ACCURACY COMPARISON OF STATIC CAIS VS DYNAMIC CAIS IN SINGLE SPACE LOSS AT UPPER ANTERIOR REGION IN FOUR TYPES OF BONE DENSITY

Miss Phloi Chaisuwannarak

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การเปรียบเทียบความแม่นยำระหว่างแผ่นจำลองนำทางผ่าตัดและเครื่องนำทางผ่าตัดเสมือนเวลาจริงที่ได้จากการวางแผนฝังรากเทียมด้วยโปรแกรมคอมพิวเตอร์ช่วยเหลือในสันเหงือกว่างชนิดเดี่ยวบริเวณฟันหน้าบนที่ความหนาแน่นของกระดูกสี่ชนิด

น.ส.พลอย ชัยสุวรรณรักษ์

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คณะทันตแพทยศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
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Thesis Title	ACCURACY COMPARISON OF STATIC CAIS VS DYNAMIC CAIS IN SINGLE SPACE LOSS AT UPPER ANTERIOR REGION IN FOUR TYPES OF BONE DENSITY
By	Miss Phloi Chaisuwannarak
Field of Study	Esthetic Restorative and Implant Dentistry
Thesis Advisor	Associate Professor ATIPHAN PIMKHAOKHAM, D.D.S.,M.P.A.,Ph.D.
Thesis Co Advisor	Associate Professor PRAVEJ SERICHETAPHONGSE, D.D.S.,M.S.

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
(Assistant Professor SUCHIT POOLTHONG, D.D.S.,M.Sc.,Ph.D.)

THESIS COMMITTEE

.... Chairman
(Associate Professor SIRIVIMOL SRISAWASDI, D.D.S.,M.S.,Ph.D.)

.... Thesis Advisor
(Associate Professor ATIPHAN PIMKHAOKHAM, D.D.S.,M.P.A.,Ph.D.)

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

.... External Examiner
(Assistant Professor Chaimongkol Peampring, D.D.S.,Ph.D.)

พลอย ชัยสุวรรณรักษ์ : การเปรียบเทียบความแม่นยำระหว่างแผ่นจำลองนำทางผ่าตัดและเครื่องนำทางผ่าตัดเสมือนเวลาจริงที่ได้จากการวางแผนฝังรากเทียมด้วยโปรแกรมคอมพิวเตอร์ช่วยเหลือในสันเหงือกว่างชนิดเดี่ยวบริเวณฟันหน้าบนที่ความหนาแน่นของกระดูกสี่ชนิด. (ACCURACY COMPARISON OF STATIC CAIS VS DYNAMIC CAIS IN SINGLE SPACE LOSS AT UPPER ANTERIOR REGION IN FOUR TYPES OF BONE DENSITY) อ.ที่ปรึกษาหลัก : ผศ. ดร.อาทิพันธุ์ พิมพ์ขาวขำ, อ.ที่ปรึกษาร่วม : รศ. ทพ.ประเวศ เสรีเชษฐพงษ์

วัตถุประสงค์: งานวิจัยนี้มีวัตถุประสงค์เพื่อเปรียบเทียบความแม่นยำของการฝังรากเทียมบริเวณสันเหงือกว่างตำแหน่งฟันหน้าบนที่มีการสูญเสียฟัน 1 ซี่ในบริบทของความหนาแน่นของกระดูกที่แตกต่างกัน4ชนิดโดยวัดความความคลาดเคลื่อนของตำแหน่งรากเทียมที่ฝังเปรียบเทียบกับตำแหน่งที่วางแผนไว้ก่อนการเริ่มการทดลอง การฝังรากเทียมทำโดยใช้คอมพิวเตอร์แบบแผ่นจำลองนำทางผ่าตัดและเครื่องนำทางผ่าตัดเสมือนเวลาจริง

วัสดุและวิธีการ: แบบจำลองฟันบนที่มีสันเหงือกว่างที่มีการบรรจุกระดูกเทียมตามความหนาแน่นทั้ง4แบบบริเวณสันเหงือกว่างซี่ 11 จำนวน 64 ชิ้น โดยจะแบ่งการทดลองออกเป็น 2 กลุ่มได้แก่กลุ่มที่ใช้คอมพิวเตอร์แบบแผ่นจำลองนำทางผ่าตัดและกลุ่มเครื่องนำทางผ่าตัดเสมือนเวลาจริงขนาดทดลองของแต่ละกลุมคือ 32 ชิ้นและประกอบไปด้วยกลุ่มย่อยของความหนาแน่นกระดูกในแต่ละประเภทอย่างละ8ชิ้น โดยการทดลองในแต่ละระบบนั้นจะมีการถ่ายภาพรังสีส่วนตัดอาศัยคอมพิวเตอร์แบบโคนบีมทั้งก่อนและหลังฝังรากเทียม จากนั้นเมื่อได้ภาพถ่ายรังสีมาแล้วนำภาพถ่ายรังสีเข้าสู่กระบวนการวางแผนการรักษาด้วยโปรแกรมทางคอมพิวเตอร์ทั้ง 2 ซอฟต์แวร์ หลังจากนั้นทำการฝังรากเทียมตามที่วางแผนไว้ในแบบจำลองฟันบนโดยมีแบบจำลองฟันล่างทำหน้าที่เป็นคู่สบติดอยู่กับหัวจำลองเพื่อจำลองสถานการณ์เสมือนจริงของผู้ป่วยโดยมีทันตแพทย์ผู้ผ่าตัด 1 คนเป็นผู้ทำการฝังรากเทียม เมื่อเสร็จสิ้นการฝังรากเทียม แบบจำลองทั้งหมดจะถูกถ่ายภาพรังสีส่วนตัดอาศัยคอมพิวเตอร์แบบโคนบีม จากนั้นจะถูกนำเข้าซอฟต์แวร์เพื่อทำการวิเคราะห์ความคลาดเคลื่อนที่ตำแหน่งขอบบนของรากเทียม, ปลายรากเทียม และความคลาดเคลื่อนเชิงมุม

ผลการศึกษา: จากผลการทดลองของตัวอย่าง 64 ชิ้น ผลรวมความคลาดเคลื่อนเฉลี่ยเชิงมุมในกลุ่มใช้คอมพิวเตอร์แบบแผ่นจำลองนำทางผ่าตัดคือ 0.62±0.31องศา และ ในกลุ่มเครื่องนำทางผ่าตัดเสมือนเวลาจริงคือ 1.30±0.48 องศา นอกจากนี้ความคลาดเคลื่อนที่ตำแหน่งขอบบนของรากเทียมในกลุ่มใช้คอมพิวเตอร์แบบแผ่นจำลองนำทางผ่าตัดคือ 0.93±0.29 มม. และ1.02±0.37 มม. ในกลุ่มเครื่องนำทางผ่าตัดเสมือนเวลาจริงตามลำดับ และความคลาดเคลื่อนเฉลี่ยที่ตำแหน่งปลายรากเทียมในกลุ่มใช้คอมพิวเตอร์แบบแผ่นจำลองนำทางผ่าตัดคือ 0.98±0.31 มม.และในกลุ่มเครื่องนำทางผ่าตัดเสมือนเวลาจริงคือ 1.26±0.47 มม. ตามลำดับ โดยพบความแตกต่างอย่างมีนัยสำคัญทางสถิติระหว่างกลุ่มใช้คอมพิวเตอร์แบบแผ่นจำลองนำทางผ่าตัดและเครื่องนำทางผ่าตัดเสมือนเวลาจริงในแง่ของความคาดเคลื่อนเชิงมุมและความคลาดเคลื่อนบริเวณปลายรากเทียมโดยกลุ่มคอมพิวเตอร์แบบแผ่นจำลองนำทางผ่าตัดให้ผลแม่นยำกว่าอย่างมีนัยสำคัญทางสถิติ ในทางตรงกันข้ามความคลาดเคลื่อนบริเวณขอบของรากเทียมและความคลาดเคลื่อนที่ความแตกต่างในเชิงความหนาแน่นของกระดูกนั้นให้ความแม่ยำไม่แตกต่างกันอย่างมีนัยสำคัญทางสถิตในการทดลองของทั้งสองกลุ่ม

สรุปผลการศึกษา: การฝังรากเทียมในสันเหงือกว่างที่สูญเสียฟัน 1 ซี่ โดยใช้คอมพิวเตอร์แบบแผ่นจำลองนำทางผ่าตัดและเครื่องนำทางผ่าตัดเสมือนเวลาจริงให้ผลความแม่นยำ ถึงแม้ว่าจะพบความคลาดเคลื่อนของในบางหน่วยวัดแต่ไม่เกินขอบเขตไม่ปลอดภัยในการฝังรากเทียม นอกจากนี้การฝังรากเทียมทั้ง 2 ระบบให้ความแม่นยำในความหนาแน่นที่ความแตกต่างกันของกระดูกเทียบเท่ากันทั้ง 2 ระบบ

สาขาวิชา	ทันตกรรมบูรณะเพื่อความสวยงามและทันตกรรมรากเทียม	ลายมือชื่อนิสิต ....
ปีการศึกษา	2561	ลายมือชื่อ อ.ที่ปรึกษาหลัก ....
		ลายมือชื่อ อ.ที่ปรึกษาร่วม ....

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KEYWORD: dental implant computer assisted surgery static dynamic accuracy stereolithographic template anterior tooth

Phloi Chaisuwannarak : ACCURACY COMPARISON OF STATIC CAIS VS DYNAMIC CAIS IN SINGLE SPACE LOSS AT UPPER ANTERIOR REGION IN FOUR TYPES OF BONE DENSITY. Advisor: Assoc. Prof. ATIPHAN PIMKHAOKHAM, D.D.S.,M.P.A.,Ph.D. Co-advisor: Assoc. Prof. PRAVEJ SERICHETAPHONGSE, D.D.S.,M.S.

