1999, Misch et al. proposed four bone density groups based on cortical and trabecular bone which similar to the classification of Lekholm and Zarb in 1985 (37). Bone density groups divided into D1 to D4. D1 bone is almost dense compact, D2 bone is a combination of dense to porous compact cortical bone on the outside and ‘‘coarse’’ trabecular bone on the inside, D3 bone is porous, thinner cortical bone and ‘‘fine’’ trabecular bone, D4 bone is ‘‘fine’’ trabecular bone that has very light density and little or no cortical crestal bone (38) (Figure6).

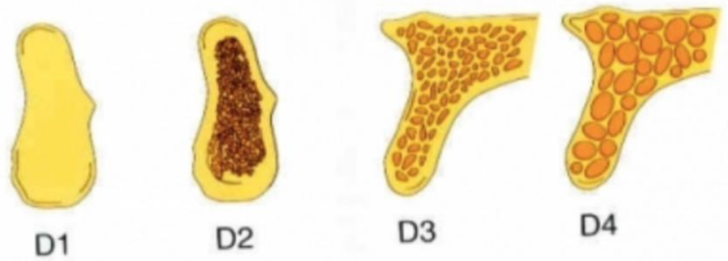


Figure 5 Four different type of bone according to Misch classification

(Copied from reference No. #41)

Each area of the jaw bone consist of individual type of bone quality. The anterior maxilla region (second premolar to second premolar), usually has D3 and D2 bone quality. In the posterior maxilla region (molar region) usually has D4 bone but in cases of sinus grafting it may have D3 bone 6 months after grafting. In addition, at the anterior mandible region (first premolar to first premolar) usually has D2 bone, but the resorbed anterior mandible may have D1 bone quality in approximately 25% of cases, more commonly in males. Lastly The posterior mandible region (second premolar and molars) usually has D3 bone, but in some case it can have D2 bone quality.

Chapter III

Research question

Is there any different in accuracy of implant position using dynamic CAIS system with 4 different bone types in edentulous area?

- P opulation: Bone blocks which receive dental implant placement
- I ntervention: Dynamic CAIS systems

- C omparison: Accuracy of implant position in 4 different bone types by using dynamic CAIS systems
- O utcome: deviation of post-op implant position from virtual planning

Objective

To compare the accuracy of implant position using dynamic CAIS system (navigation system) among 4 different bone types (D1 to D4)

Hypothesis

H_0 : Implant deviation at the global, lateral, depth, and angle in four bone types are not different.

H_1 : Implant deviation at the global, lateral, depth, and angle of the implants are different among four bone types.

Conceptual framework

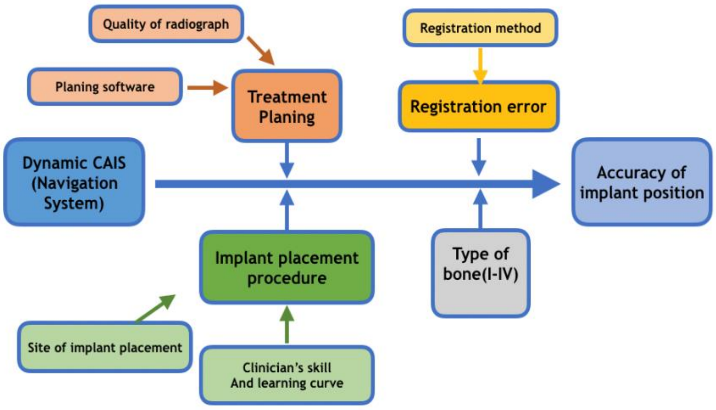


Figure 6 Conceptual framework

Chapter IV

Materials & Methods

Population and sample

according to the PICO the population are Typodonts, Dentist and field of surgery

1.Edentulous maxillary block with four different bone type I to IV.

2.Single doctor planed each implant position on the CBCT scan of dynamic navigation machine (E-PED I-ris 100) of the maxilla model and also performed implant delivery on the edentulous model by the same doctor.