Purpose: To compare the precision of implant placement in the single space missing of anterior tooth in different circumstances of bone type using static CAIS system (Co-diagnostic system Straumann ®) and dynamic CAIS system (E-PED, I-RIS100). The author hypothesized that the overall accuracy of implant placement using static and dynamic CAIS system among four types of bone are not different.

Methodology: 64 upper models with artificial bone density D1-D4, divided in to 2 main groups of static CAIS group and dynamic CAIS, which each subgroups contain 8 models for individual bone group, were prepared with single space edentulism on tooth no.11.Virtual implant position were planned according to CBCT using co- DiagnostiX™ software and E-PED software. After stereolithographic 32 surgical stents were designed and printed out for static CAIS group and 32 occlusal appliances arch holding with fiducial markers were created and virtual planned had prepared. Single surgeon placed the implant size 3.3x10 mm.(Straumann ®) according to the protocol of the software. Then CBCT were taken again for all the samples after obtaining postoperative CBCT, the DICOM file of samples were superimposed with virtual planned of individual model.

Result :The data from 64 models, 8 models for each bone types, involving 64 implants were evaluated. Each densities type of bone provided no significant role of misalignment in static and dynamic groups of CAIS.The overall mean angular deviation was 0.62±0.31° in static CAIS and 1.30±0.48° in dynamic CAIS, the overall mean total offset at platform deviation was 0.93±0.29 mm in static CAIS and 1.02±0.37 in dynamic CAIS. Besides the overall mean total offset at apex deviation was 0.98±0.31 mm in static CAIS and 1.26±0.47 mm. in dynamic CAIS. The overall angle deviation and total offset at apex deviation of static CAIS group demonstrated statistically significant difference when compared with dynamic CAIS ($p<0.05$). However overall total offset at platform of static and dynamic CAIS and difference in densities of bone show no significant difference between static and dynamic CAIS ($p>0.05$).

Conclusion: Using CAIS system for implant placement in single tooth loss showed small deviation from virtual implant planned position among four bone types. The result reflected accuracy and precision can be achieved from CAIS system when placing implant in any density of bone.

Field of Study:	Esthetic Restorative and Implant Dentistry	Student's Signature ....
Academic Year:	2018	Advisor's Signature ....
		Co-advisor's Signature ....

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Phloi Chaisuwannarak

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Chapter I

Background and rational

Dental implants are commonly use to replace teeth lost that overcome the benefit over alternative restoration such as bridges and removable denture(1) which are one of those alternative ways. After implants have been introduced. Implants are the best choice that can maintain and stabilize alveolar bone. Moreover implants provide predictable long term success rate and longevity. However implant placement comes with several challenges such as narrow bone with thin margin, limitation of critical anatomy and type of bone. The recent placement implant concept is driven by prosthetic. In term of achievement the success in function and esthetic, implant position must be placed in a proper position according to appropriate treatment plan and proper surgical procedure. Implantation must also be placed accurately in 3 dimensional positioned to support restorations that esthetically and functionally align with adjacent and occluding dentition. In the anterior region of maxilla implantation require greater valid positioned accuracy due to the obvious visualization and social association besides if a high lip line is present, the smile line is more revealing. Therefore increasing the need for an esthetic result is required, with some authors ranking function and esthetics in the anterior maxillary region to be of equal importance(2-5).Traditional methods for implant placement include freehand approach and use of conventional surgical guide stents that fabricated from preliminary study models. These methods, patient's anatomical information is obtained from conventional periapical or panoramic radiographs while critical anatomies, such as inferior alveolar canal, maxillary sinus and periodically bone cleft and defect of bone at the anterior region, are not clearly display with two dimension image when compare with three dimensional data.

Hence, when traditional methods are engaged, the clinical outcomes often display unpredictable result and that may lead to malposition of implants followed by unwanted complications(6).These challenges are being met by the recent development and utilization of visualization tools that assist in improving the accuracy of implant planning and surgical guides that assist in accurate placement of implants(1, 4). In recent year the use of cone-beam computer tomography CBCTs imaging had significant increase due to less exposure to radiation and the software allow 3 dimensional(3D) planning of implant to level of accuracy and margin of safety CBCT imaging has also been developed the technology of computer-assisted surgical implant placement system(CAIS). Both static and dynamic image navigation are highly accurate, dynamic navigation system have following advantages.

1.The patient can be scanned, planned and undergo surgery on the same day.

2. The plans can be altered during surgery when clinical situation dictate a change

3.Accuracy can be verified at all time(1) In the esthetic zone, the correction of 3D position implants placement is a strictly requirement for achieving optimum esthetic and functional outcomes with implant therapy. According to the previous studies had proved that there are no significant different in accuracy using static and dynamic CAIS, however most studied performed testing on variety area of tooth site include anterior and posterior teeth. Nonetheless, There are no study that had reported accuracy of static and dynamic CAIS only in esthetic zone with single tooth missing and investigate the accuracy of implant placement among four different bone types that might contain the impact on the accuracy of implant placement by using static and dynamic CAIS. Therefore this study will focus on testing the three dimension accuracy by comparing the utilisation between the static and dynamic CAIS in an esthetic zone with single tooth missing area in four different types of bone. CAIS system can be categorized into two groups which are static and dynamic(1, 7). Static CAIS system utilise with surgical guides fabricated with computer aid design (CAD/CAM) base on 3D scan of the patient(1, 7, 8) Subsequently, 3D acrylic resin surgical guide stents are fabricated by a computer-guided laser beam that polymerizes photosensitive liquid acrylic (stereolithography).

The metal cylinders used as drill-guiding tubes are then integrated into the acrylic stent space, and the guides are spontaneously in function for use clinically (9). In contrary, dynamic CAIS system workflow with tracking sensor that connect with the patient and surgical instruments and present real time position and guidance feedback a computer display(1, 10). At the time of surgery, the surgeon performing the implant placement, tracking sensors attached on patient’s jaw and the handpiece. The sensor of both will transfer 3D positional information to an overhead tracking camera. Consequently, the system immediately calculate and display the actual position of the surgical instruments in the surgical area superimpose on the preoperative CBCT image on a monitor screen throughout the implant placement procedure (11). The literature demonstrate that the majority number of implants placed using the CAIS system provided great accuracy and the complex workflow of available system(1, 7, 8, 10).

Recent development of new software and hardware offer dental surgeon a larger choices of selection in CAIS devices. Awareness and recognition of indications and limitation of both types of CAIS system is important(1, 12, 13).

Chapter II

Review literature

II.1 Complication from malposition of implant placement

Proper implant position in relation with optimum volume of hard and soft tissue support are the important factors for successful treatment. As a consequence, the significant of proper amount bony support and appropriate thickness of soft tissues were understood as a necessity to achieve esthetic outcomes in the anterior maxilla. In addition correct of three-dimensional (3D) implant placement in term of "restoration-driven implant placement" is important achievement. This was derived the concept of "comfort" and "danger" zones for the position of implants in relation to the adjacent natural teeth(7, 8).

In a mesiodistal dimension, the implant should be positioned within the comfort zone (green zone). The danger zone is 1.0–1.5 mm close to the adjacent teeth (Figure1)(14). In Apicocoronally, the implant shoulder should be positioned about 3 mm apical to the gingival margin of the contralateral tooth in patients without gingival recession. The danger zone is entered when the implant shoulder is placed too deeply, or too coronally in relation to the comfort zone (green zone)(Figure2)(14). In the sagittal plane, the facial extent of the implant shoulder is about 1.5–2 mm buccally to the emergence point of the adjacent teeth (within the green comfort zone). The implant enters the danger zone when the shoulder is placed too facially this increases the risk of mucosal recession (Figure3)(14).

Figure 1 The concept of comfort and danger zone for position of implant in relation to adjacent teeth in mesio-distal aspect(14).

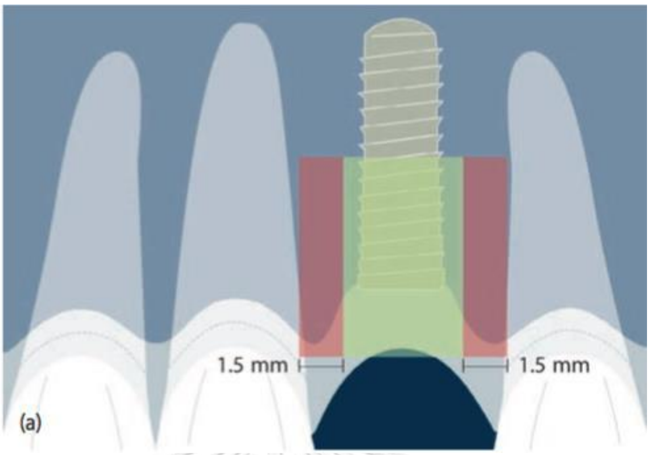


Figure 2 The implant should place 3 mm appicocoronally to adjacent teeth(14).

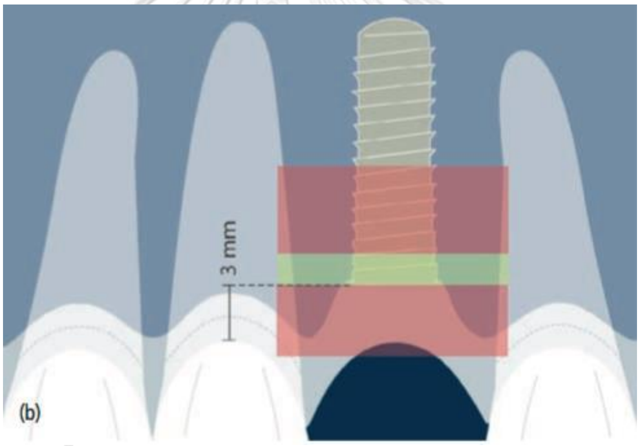
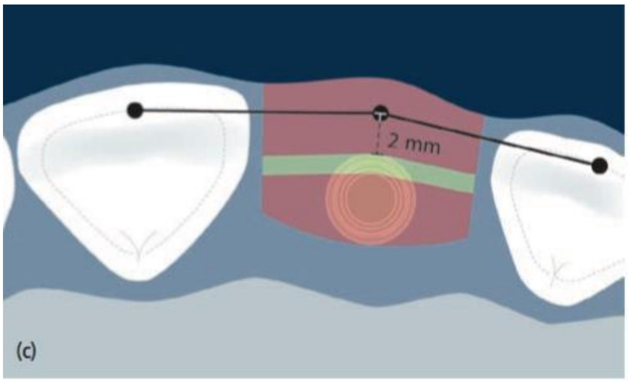


Figure 3 The facial extent of implant shoulder should position about 1.5-2 mm palatally in point of emergence profile of the adjacent teeth(14).



Malposition of dental implant placement may cause the complications to implant and component in two ways. First is that malposed implants in relationship to bone and peri-implant mucosa may predispose the implant to biologic failure. The second way is that malposition of dental implants relate to planned prosthesis position may have consequence in esthetic failure, biologic failure (by difficult oral hygiene practice), and/or mechanical/technical failure by increasing the improper forces acting within the prosthesis, abutment, abutment screws, implant fixture, implant–abutment interface or occasionally at the implant–bone interface(1).

Complications that occur from implant malposition in mesiodistal aspect may cause risk of reduced papilla height at the adjacent tooth due to crestal bone resorption and remodeling during the healing phase(10).Thus, the clinician has to maintain a distance of at least 1.5 mm with these implant types to the root surface of adjacent teeth in order to avoid crestal bone loss at the adjacent teeth and reduction in the papilla height. If an implant is placed too close to the adjacent tooth, there may not be enough space for developing appropriate soft tissues, resulting in complete absence of a papilla. When the mesiodistal malposition of the implant is extreme and differs 2–3 mm from the ideal prosthetic position, this can lead to significant and permanent loss of hard and soft tissue support with extremely adverse esthetic outcomes(14).

In corono-apical malposition direction can possibly cause two different complication. First, if the implant is not inserted properly in depth into the tissues, the metal implant shoulder can be visible then lead to an unpleasant esthetic outcome, although no recession of the mucosa is present. Second, implant placement that is too deep into the tissues. This apical malposition is able to cause recession of the facial mucosa, if the implant only accompany with a thin facial bone wall at implant placement. Following further restoration at the thin bony wall area, facial bone is able to resorb during the bone remodeling process. The inappropriate depth in position can also lead to persistent inflammation of the peri-implant mucosa, difficulty in maintaining adequate plaque control, and a poor soft tissue esthetic outcome(14). In Palato-facial aspect, the first complication occurs if the implant is positioned too far palatally. This consequence will often lead to a ridgelap design of the implant crown, that may make more difficult for the patient to maintain optimum plaque control with subsequent long-term implications for peri-implant tissue. Moreover increases dimensional of the crown on the palatal side, may impinge on the tongue space. The second complication is a recession of the facial mucosa if the implant is clearly positioned too far facially. This can cause severe esthetic complications, since the harmonious gingival course is significantly disturbed and often requires the removal of the implant(14). For the axis alignment problem, that compromise esthetic outcome would be in the position of inclination too far facially, are usually associated with recession of the facial mucosa. If the axis problem is severe and if it combined with facial malposition of the implant shoulder, the esthetic complication is usually very difficult to resolve. Implant malposition combined with multiple adjacent implants often lead to esthetic disasters. These scenarios are usually a result of inappropriate diagnosis, poor treatment planning, lack of understanding of the biological response of the hard and soft tissues, and poor execution of the surgical treatment.

Implant malposition problems can prevent by thoroughly implant planning procedures, Implant insertion in a correct 3D position is only one important prerequisite for successful esthetic 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 esthetic result. In esthetic 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 remodeling activities will lead to the resorption and flattening of the facial contour in postextraction 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 select CAIS program assist in implantation to obtain accurately implant position planning.

II.2 Computer-assisted implant surgery (CAIS)

Every computer-aided implant surgery (CAIS) system for dental implant planning contains its own characteristic advantages, disadvantages and limitation. The common goal of these systems is the achievement of optimum surgical safety on the basis of an exact diagnosis, virtual planning and high accuracy for the surgical transfer.

Three-dimensional (3D) visualization is a basic means of CAIS systems and allows exact diagnosis and optimized virtual planning as necessary pre-conditions for the achievement of optimal esthetical and long-term results in implant dentistry. Until 1998, 3D visualization in dental medicine was mainly available by medical computed tomography (CT) with certain compromises in terms of device and image costs, radiation exposure and operational availability. Since the introduction of the cone-beam CT (CBCT) technology, 3D diagnosis became fully applicable in dental practices often combined with the benefit of a significantly lessen radiation exposure to the patient when compared with a conventional medical CT diagnosis.

Different CAIS systems exploit the advantages of optimal 3D diagnosis and software-based planning by precisely transfer the virtual implant positions to the corresponding anatomical patient's sites. Accurate delivery of 3D dental implant planning becomes particularly crucial for approaches in flapless surgery, preparation prosthesis prior to the surgery in case of immediate loading, decrease the risk of critical anatomical structures injury and to eliminate conventional placement method failure.

Since 1997, different approaches for computer-assisted implant planning are available. The suggested solutions mainly compose of real-time tracking systems stimulate as dynamic or active systems, while static surgical drill templates referred to passive systems.

II.2.1 Static computer assisted system

Static CAIS system or computer-guided surgery uses computer-aided design and computer-aided manufacturing (CAD/CAM) technology together with CBCT and 3D implant planning software. The 3D image reconstruction from CBCT conduct to planning software in order create digitally virtual implant planning. In addition the correlation between the virtual implant position and radiographic template is used to fabricate a stereolithographic surgical template which perfectly pair with the bone or tooth surface. A stereolithographic guided surgery system comprise of a stereolithographic surgical guide with implant system that correspond with installation of fixture mounts, additional guide sleeves for fixation screw installation, drill keys with variable length, measurement of calibrated drills in order to properly prepare the osteotomies(12).

The process of computer-generated guide production begin with patient underwent with a cone-beam CT scan (CBCT) taking. Patient has to wear a radiographic template encouraging the preoperative prosthetic design as an prosthetic driven imaging guideline. The CBCT Digital Imaging and Communications in Medicine (DICOM) file was then transferred into the implant planning software. In the mean time the CBCT data was converted into the surgical software to demonstrate the planned position of the teeth in relation to the bone. Using the 3D implant planning software, evaluate the intrabony structure in relation to the position of the prosthetic teeth through the merging of individual data. Then the proper size of implant is planned through prosthetic driven concept(13, 15, 16). After the plan is completed, data is sent to the milling center in order to fabricate the stereolithography surgical template via a CAD/CAM procedure, with the implant positioning sleeves. Surgical template is adjustable till it meet the proper seating position on the cast and patient(17).

The advantages of utilisation of surgical guided procedure include 1) reduction of surgery times, 2) Decrease treatment times, 3) less invasive, available to perform flapless surgery consequence in lower incident of swelling, reduce pain and trauma, and accelerate initial healing times, 4) availability of a prefabricated definitive or provisional prosthesis immediate insertion(12). The CAD/CAM surgical template provide accessible transfer the virtual implant planned positions from the software to the patient with the surgical instrumentation operation and protocol of the software. Due to the design of the surgical instrumentation, the osteotomy site preparation is more precise, therefore, there is a greater possibility of having more stable implant. A limitation of this procedure is interarch space for the surgical instrumentation particularly in partially edentulous patient. Surgical drills have an extra 10 mm in length, therefore, this obstacle may lead to difficulty of appliances placement in patients with limited opening or those who need implant placement in the second molar area(17).In addition, CT-generated guided implant surgery requires several preoperative steps , according to such a complex treatment planning sequences with many potential sources of error, necessitate time delays and additional cost to the patient(18). Beside the utility of the CT planning software requires training skill to gain proficiency with the planning software and build a workflow barrier for the use of static CT-generated guides(19). Intraoperative disadvantages of CT-generated guides are the inability to prevent deviation of drill movement. If the sleeves are not truly fit with diameter of the drill, it will be unable to alter implant position and surgical plan when necessary. As well as impair the ability to irrigate the drill during the osteotomy preparation that may lead to potential for accelerate heat production. Therefore clinician will require the appropriate surgical kit that coordinate to the implant and CT.

Traditional method comprises of freehand approach and undergo the surgery with conventional surgical guide stent. Conventional dental panoramic tomography and plain film tomography are generally used for treatment planning that do not include three dimensional data. However conventional surgical templates allow guiding the bone entry position of the drills, surgical stent does not involve exact 3-dimensional guidance. Radiographic templates representing the prosthetic set-up often apply in terms of planning the optimal implant position on radiographs. The same templates can be used as a prosthetic reference during implant surgery. However, with this kind of preoperative planning the third dimension of the patient's anatomy is missing. Consequently, the templates are fabricated on the diagnostic stone cast without reference of the underlying anatomical structure. Thus, when traditional methods are engaged, the surgical outcome is often encounter with unpredictable result and malposition of implantation follow with many complications(6, 11).

Computer-assisted surgical implant placement (CAIS) has been introduce to overcome the limitations from freehand approach and conventional surgical guide stent method(6, 11, 20). The development of cone-beam computed tomography

(CBCT) and 3D implant planning software have been great development achievement in this field. These technology enable three dimensional imaging reconstructions and simulation of virtual implant placement on computer software(6, 21-23) generated guide system.

II.2.1.1 Accuracy of static CAIS system

Edelmann et al had studied about the accuracy of implant placement using static CAIS anterior maxilla area. The previous study reported that average implant placement deviations range between -0.04 to 0.37mm mesio-distally and -0.42 to 0.38 mm facio-lingually and at apex was 1.41 ± 0.9 mm with -1.59 to 4.05 degree angulation. This study was done with two experienced implant surgeons in each surgery(24).