3.The field of surgery consist of opposing arch and mouthed in manikin frame in order to stimulate the real situation that have limitation of visibility and sense of tissue interrupted.

Materials & Methods

This study is randomize control trial experiment study which evaluates the accuracy of implant placement in dental models under guidance from the Navigation implant placement machine (Iris – 100, EPED Inc., Taiwan). The experiment consists of four groups that comprised of bone types 1 2 3 and 4 were done by single surgeon with experiences of implant placement. Samples size was calculated from previous study, based on the implant platform, apex, and angle deviation values of edentate mandible and maxilla with dynamic CAIS systems (0.49 ± 0.16 mm vs. 0.58± 0.18 mm, 0.48 ± 0.13 mm vs. 0.63± 0.17 mm, and 1.25 ± 2.47 degrees vs. 1.26 ± 2.18 degrees) (1), the minimum required sample size of 114, 64 and 32 implants was separately calculated using a statistical software (G*Power software version 3.1, Erdfelder, Faul, & Buchner, 1996) for Oneway ANOVA with 80% of study power and significant level (α) of 0.05. In this study, it consists of 4 groups with 64 subjects which divided into 16 implants per group.

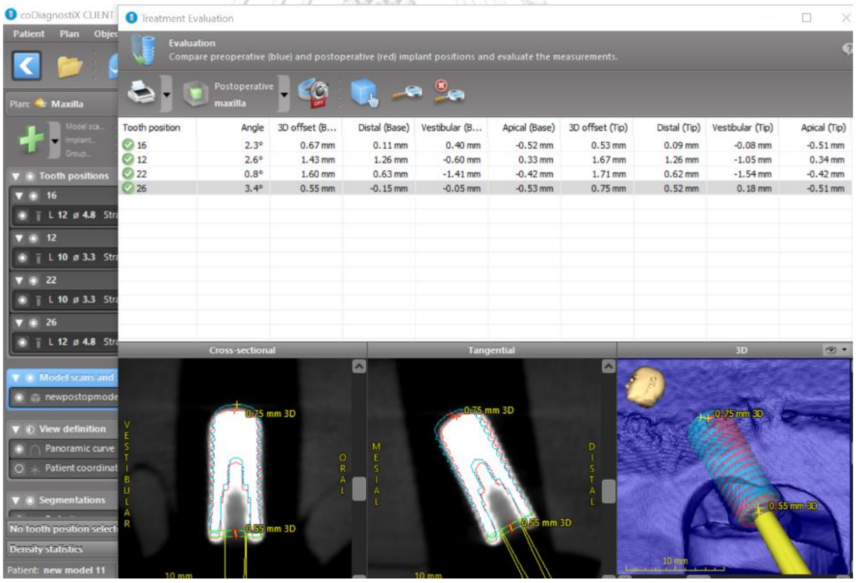
The poly-urethane model of maxillary edentulous arch which contained synthetic bone type D1-D4 (Sawbone®; Pacific Research Laboratories Inc., Washington ,USA) were used in this study (Figure 7). These bones made out from polyurethane foam for mechanical testing that had considered to be a standard used for performing orthopedic implant mechanical testing. The properties of artificial bone consist of variable range of densities. D1 was stimulated used 40 pound per cubic foot (pcf) with bone density of 0.64 g/cm3 polyurethane foam. D2 bone was stimulated using 30 pcf polyurethane foam with density of bone 0.48 g/cm3. D3 bone was stimulated 20 pcf polyurethane foam with density of bone 0.32 g/cm3, and D4 bone using 10 pcf with 0.16 g/cm3 to stimulate the artificial bone. Prior to CBCT examination, the surgeon places 3 mini-implants (S-Mini Ball Type RBM Surface & For Over Denture, NeoBiotech) in order to support the occlusal stent. The cone-beam computed tomography (CBCT) scan was performed using i-CAT machine (Imaging Science International LLC. Hatfield, PA, USA). During the CBCT scan, an occlusal guide device with four radiopaque fiducial markers (Iris-100, EPED Inc., Taiwan) was placed on the mini-implant supported guide of the maxillary model. The DICOM data set from the CBCT was imported into the dynamic navigation planning system (Iris-100, EPED Inc. Taiwan) to identify the arch and define the implant's dimensions, then the optimal 3-dimensional position of the implant was planned according to the concept of all-on-four. Moreover, the drilling sequence protocol was prepared and the four visible radiopaque fiducials on the CBCT image were labeled in order to use for registration respectively.