George R. et al had studied about the accuracy of implant placement using static CAIS system(3shape system) in anterior maxilla(tooth 11).The result show that mesiodistal and facio-lingual deviations ranged from 0.05-0.62 mm and 0.08-0.72 mm, respectively. Angular difference between the planned and placed implant positions ranged from 0.08-4.83 degrees mesiodistally and 1.12-6.43 degrees faciolingually(25).

Dalton M et al in 2013 had studied about the accuracy of implant placement using static CAIS system(Dental slice,Biopart) in anterior maxilla area. The result show that in maxilla area mesiodistal 2.17 ± 0.87mm.,apico coronal2.86 ± 2.17mm and mean angular deviation from virtual implant planned and placed was 1.93 ± 0.17degree

Valente et al.(26) studied the accuracy of implant placement using static CAIS system (Simplant, CSI Materialise) and found that mean deviation of 89 implants placed in 28 patients were 1.4 ± 1.3 mm at entry point, 1.6 ± 1.2 mm at apex and 7.9 ± 4.7 degrees for angle deviation.

Cassetta et al.(27) studied the accuracy of implant placement using static CAIS system (Simplant, CSI Materialise). The study found that mean deviation of 116 implants placed in 10 patients at the entry point was 1.47 ± 0.68 mm, at the apex was 1.83 ± 1.03 mm and angle deviation was 5.09 ± 3.7 degrees.

Farley et al.(28) compared the accuracy of 20 implants in 10 patients between using static CAIS system (Implant Master software, iDent Imaging) and conventional freehand guide. The study reported that Implants placed with CAD/CAM guides were closer to the planned positions than conventional guide in all parameters examined (1.45 ± 0.06 mm vs 1.99 ± 1.00 mm at the entry point, 1.82 ± 0.60 mm vs 2.54 ± 1.23 mm at the apex and 3.68 ± 2.19 degrees vs 6.13 ± 4.04 degrees for angle deviation) but statistically significant differences were shown only for coronal horizontal distances (Table1)

Table 1 The table demonstrate the overall accuracy in each static CAIS system use

Study	System	Implant (N)	Mesiodistal(mm)	Error facio-ligual(mm)	Error apex(mm)	Error angle (degree)
Edelmann et al	Simplant	94	-0.04 ± 0.37	-0.42 ± 0.38	1.41 ± 0.9 mm	4.05
George R. et al	3 shape	40	0.05-0.62	0.08-0.72	-	0.08-4.83
Dalton M et al	Dental slice Biopart	62	2.17 ± 0.87	2.32 ± 0.34,	2.86 ± 2.17	
Valente et al.	Simplant	89	1.4 ±1.3	-	1.6 ±1.2	7.9 ± 4.7
Cassetta et al	Simplant	116	1.47 ±0.68	-	1.83 ± 1.03	5.09±3.7
Faley et al	ident conventional	20	1.82 ± 0.60	-	3.68 ± 2.19	6.13 ± 4.04

II.2.1.2 Factors influence the accuracy of static CAIS system

Type of arch (maxilla / mandible)

Behneke et al.(18), studied 132 implants placed in 52 partially edentulous patients using static guide stents, had found a larger amount of maxillary deviations between planned and actual placed implant position may be due to the lower bone density of the maxilla, which is more susceptible to transfer inaccuracies than the compact mandibular bone. The result showed a borderline significant difference between maxilla and mandible for the linear deviation between planned and placed implant position at apex which larger in maxilla (0.50 vs. 0.40 mm, P = 0.033) but not for the linear deviation at neck and angular deviation.

Effect of age factors on the accuracy of guided surgery(29)

Age factor data was retrieved from 11 studies. Three age groups were created: 40-50 (four studies, n=493 implants); 50-60 (five studies, n=648 implants) and 60 or older (two studies, n=104 implants).The mean angular deviation was 4.15° (95% CI: 3.62-4.67) for the 40-50 group, 4.32° (95% CI: 3.78-4.87) for the 50-60 group and 4.43° (95% CI: 0.37-8.48) for the 60 or older group. The mean deviation at the entry point for the three age groups was 1.21mm (95% CI: 1.15-1.26), 1.23mm (95% CI: 0.81-1.64), and 1.03mm (95% CI: 0.40-1.65), respectively, and their corresponding mean apical errors were 1.47mm (95% CI: 1.40-1.53), 1.64mm (95% CI: 1.14-2.14), and 1.27mm (95% CI: 0.27-2.27.

Factor of flap approach(29)

Three studies (two prospective studies and one retrospective study, n=190 implants) compared the effect of open flap or flapless approach on guided surgery accuracy. Guided surgery with a flapless approach indicated a statistically significant greater reduction (P<0.001) in angle deviation (MD: 1.20 [95% CI: 0.90 to 1.50]) and coronal deviation (MD: 0.55 [95% CI: 0.45 to 0.65]) for deviation at the apex, the outcome of subgroup with retrospective study showed no statistical difference between flap and flapless group (P = 0.07), however, the global analysis showed that flapless group had significantly more accuracy (P<0.001) than open flap group.

Number of sleeve-guided site preparation steps (fully guided placement / freehand placement / freehand final drilling)

Behneke et al.(18) studied the accuracy of CT-generated guide surgery for different sections of the implant surgery. The fully guided placement mean that the implant were inserted through the sleeves into the guided osteotomy using a special implant carrier which fit the internal diameter of the guide sleeves. Freehand placement meant that the templates were used for controlling all of the osteotomy preparation procedure and the implants were inserted manually without a surgical guide using a regular implant carrier.

Freehand final drill mean that template were used for supported osteotomy up to the standard diameter (4–4.1 mm). The site development for implants with a wider diameter was performed manually. The implants were set without a surgical guidance. This experiment reported that significant differences were found in all aspects of measurement (implant coronal level, apex level, and angle). The highest deviations were found in the freehand final drilling method.

Surgical guides may interfere with effective use of the drills in the posterior jaws segments especially in the patient with limited mouth opening. Therefore the templates may be used only for the initial steps of osteotomy preparation but this can affect the accuracy of implant placement as reported previously in this study. Freehand final drilling, results in significantly higher deviation of implants than freehand placement and fully guided placement (at shoulder: 0.52 (0.97), 0.30 (0.78), and 0.21 (0.60) mm respectively, at apex: 0.81 (1.38), 0.47 (1.30), and 0.28 (0.77) mm respectively). The result shows that an increase in the number of sleeve-guided site preparation steps results in higher accuracy of implant placement.

Operator's skill (experienced / inexperienced)

Rungcharassaeng et al.(30) had studied the effect of operator's level of experience on the accuracy of implant placement with a computer-guided surgery protocol. The study reported that vertical direction is the aspect of deviation that had found significant misaligned among inexperienced surgeon.

II.2.2 Dynamic computer-assisted implant system / Navigation system (Dynamic CAIS)

Dynamic CAIS system or navigation system has been first introduce by Watzinger et al.(31) in 1999 as a technology that allows direct visualization procedure of the implant delivery on a computer monitor at real time, surgical procedure based on data retrieved from the patient's computed tomography. The dynamic navigation systems available for dental implant placement use optical technologies to track the patient and the hand piece with real time display operation images in a monitor(32, 33). The optical systems use either passive or active tracking arrays. Passive system use tracking arrays that reflect light emitted from a light source back to the stereo cameras. Active system arrays emit light that is tracked by stereo cameras(Figure4).

The workflow of dynamic navigation begins with attach the fiducial markers to the arch. A clip that contains 4 metallic fiducial markers is properly intact onto the patient's teeth in the opposite site of the surgical field. If an esthetic plan is involved, adding radiopaque teeth can be engaged in the mouth as an imaging guide to allow for later virtual implant positioning. The CBCT scan should be taken with the clip that attach occlusal appliance with fiducial markers. The clip can then be removed and stored for using during the surgery. The DICOM data set is then transferred to the navigation system's software. A virtual implant is then placed. 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. At surgery, the clip with the fiducial markers is attached to an array. The clip with the attached array and the handpiece with similar arrays should be registered to the navigation system by the staff. The surgeon can use traditional anesthesia and small incisions, with minimal flap reflection. The clip array should be securely repositioned onto the arch. The drill lengths should have been registered during the preparation process. The surgeon then positions the patient and arrays for direct line of sight to the overhead cameras(21). The advantages of the dynamic navigation method include its accuracy,(21) time and the ability to change the implant size, system, and location during the surgical procedure. It also requires less-invasive flap reflection compared with free-hand approaches and results in less trauma to the surgeon because the surgeon’s posture is improved, with less back and neck bending. In a patient who has difficulty with mouth opening or requires an implant at a second molar site, which can be difficult to access, dynamic navigation allows for implant placement by relying on the navigation screen to guide the drills without direct visualization in the patient’s mouth(34-37).

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Figure 4: Line drawings depict 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 (19).

II.2.2.1 Accuracy of dynamic CAIS system

Several clinical studies reported the accuracy of implant placement with dynamic CAIS system. Mean entry deviation was 1.1 – 1.37 mm, mean apex deviation was 0.8 – 1.56 mm and mean angular deviation was 3.62 – 6.4 degrees

Table 2 Mean deviation of each studies using dynamic CAIS to delivered implant on vary site of both arches

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	L a0.38 ± 0.25 Li 0.33 ± 0.25	La 0.44 ± 0.23 Lin 0.23 ± 0.12	0.78 ± 0.24
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

Block et al.(21) compared the accuracy of implant position between using dynamic CAIS system (X-Guide, X–Nav Technologies) and freehand approach in 100 patients with single tooth gap. The study 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 (Table2).

According to Robert W. et al (38) 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 planned and used to determine deviations from the virtual planned. The primary outcome variables were platform and angular deviations comparing the actual placement to the virtual planned. The angular accuracy of implants delivered using the tested device was 0.898 ± 0.358 degree for dentate case types measured relative to the preoperative implant plan. Three-dimensional positional accuracy was 0.38 ± 0.21 mm for dentate, measured from the implant apex (Table2).