Figure 7 The poly-urethane model of maxillary edentulous arch which contained synthetic bone type D1-D4

In advance of the implant placement, the passive arrays were registered to determine the relationship between the geometry of the handpiece tracking array and the bur's axis. Each group's surgical implant preparation and insertion protocol were followed. Bone level tapered implant diameter 4.1 mm height 12 mm (Straumann, institute Straumann AG, Basel, Switzerland) was used in this experiment.

Following implant placement, all models with occlusal guided device were scanned using the same CBCT machine. Post-operative DICOM data was transferred and superimposed to the previous implant planning data.

Implant accuracy analysis was evaluated using the implant planning software (CoDiagnostiX 9.12 Dental Wings Inc, Montreal, QC, Canada) by comparing the placed implant position to the planned implant position. The primary outcomes were together with, 3D platform deviation (dislocation between the center at the platform of the planned and placed implant), 3D apex deviation (dislocation between the center at the apex of the planned and placed implant), and angular deviation (deviation between the axis of planned and placed implant) were calculated automatically by the software (Figure 8).



Treatment Evaluation

Evaluation

Compare preoperative (blue) and postoperative (red) implant positions and evaluate the measurements.

Tooth position	Angle	3D offset (B...	Distal (Base)	Vestibular (B...	Apical (Base)	3D offset (Tip)	Distal (Tip)	Vestibular (Tip)	Apical (Tip)
✓ 16	2.3°	0.67 mm	0.11 mm	0.40 mm	-0.52 mm	0.53 mm	0.09 mm	-0.08 mm	-0.51 mm
✓ 12	2.6°	1.43 mm	1.26 mm	-0.60 mm	0.33 mm	1.67 mm	1.26 mm	-1.05 mm	0.34 mm
✓ 22	0.8°	1.60 mm	0.63 mm	-1.41 mm	-0.42 mm	1.71 mm	0.62 mm	-1.54 mm	-0.42 mm
✓ 26	3.4°	0.55 mm	-0.15 mm	-0.05 mm	-0.53 mm	0.75 mm	0.52 mm	0.18 mm	-0.51 mm

Figure 8 Implant accuracy analysis was evaluated using the implant planning software (CoDiagnostiX 9.12 Dental Wings Inc, Montreal, QC, Canada)

Statistical Analysis

The statistical analysis was done using IBM SPSS Statistics program version 28.0 (IBM, Armonk, NY). To determine the normality of the bone type, angulation, and tooth site, the Shapiro-Wilk test was used. The Levene test was used to identify homogeneity of variance. To assess if there were any significant differences in the deviation of the groups, one-way ANOVA and Games-Howell post-hoc analysis was used. To determine the different between angulated and straight implant in each bone type, the independent t-test was analyzed.

The Pearson correlation was used to assess the relationship between each bone type and implant accuracy parameters. A significance level of 0.05 was determined as statistically relevant.