Some laboratory studies compared the accuracy of implant placement between using several methods. Somogyi Gnass et al.(23) compared 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 (Materialise Dental, Leuven, Belgium), Straumann Guided Surgery (Institut Straumann AG, Basel, Switzerland), NobelClinician, (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.

II.2.2.2Factors influence the accuracy of dynamic CAIS system

There are some factors that have an influence on the precise transfer of virtual planning to the surgical site when using navigation system. These factors include the human error, resolution of image, registration error.

Experience of the surgeon

According to the study of Block et al. had studied the accuracy of implant placement in 80 patients using navigation system. Three surgeons were included in this study. One surgeon had previous experience with dynamic navigation system while the others two had no prior dynamic navigation experience.

The result reported that implant placed by experienced surgeon had minimal deviation and flat learning curve while the others two showed more deviation for the first 10 and second 10 cases, and then their learning curve flattened. Therefore the study concluded that the proficiency from using navigation system is obtained by the 20th surgical procedure(30).

Accuracy of the registration

The validity virtual planning transfer to the surgical site depend on the accurately registration procedure, which pair with the coordinated points between patient jaw and CT image. The following errors that met with registration procedure are included (i) Fiducial localization error (FLE), the error in locating the fiducial points by a measurement hardware that calculated with locating two fiducial markers apart on patient’s jaw by the measure probe. (ii) Fiducial registration error (FRE), the root-mean square distance between corresponding fiducial points after registration, is computed by the registration algorithm. (iii) Target registration error (TRE), the distance between corresponding points other than the fiducial points after registration, is critical and direct measurement of registration error. TRE is measured after registration by transformed the position of specific points on the jaw back to CT-space and comparing these positions to the corresponding points on the original image.

Accuracy of the image acquisition

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

In the nutshell, there are no significant different in accuracy in position of implant placement between using static and dynamic CAIS according to the previous studies. However there are still limited studies that revealed the information which comparing the two systems.

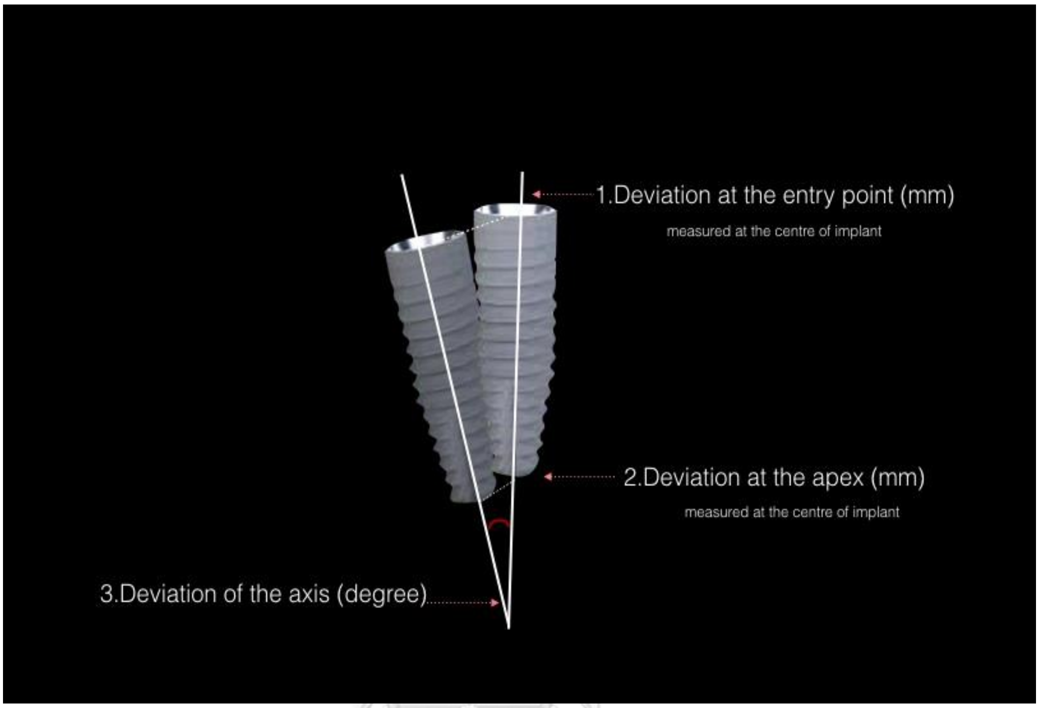
II.3 Accuracy analysis

Accuracy of implant placement using computer-assisted surgery is obtained by measure the deviation of the actual implant position from the virtual planning position. The image data of postoperative CBCT scan are superimposed on the virtual planning image automatically by implant planning software. A mathematical algorithm was implemented on both images data to calculate the positional and angular deviation between the planned and the actual placed implant position(21). Several measuring parameters were used in the previous systematic reviews for the comparison of these positions(11, 39-41)

- 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)

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 studies 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 deep as the plan (Figure 5.).

Figure 5 Deviation of planned and placed implant in variable parameters which indicate 3-dimensional deviation.



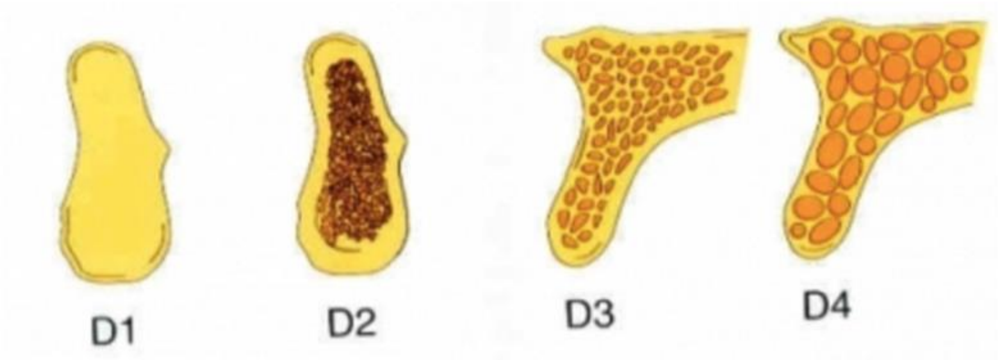
There are comparable advantages between two methods of using static or dynamic CAIS system to delivered precise implant position. Beside CAIS system also provide superior result of accuracy in placing implant when compare with conventional methods. In addition, Virtual implant planning of CAIS system can ensure appropriate implant angulation and depth for esthetic situation also allows for prosthetic and surgical collaboration with precise planning and accurate orchestration of the plan to achieve a high level of patient-specific results(19). However there are no previous study that has been investigated the accuracy of using CAIS system in specific area and differentiate types of bone density.

II.4 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 (42). 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(43, 44). 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 (45-47)(Figure6).

Figure 6 Bone dentsities type 1-4 classified according to Misch’s classification(47)



Each area of the jaw bone consists 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 cases, they can have D2 bone quality.

Chapter III

Research question

Is there any difference in accuracy of implant position between using static CAIS system and dynamic CAIS system in single space missing anterior region in four different bone types in vitro study.

P opulation: Models with artificial bone which receive dental implant placement

I ntervention: Static CAIS system and dynamic CAIS systems

C omparison: Accuracy of implant position in 4 different bone types by using static and dynamic CAIS systems

O utcome: deviation of post-op implant position from virtual planning

Objective

To compare the accuracy of implant position between using static CAIS system (CT-generated CAD/CAM stent) and dynamic CAIS system (navigation system) in four different types of bone densities.

Hypothesis

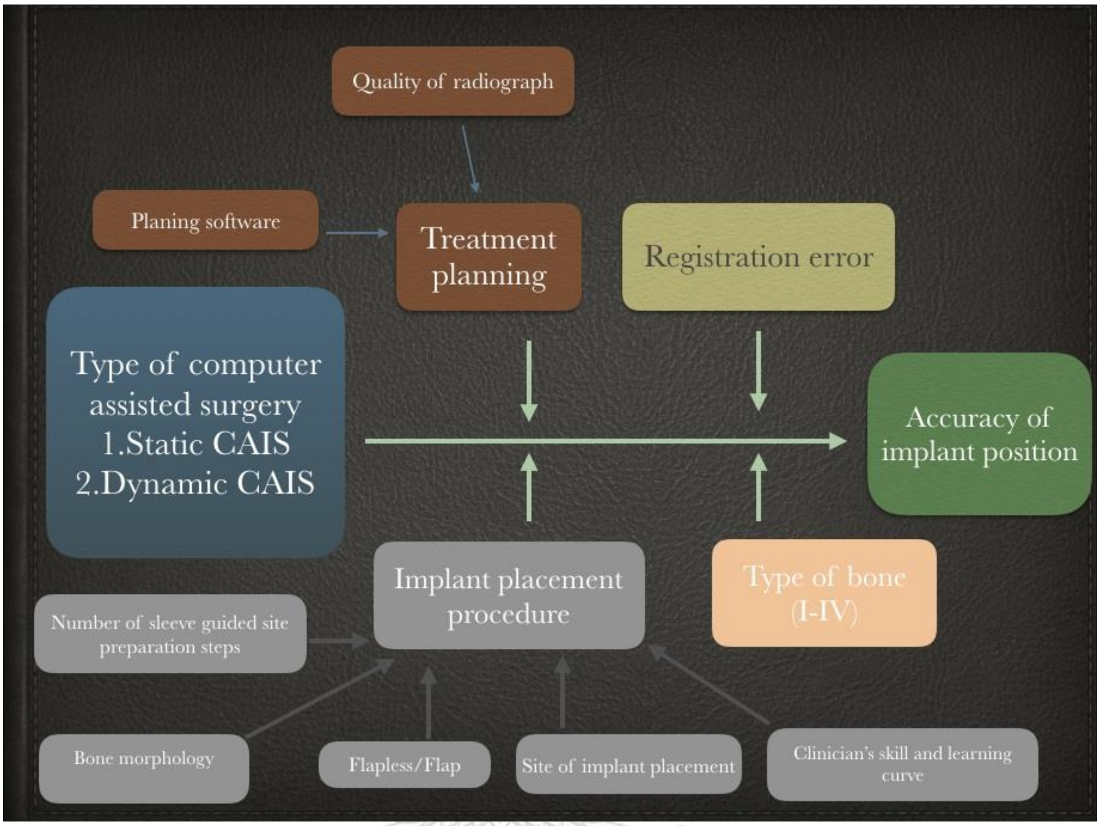
H_0 : Overall accuracy of implant deviation at total offset at platform, total offset at apex and angle between two groups are not different in static and dynamic CAIS.

H_1 : Overall accuracy of implant deviation at total offset at platform, total offset at apex and angle of the implants are different in the static CAIS group and dynamic CAIS group

H0 : Types of bone densities provide similar overall accuracy in static and dynamic CAIS.

H1 : Types of bone densities provide dissimilar overall accuracy in static and dynamic CAIS.

Conceptual framework



Chapter IV

Material and methods

This study is randomize control trial experiment stimulated under models study. The experiment consists of two groups in which static and dynamic CAIS were done with single surgeon with experiences of implant placement. Samples size were 64 models, each group contains 32 models with 8 models in 4 subgroups that comprised of bone types 1,2,3 and 4.

Sample size calculation

G*Power version3.1 software (Faul,Erdfelder,Buchner&Lang,2009)

Cone Beam Computed Tomography (CBCT) scanner

i-CAT machine (Imaging Science International LLC.Hatfeild,PA,USA)

Implant

Screw with Bone level tapered type diameter 3.3 mm height 10 mm. (Straumann, institute Straumann AG, Basel, Switzerland).

Statistic analysis software

IBM SPSS Statistic software version22 (SPSS Inc.,Chicago,IL).

sample size calculation

the overall minimum sample size requirement was 46 implants, using independent t-test as a calculation statistic base on the previous study implant deviation value of static and dynamic CAIS which were 1.35± 1.11 degree and 3.62±2.73 degree respectively(19). Calculation was done under statistic software (G*Power version 3.1, Erdfelder, Faul, & Bucher, 1996) with 95% of study power and significant level over 95%.

Inclusion criteria

1.Dentate bone models with four different bone type 1 to 4 with a single tooth missing in anterior region at tooth number 11.
2.Single doctor planned each implant position on the static CAIS (co-diagnosis program) and on dynamic navigation machine (E-PED I-ris 100) of the maxilla models according to the CBCT scan radiographic (DICOM file) of each individual sample.
3.The field of surgery consist of opposing arch that mouthed on the manikin frame in order to stimulate the clinical situation that have limitation of visibility and sense of tissue interrupted.
4. Single experiences doctor performed the experiment with blind technique of the bone type of each sample.
5.The same doctor who done the virtual planning is responded for the accuracy measurement.

Exclusion criteria

1. The study only perform in an upper anterior region with single tooth missing and not involved the posterior teeth, lower teeth and multiple teeth missing also excluded multiple space loss.
2. Each model has no bone defect involved eg. dehiscence, fenestration and vertical and horizontal bone loss.
3. If misfit of surgical stent in static CAIS occur, new guided surgical stent will need to be printed out again without adjusting.

The overall design of the study consisted of a single doctor planning each implant on a CBCT scan of a jaw model and performing a mock surgery and implant delivery on the jaw model under guidance.

Participant biases were minimized by the following procedures(26):

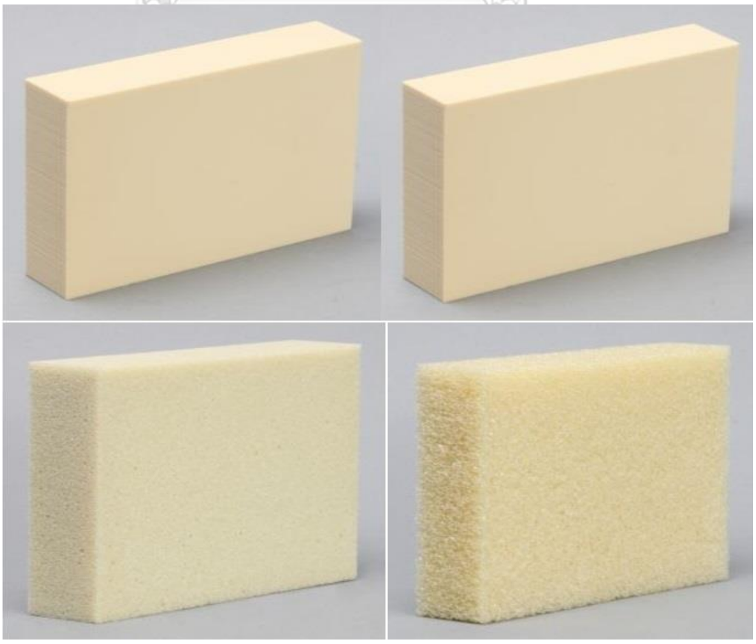
1) The doctor who placed implant was not involved in the accuracy evaluation process nor privy to the accuracy data until completion of the study.
2) The operator performing CBCT scan alignment and determining the location of the implant in the postoperative CBCT scan was blinded to the preoperative plan data.
3) The final step of computing accuracy metrics was automated.

Maxillary model with single space edentulism of tooth no.11 was prepared as a primary mother model (Nissin primary PE-ANA003, Nissin,Kyoto,Japan). In the meantime, the others 64 models were made from the mother model by using polyurethane and integrated the artificial bone type 1-4 (Misch's classification) in to the edentulous area with the quality that mimic natural bone (Sawbone®; Pacific Research Laboratories Inc., Washington,USA), which made out from polyurethane foam for mechanical testing that had considered to be a standard used for performing orthopedic implant mechanical testing. Moreover the synthetic bone provide 95% consistent material with properties in range of human bone. The properties of artificial bone consist of variable range of densities. D1 bone stimulation used 40 pound per cubic foot (pcf) with bone density of 0.64 g/cm^3 polyurethane foam. D2 bone was stimulated using 30 pcf polyurethanefoam with density of bone 0.48 g/cm^3. D3 bone imitated 20 pcf polyurethane foam with density of bone 0.32 g/cm^3, and D4 bone using 10 pcf with 0.16 g/cm^3 to stimulate the artificial bone (figure7).

After all models were prepared, models were taken CBCT scan (i-CAT machine; Imaging Science International LLC.Hatfeild,PA,USA) at standard setting of 120 kV,15mA, exposure time of 9.6 s, and voxel size of 0.2mm . Then Digital Imaging and Comunications in Medical (DICOM) files were obtained. The DICOM files were then transferred to implant planning software (co-DiagnostiX™; Straumann,Basel,Switzerland) and EPED((Iris-100,EPED Inc., Taiwan). Moreover only all maxillary models of static group were scanned by 3D model scanner machine individually (Omnica CEREC Sirona,Densply,Erlangen,Germany) and the files were converted into STL file before uploading to the software in order to match with the DICOM file of each individual sample(27). Afterward preoperative planned of each sample was done under individual software according to prosthetic driven concept.

Figure 7. The models used in this study, which contained synthetic bone type 1-4.

Figure 8. Synthetic bone blocks which demonstrated bone type1(upper left), 2(upper right) ,3(lower left) and 4(lower right).



Surgery procedure

Implant placement in static CAIS

1.Single surgeon with experience of implant placement performed the experiment with blind technique of bone type selection.

2.DICOM and STL files on each individual was transfer to co-DiagnostiX™ program for implant position planning. The proper position is planned according to prosthetic driven concept by another dentist. Finally implant position and crown form were created.

3. Guide sleeve of size 5 mm in diameter was selected to be united with the full arch templates of 3 mm thickness.

4. 32 Stereolithographic surgical templates had been printing out by 3D printing machine according to the virtual plane individually (VisiJet MP200, Disijet M3 Stone Plast, 3D Systems, Inc.,South Carolina,USA).

5. 32 polyurethane models with four different bony types with opposing mandibular arch were mounted on the mannequin head to stimulate intraoral situation (Nissim type1 advance, Nissin, Kyoto Japan).

6.Each stereolithographic surgical template incorporated with 5mm diameter T-sleeve was position into individual model and fit was checked and controlled visually and manually before beginning the surgery.

7.Implant placement at tooth site 11 was performed under the protocol of the software, using implant diameter 3.3 length 10 mm. (BLT, Straumann, Basel, Switzerland) with the guided surgery kit (Straumann) for delivering implants.

Accuracy measurement of static CAIS

1.After delivered all implants to the sample, all models were retaken with CBCT scan (i-CAT) in order to obtain the postoperative DICOM file of placed implant position.
2.The DICOM files of virtual planned and postoperative placed were superimposed into the same coordination system, via the co-DiagnostiX™ software for 3-dimensional implant precision measurement.
3.Deviation was measured in 3 dimension at the center of virtual planned and postoperative implant. To calculate the planned and actual implant position, vertical line and middle of occlusal plan line of both implants were drawn and the intersection distance was measured.
4.These are the main parameters outcome; deviation of the axis (degree angle), deviation of 3D offset at platform(mm) and deviation 3D offset at apex of implant(mm). The negative value described the opposite direction of implant placement compare with the planned position.
5.To calibrate the precision of software measurement error, accuracy was recalculated five times for each sample with blinding of unknown sample.

Dynamic CAIS

This study evaluated the accuracy of implant placement in dental models under guidance from the navigation implant placement machine (Iris – 100, EPED Inc., Taiwan). EPED is a dynamic CAIS system operating on the principles of stereo with 4 radiopaque fiducial markers from optical cameras. EPED dynamically tracks the motion of 2 dynamic reference frames (DRFs) during surgery, 1 rigidly attached to the model's surgical block and 1 rigidly attached to the surgeon's surgical hand piece. EPED uses the tracking data to compute real-time guidance information, which is displayed in real time monitor to assist surgeons in guiding their drill to an implant location they previously planned based on an imported CBCT scan(29-31)(I-CAT machine (Imaging Science International LLC. Hatfield, PA,USA).