Chapter V

Result

Altogether, sixty-four dental implants were placed in the edentulous models which divided into four different bone densities of sixteen models in each individual bone type. The overall result demonstrated that angle (degree) deviation was 2.60 ±1.04°, Mean implant deviations at platform and apex were 1.27±0.55 and 1.25±0.62 respectively

The data distribution was normal in all data sets of primary outcomes with the homogenous variances. Hence, One-way ANOVA was used for comparison. No significant differences were found between four groups of bone density in all parameters; The angular deviation, Implant 3D platform deviation and 3D apex deviation. The results of the implant deviation in each bone density were summarized in Table 2 and Figure 11-13. Significant differences were found in apex deviation between the angulated and non-angulated implants of Bone D4. The lowest bone density group (type4) also illustrated the highest deviation for all implant deviation differences between groups analyzed by the Post Hoc test

When comparing angulated to non-angulated implant, overall result shows no statistical relation as shown in Table 3. All parameters illustrate negative correlations in each type of bone density and there were significant negative correlations between bone density and apex deviation (P=0.38) as shown in Table 4 and Figure 10.

Parameter	**Bone Type**	**Deviation**	ρ **-value (0.05)**
3D Platform deviation (mm)	D1	1.12±0.07	0.855
	D2	1.08±0.11	0.359
	D3	1.05±0.12	0.510
	D4	1.21±0.12	0.105
3D Apex deviation (mm)	D1	1.00±0.11	0.710
	D2	1.07±0.10	0.332
	D3	1.00±0.12	0.910
	D4	1.39±0.13	0.423
Angular deviation (degree)	D1	2.17±0.24	0.768
	D2	2.28±0.26	0.427
	D3	2.53±0.23	0.574
	D4	2.73±0.19	0.159

Table 2 The 3D deviations of the planned and placed implant using DNS at platform, apex, and angle deviation of the axis

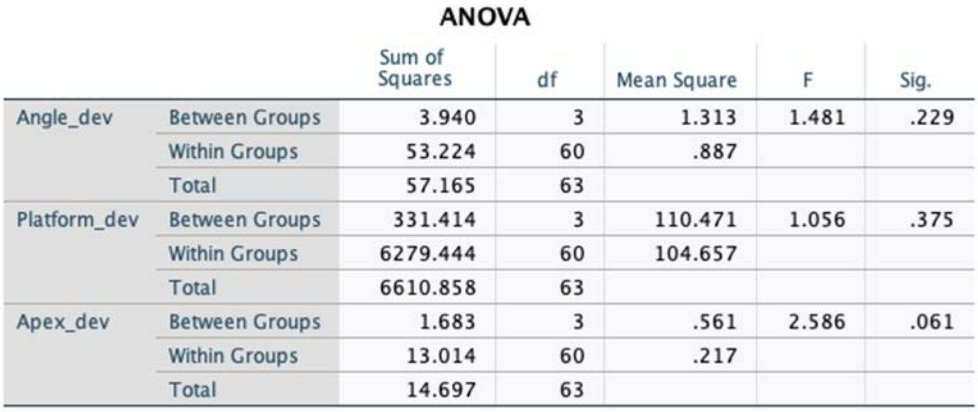
Parameter	**Angulated**	**Straight**	ρ **-value (0.05)**
Angular deviation (degree)	2.44±0.96	2.42±0.93	0.934
3D Platform deviation (mm)	1.06±0.48	1.16±0.36	0.368
3D Apex deviation (mm)	1.04±0.44	1.18±0.51	0.235

Table 3 The 3D deviation between angulated and straight implant using DNS

	Bone density	Angle deviation	3D- Platform deviation	3D-Apex deviation
Pearson Correlation	1	-2.34	-.060	-.260*
Sig.(2-tailed)		.062	.637	.038
N	64	64	64	64

Table 4 Pearson correlation between bone density and all implant deviations

*Statistically significant difference is **



ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Angle_dev	Between Groups	3.940	3	1.313	1.481	.229
	Within Groups	53.224	60	.887		
	Total	57.165	63			
Platform_dev	Between Groups	331.414	3	110.471	1.056	.375
	Within Groups	6279.444	60	104.657		
	Total	6610.858	63			
Apex_dev	Between Groups	1.683	3	.561	2.586	.061
	Within Groups	13.014	60	.217		
	Total	14.697	63			

Figure 9 One-way ANOVA between four groups of bone density in all parameters; The angular deviation, Implant 3D platform deviation and 3D apex deviation.