Implant placement in dynamic CAIS

1.All models were duplicated into stone cast by irreversible hydrocolloid material.

2.All diagnostic models of each sample were prepared for making occlusal stent with vacuum trays of 1.5 mm thickness (3A MEDES, South Korea). In the meantime, Vacuum trays of individual sample were fabricated in order to attach with patient's tracking sensor and occlusal appliance that contained 4 radiopaque fiducial makers (Iris-100,EPED Inc., Taiwan).

3.The models with occlusal appliance attachment were taken CBCT (i-CAT). Afterward DICOM files of individual sample were achieved and transferred to EPED program for implant planning position. The proper position is planned according to prosthetic driven concept by another dentist. Finally implant position and crown form were created. The planning software was used to define the arch, nerve mapping, and implant dimensional manipulation. Multiple views were used to ideally orient the virtual implants. Virtual plan designated the diameter, length and optimal position of implants and crowns. The drilling sequences with difference dimeter of burs are also determined and the 4 radiopaque fiducials that appear on the CBCT image are marked. After dental implants were planned in the maxillary models. The position and angle were determined based on the specific tooth sites. Files from intraoral scanners or laboratory-based scanners can be superimposed on the DICOM images for fine detail at the time of treatment planning; however, planning in this study was based only on the CBCT data sets.

4.Single surgeon with experience of implant placement performed the experiment with blind technique of bone type selection.

5.At the time of surgery, each model was registered via occlusal appliance that contain fiducial marker and patient tracking sensors then connected with the registration camera by pairing the registration probe into the 4 makers on the occlusal appliance. Then occlusal appliance was removed from patient's arch, only patient tracking sensor were remained.

6.Implants were placed according to the virtual planning at real time GPS intrabony structure, used implant diameter 3.3 length 10 mm. (BLT, Straumann, Basel, Switzerland).

Accuracy measurement in Dynamic CAIS

1.After delivered all implant to the sample, all models with occlusal appliance attachment were retaken with CBCT scan(i-CAT) in order to obtain the postoperative DICOM file of placed implant position.

2.The DICOM files of all post operative sample were obtained. Afterward all files were transfers to the EPED software program for superimposing with preoperative virtual planning, to calculate the planned and actual implant position, vertical line and middle of occlusal plan line of both implants were drawn and the intersection distance was measured.

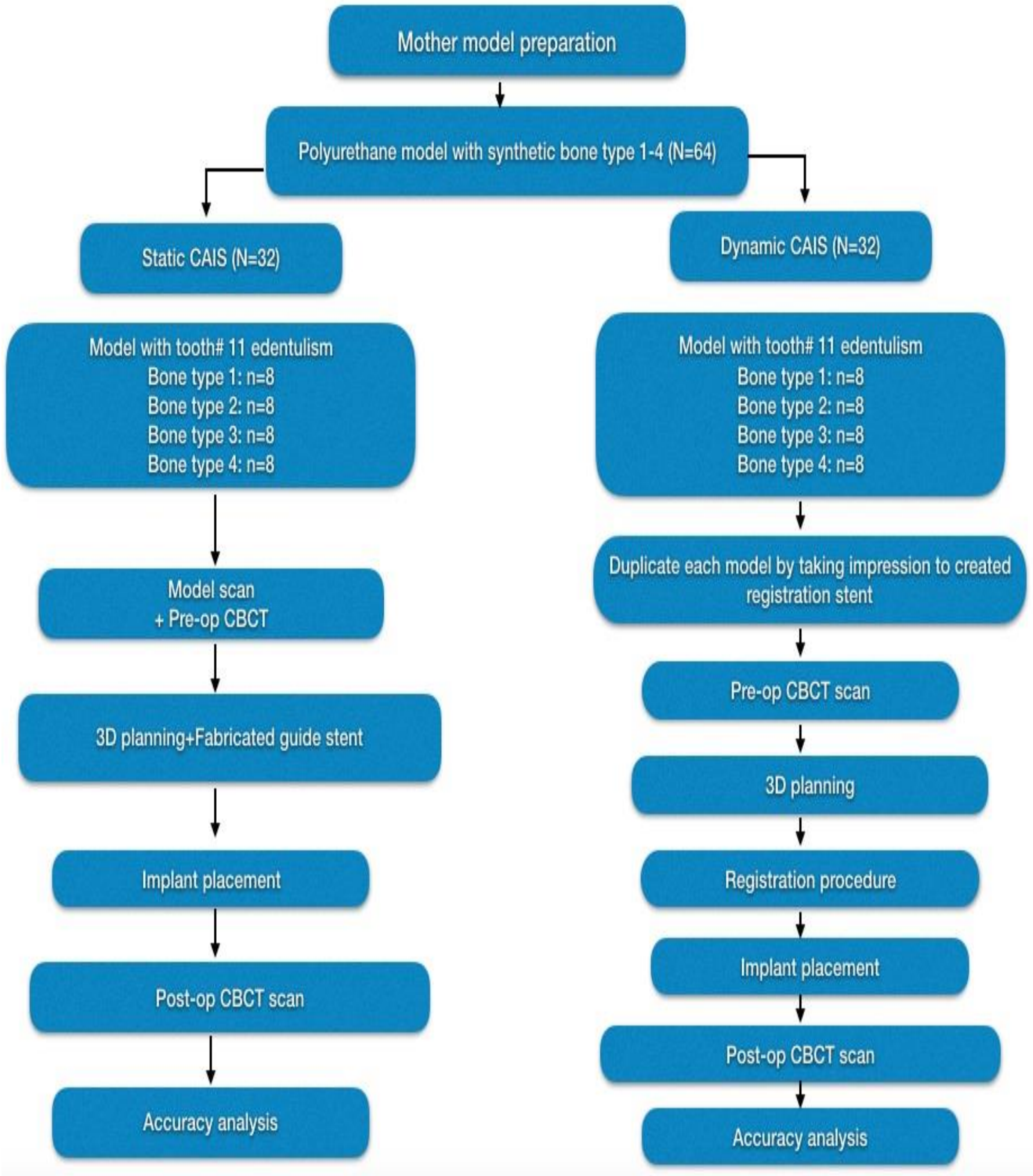
3.These are the main parameters outcome; deviation of the axis(degree angle), deviation of 3D offset at platform(mm) and deviation 3D offset at apex of implant(mm). The negative value described the opposite direction of implant placement.

4.To calibrate the precision of software measurement error, accuracy was recalculated five times for each sample with blind of unknown sample.

Statistic analysis

All data were calculated under the SPSS software program version22 (SPSS Inc.,Chicago,IL). There are main three parameters deviation of the axis(degree angle), deviation of 3D offset at platform(mm) and deviation of 3D offset at apex of implant(mm). The negative value described the opposite direction of implant placement. Comparing between 2 main groups and 8 subgroups of each bone types using factorial ANOVA and independent t-test testing. P value < 0.05 was considered as statistically significant.

Study schema



Chapter V

Result

Sixty four models that divided into thirty two of each static and dynamic CAIS groups with four different bone densities of eight models in each individual bone type. The overall result demonstrated that angle(degree) deviation was 0.62±0.31° in the static CAIS group which provided significantly greater accuracy than in the dynamic CAIS group of 1.30±0.48° ($P<0.05$). In addition the accuracy measurement of the offset apex deviation in static CAIS was 0.98±0.31 mm. and in dynamic CAIS was 1.26±0.47 mm which apparently static CAIS performed better accurate in this parameter ($P<0.05$). However each densities type of bone provided no significant role of misalignment in static and dynamic groups of CAIS ($P>0.05$). In addition the result of total offset at platform(mm) deviated from the virtual planned in static CAIS was 0.93±0.29 mm. and in dynamic CAIS was 1.02±0.37 mm. Both static and dynamic groups of CAIS showed no statistically significant different in this aspect($P>0.05$) also bony types of both groups had illustrated no distinction outcome between each group($P>0.05$). (table3)

In groups of bone type 1, the parameters of angle deviation was 0.68±0.34° in static CAIS and in group of dynamic CAIS was 1.26±0.46°. The perspective of total offset at apex was 1.05±0.30 mm. in the static group and 1.44±0.19 mm. in dynamic CAIS. which static CAIS demonstrated higher accuracy than group of dynamic in both angle deviation and deviation in total offset at the apex respectively ($P<0.05$). However the parameter of total offset at the platform of static and dynamic CAIS group were 1.01±0.32mm. and 1.23±0.22 mm. respectively which showed no significant different in deviation($P>0.05$) (table4).

In group of type 2 bone density, the parameters of angle deviation was 0.68±0.23° in static CAIS and 1.21±0.15° in dynamic CAIS, besides result of total offset at the apex in static and dynamic CAIS were 1.09±0.33 mm. and 1.39±0.12mm. severally. From these consequences static CAIS showed greater accuracy than in dynamic group in both parameters that previously mentioned ($P<0.05$). In aspect of total offset platform, the accuracy of static and dynamic CAIS showed statistically similar precision as 1.00±0.31mm and 0.99±0.16 mm. individually (P > 0.05) (table5).

In group of bone type 3, Angle deviation of the static CAIS group was 0.66±0.28° which presented more statistically validity than in dynamic CAIS group of 1.41±0.39° (P<0.05). Total offset at platform and total offset at apex deviation demonstrated statistically identical accurate in both groups (P>0.05) which were 0.99±0.25 mm in total offset at platform and 1.00±0.30mm of total offset at apex in static CAIS and 0.98±0.48 mm of total offset at platform and 1.06±0.58 mm. of total offset at apex of dynamic CAIS.