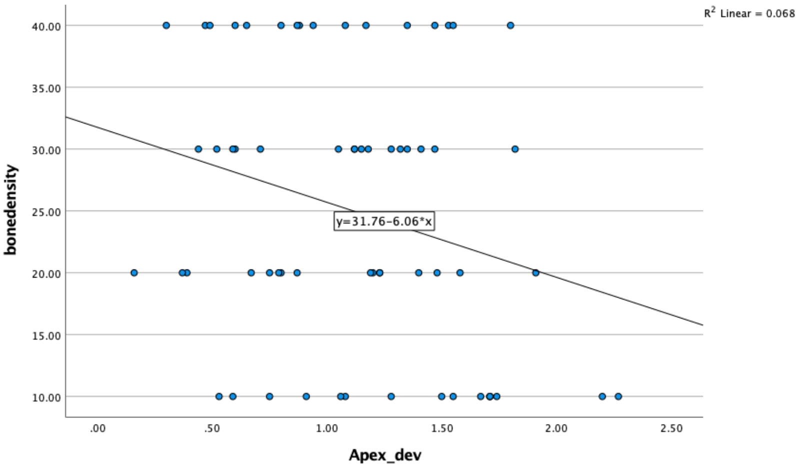


Figure 10 Negative correlations between bone density and apex deviation

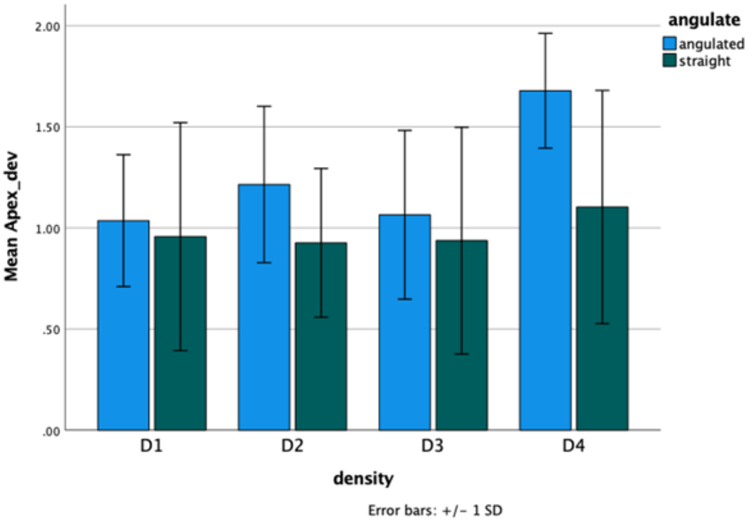


Figure 11 apex deviation between the angulated and non-angulated implants of Bone D4

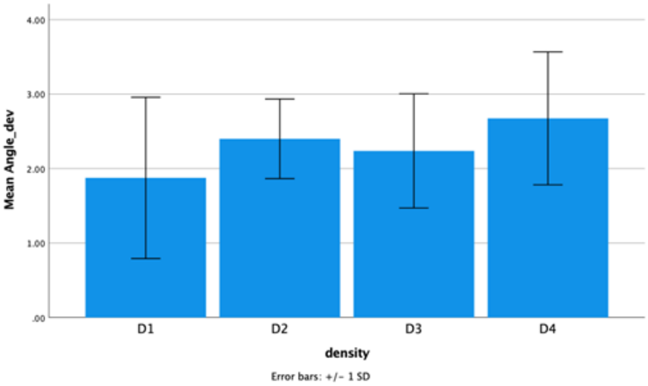


Figure 12 Bar graphs show angular deviation (degree) in each bone density

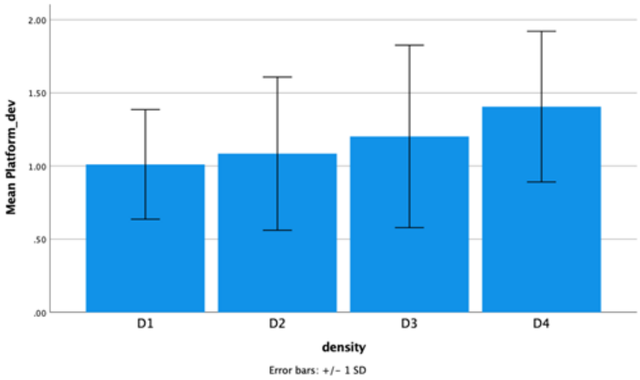


Figure 13 Bar graphs show mean platform deviation (mm) in each bone density

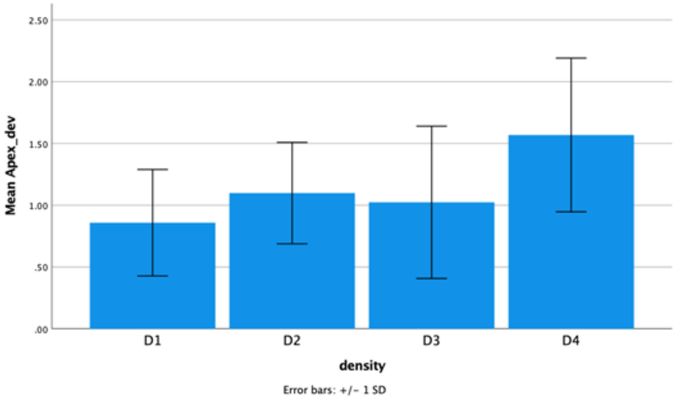


Figure 14 Bar graphs show mean apex deviation (mm) in each bone density

Chapter VI

Discussion

Bone condition evaluation performed prior to implant placement surgery to determine the implant number, size, and angulation. Following that, three-dimensional CT images can provide accurate anatomical information about the bone condition (19, 20) (36) as well as determining the healing process, which is related to contact of bone and biomechanical properties of surrounding bone, and which occurs at the time when the implant is first placed. As a result, secondary stability became important during osseointegration. Furthermore, bone density can have an impact on implant placement. Treatment planning, implant design, surgical technique, and initial loading of a prosthesis can all be influenced by bone density. Because of the lack of implant stability and extensive bone resorption, low bone density is linked to an increased risk of implant failure. For long-term success, bone densities and implant planning positions at the recipient site must be properly recognized before, during, and after the implant is delivered.

In terms of the dynamic CAIS system, this has a considerable impact on implant placement accuracy. in overall aspects compared to conventional technique implantation in all types of bone densities. Several in vitro studies have illustrated that achieve more accurate implant placement using CAIS system over the conventional technique. Dynamic navigation resulted in higher accuracy than the freehand method, and similar accuracies were found between dynamic navigation and static guidance for platform deviation, apical deviation or angular deviations. Additionally, the navigation system provided real-time monitoring of the depth of drilling, based on which, the dentist could decide the point at which to stop drilling with more certainty. As a consequence, dynamic CAIS was able to mimic the risk of injuries of the critical anatomic structure like mandibular nerve, maxillary sinus floor and incisive canal. Nonetheless previous study had stated that variable densities of bone changing along the drilling socket can compromise ability of surgeon to performed implantation accurately. Gaggl, Schultes, & Kärcher, 2001; Ruppin et al. suggested that dense bone may offer better implant placed position (9, 39).

In the literature, there is controversy over the question of whether bone quality affects the accuracy of dynamic CAIS, with some studies reporting a statistically significant negative correlation between bone density and the accuracy of static CAIS (19-21). Although, according to other studies, no correlation (40) or statistically significant positive correlation has been observed between bone density and the accuracy of CAIS (41).Lower bone density could cause more deviation when using a free hand technique to place an implant, according to Ozan, Orhan and Turkyilamaz (2011) ; Noharet, Pettersson, & Bourgeois (2014), The CAIS system, on the other hand, could help to reduce malposition and solve the problem of poor bone quality. Moreover, earlier research has shown that while employing the CAIS system, arch type, age, and gender had no statistically significant differences in outcomes (42) (18, 20) . However, there is no report of the accuracy of implant placement under dynamic CAIS in different bone densities.

According to this in vitro study that performed placing implant to evaluate the accuracy of implant position through dynamic CAIS system (navigation system) in variety bone types (D1 to D4). The null hypothesis was rejected since the result showed no statistically significant different in overall accuracy measurement among each bone types (P>0.05).

Additionally, in term of precision of implant placement, the deviation achieved in every groups were smaller than the results reported by previous in vitro studies by (43) which compared preoperative and postoperative CT scans in maxilla and mandible models using navigation systems, guided and freehand placement.

Nevertheless, negative correlation was found between the bone density of the placed implant sites and apex deviations (P=0.038*) in the implant placement with dynamic CAIS ,the result also should trend towards negative correlation between bone density and the accuracy of implant placement in angular deviation (P= 0.62) and platform deviation (P=0.637) which was the border line of the statistical analysis with Spearman's rho. Moreover, the result of this study illustrated that there is highest deviation in the lowest bone density (D4) of implant placement in all parameters. Despite the fact that there were no significant accuracy differences were found between implant positions within the different quadrants, the deviation of all parameters in the left quadrants illustrate higher compared to right quadrants. This might be as a result of the location of registrational fiducial markers on an occlusal stent influencing field of vision. This observation could be the outcome of dynamic CAIS, which is still essentially a "freehand" surgical placement, as placement under dynamic CAIS is done by direct vision and manual control. Despite this, there was no indication that such an influence had any effect on overall accuracy outcomes.

Treatment of edentulous jaws in a single surgical procedure without the use of bone transplants, maximizing available bone. As a result, the notion of all-on-four was established with the concept of two most anterior implants are placed axially, whereas the two posterior implants are angled and put distally to reduce cantilever length and allow prosthesis to be applied (5). In terms of angulation, the results of this study showed that there is no significant difference in angular deviation between straight and angulated implant. It might be due to the navigation system's accuracy and usefulness. Meanwhile, in term of apex deviation, angulated implant illustrates significantly higher deviation than straight implant in lowest bone density (D4) which might be a result from the field of vision when doing angulated implant and also difficulty performing implant in soft bone.

However, there were some limitations to the present study. This study used cast models to perform the drilling experiments. The cast models were ideal for quantifying accuracy, because there was no saliva, no blood or other clinical interferences when drilling, and the models were stable throughout the drilling. However, this model did not replicate important clinical issues, such as the existing sockets, which would make stable and precise drilling more difficult. Besides, the process of this experiment could not eliminate the effect of operator experience on the results. In dynamic CAIS, common limitations and errors include TRE, or limitations related to the learning curve of using the navigation system. Hence, the results of this study may vary in a clinical setting (Chen et al 2018). In addition, future research should focus on more challenging implant placement scenarios, including as the use of CAIS in totally edentulous individuals.

Chapter VII

Conclusion

The effect of bone condition on implant placement accuracy with dynamic computer-guided surgery is statistically unaffected within the limitations of our study. Low bone density is a risk factor for implant implantation errors. As a result, even employing dynamic computer-guided surgery, the physician should take these bone conditions into account while performing implant insertion surgery. These findings will need to be confirmed in other well-designed research with a bigger sample size.

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Appendix

VITA

NAME	Jutasinee Pornpolsarun
DATE OF BIRTH	30 October 1992
PLACE OF BIRTH	Bangkok
INSTITUTIONS ATTENDED	Esthetic Restorative and Implant Dentistry Faculty of Dentistry Chulalongkorn University
HOME ADDRESS	55/5 Srinakarin road, Bangkaew, Bangpli, Samutprakarn 10540