In bone type 4 density group, total offset platform of static CAIS was 0.73±0.23 mm. and total offset apex deviation was 0.78±0.27 mm. while in dynamic CAIS total offset at platform and total offset at apex deviation were 0.92±0.49 mm. and 1.15±0.69 mm. independently. These parameters illustrated equally reliable outcome in static and dynamic CAIS group (P>0.05). In contrast static CAIS performed statistically better accurate than dynamic CAIS in aspect of angle deviation(P<0.05) which were 0.48±0.38° in static CAIS while 1.28±0.77° in dynamic CAIS. Interestingly in vertical dimension aspect measured at platform apical(mm), dynamic CAIS group demonstrated more reliable outcome in type 1,2 and 3 of bone densities when compared with static CAIS group except bone density type 4 of both static and dynamic showed no statistically significant different in this direction.

Table 3 Over all result of deviation between preoperative planned compare with placed implant in angle, offset at platform and offset at apex deviation in static and dynamic CAIS and significant of bone density in relation with CAIS.

Group	Static CAIS (N=32)	Dynamic CAIS (N=32)	P Value (Factorial Anova)
Angle deviation Mean±SD	0.62±0.31	1.30±0.48	0.000
Bone densities			0.762
Offset Platform deviation Mean±SD	0.93±0.29	1.02±0.37	0.304
Bone densities			0.525
Offset Apex deviation Mean±SD	0.98±0.31	1.26±0.47	0.006
Bone densities			0.635

Table 4 Deviation of static and dynamic CAIS in bone type 1

Group	Static CAIS	Dynamic CAIS	P Value (t-test)
Angle deviation Mean±SD	0.68±0.34	1.26±0.46	0.011
Offset Platform deviation Mean±SD	1.01±0.32	1.23±0.22	0.134
Offset Apex deviation Mean±SD	1.05±0.30	1.44±0.19	0.008

Table 5 Deviation of static and dynamic CAIS in bone type 2

Group	Static CAIS	Dynamic CAIS	P Value (t-test)
Angle deviation Mean±SD	0.68±0.23	1.21±0.15	0.000
Offset Platform deviation Mean±SD	1.00±0.31	0.99±0.16	0.647
Offset Apex deviation Mean±SD	1.09±0.33	1.39±0.12	0.031

Table 6 Deviation of static and dynamic CAIS in bone type 3

Group	Static CAIS	Dynamic CAIS	P Value (t-test)
Angle deviation Mean±SD	0.66±0.28	1.41±0.39	0.001
Offset Platform deviation Mean±SD	0.99±0.25	0.98±0.48	0.933
Offset Apex deviation Mean±SD	1.00±0.30	1.06±0.58	0.782

Table 7 Deviation of static and dynamic CAIS in bone type 4

Group	Static CAIS	Dynamic CAIS	P Value (t-test)
Angle deviation Mean±SD	0.48±0.38	1.28±0.77	0.019
Offset Platform deviation Mean±SD	0.73±0.23	0.92±0.49	0.328
Offset Apex deviation Mean±SD	0.78±0.27	1.15±0.69	0.183

Chapter VI

Discussion

Regarding to the experimental CAIS system is significant highly provide implant placement precision in overall aspects compared with conventional technique implantation in all types of bone densities. In addition CAIS is able to minimize 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(22).

However the densities of bone are considered as an important factor that should be determined prior to place implant due to the process of healing period, which primary stability occur at the time when implant is first delivered, that related with contact of bone and biomechanical properties of surrounding bone. Later on, secondary stability began to play a role with osseointegration. In addition densities of bone are able to affect implant position. Bone densities can affect the determination of treatment planning, selection of implant design, surgical approach, and initial loading of prothesis. Poor bone density associate with increasing risk of implant failure due to the lack of implant stability and excessive bone resorption. Therefore, densities of bone and implant planning position at the recipient site has to be precisely recognized prior, during and after delivered implant for the long term success.

According to this in vitro study that performed placing implant through variety of bone types, the result showed no statistically significant different in overall accuracy measurement among each bone types ($P>0.05$) when deliver implant through either type of static or dynamic CAIS system. However there are more beneficial among type of bone for accurate gain in particular parameters when compare explicitness between two CAIS systems. Deviation of total offset at apex in static CAIS provide greater accuracy compare with dynamic CAIS system in bone densities type 1 and 2 except in type 3 and 4 bone densities of both CAIS groups outcome of total offset at apex show no statistically different (P>0.05). While result of total offset at platform in all bone densities provided no significant different in precision between both CAIS system (p>0.05). Covertly result of angle deviation in static CAIS showed better accuracy in every bone types. Despite that dynamic CAIS system performed greater outcome in vertical direction in all bone type except for type 4 bone density of both CAIS group demonstrate similar consequences. In this study the experiment solely performed in tooth no.11 site stimulate the most esthetic zone that customarily comprises of type 2 and 3 also rarely type 1 and 4 densities of bone in clinical situation. Therefore the outcome of this study can imply that in anterior region both static and dynamic CAIS systems are able to provide promising result for validity implantation in rage of less than 2 degree angle and offset platform and apex deviation less than 1.1 mm. within this range of amount CAIS system can provide safety zone for anterior implant placement that contribute the proper position for further prothesis. However static CAIS perform less accurate in vertical dimension in bone type 1,2 and 3 because density of hard bone and compromise of clear visual field that had surgical stent concealed at the surgical site. Surgeon may compensate the lack of depth by overpreparation at surgical site by 0.5 mm. and cautiously avoid heat production to intraosseous when pressed taper implant through the surgical site.

Somogi-Gnass et al.(2015)(23) reported no significant were found between using static and dynamic CAIS system to placed implant in partially edentulous maxilla and mandible in human cadaver in range of 1.91 mm and 1.14 of platform and apex deviation respectively and mean angular deviation was less than 4.24 degree. However the result from previous study revealed wider in range of deviation when compared with this study and the position of placed implant is not specify in only one area. Therefore the result of this study is consistent with other studies and meta-analysises that had published in CAIS systems accuracy in clinical study, the deviation was less than 1.22 and 1.45 mm at platform and apex respectively and angular deviation less than 4.06 degree(11, 40, 48).

According to the finding of Ozan, Orhan and Turkyilamaz (2011) ; Noharet, Pettersson, & Bourgeois (2014) stated that lower bone density can cause greater deviation when using a free hand technique to place implant however CAIS system can reduce malposition and overcome this problem in poor bone quality. Furthermore, previous studies had illustrated that type of arch, age and gender had no statistically significant different outcome when using CAIS system(29) (49, 50).

Precise implant delivery should be routinely recognition goal and provide this standard care for every patients. If an implant is not accurately placed in term of prosthetic driven, it would be obstacle to fabricate the good position of prosthesis in relation to support soft and hard tissue. Then if this problem occurs, it can still restorable but this will literally need additional prosthetic manipulation through the use of custom abutments, angled screws, deeper cement margins, consuming more chair time, and additional expenditure.

The treatment evaluation of CAIS systems provide highly accurate to transfer virtual implant planning to the surgical process also greater validity improvement over conventional implant placement outcome. Even with the aid of a laboratory-fabricated guide, which is not true guidance, the error with the conventional approach is higher. Moreover the experience level of surgeon who performed less than 20 implants is able to affect the consequence in particularly vertical dimension which is the most inaccurate dimension(15, 30).

Despite the fact that CAIS system also contain several disadvantages of use. In static CAIS system types of support surgical template are considerably affect the accuracy. Teeth support offer more reliable outcome when compare with bone support and mucosa-supported, however the error can cause by movement of template during surgery. Moreover misfit of surgical template can cause inaccurate transfer virtual implant planning to the surgical site. This problem is able to correct through observation window manually and visually. Beside length of the drill can compromise accuracy when transfer implant virtual planning position in the molar area due to limitation of mouth opening and interference of opposing dentition. On the other hand, this study performed the surgery through anterior region hence hinder of length of drill and surgical template is out of concern. In dynamic CAIS system, Tracking Registration Error (TRE) is the deviation of point between corresponding CT image and surgical site after registration of tracking sensor via fiducial markers. In this study the process of registration were done under one clinician who has done reliability test of registration precision practices prior to begin the experiment. The intraclass correlation coefficient was 0.84 which was in range of good indication reliability hence the experiment were not consider affected by human error. In addition experiences of surgeon who performed the surgery also have great effect on result of accuracy since the procedure need hand and eye coordinate skill to transfer precisely implant placement. Block et al.(2016)(19) stated that surgeon with experiences achieved better accuracy of implant placement when perform surgery under dynamic CAIS. Therefore practice surgical using dynamic CAIS require learning curve in order to obtain the best result. According to this study single surgeon who has more than ten year of experiences in implant surgical field performed the experiment therefore experience of surgeon's skill is not obstacle to transfer virtual implant placement under guidance of navigation. Thus dynamic CAIS equip the clear visualisation and irrigation through intraosseous also real time virtual planning adjustment incase of avoiding the damage of critical structure and adjacent tooth root moreover dynamic CAIS is recommended to utilize in second molar regions and in patient with limit mouth opening.

There are some limitation of this study since there were limit amount number of sample sizes as well as the model study does not reflect the real life clinical situation such as no bleeding and saliva, no movement of patient and no patient in-compliance. In addition further study should be done in clinical situation and comprise of larger amount of sample size. Moreover this study had done accuracy testing under CT scan images therefore further study may involve precision measurement with scan body technique also engage others tooth area in esthetic zone. In addition accuracy testing should participate in other software systems of CAIS due to the sensitivity of each software could interpret different result of accuracy.

The null hypotheses that there were no significant different in overall accuracy between static and dynamic CAIS system in all parameters measurement, would be rejected since there were particular parameters that depicted better validity than the others according to the previously mentioned result. However the null hypotheses of bone densities that there were no significant different reflected in overall accuracy in static and dynamic CAIS, would be accepted. However this study had compared accuracy of individual type of bone between group of static and dynamic CAIS by each parameter, the result illustrated the significant different in particular parameter. Despite when consider overall accuracy static and dynamic CAIS system provide constantly reliable outcome in all bone densities.

In addition there are two factors that should be considered when interpret the outcome. First, in this experiment all implant were delivered by highly experienced surgeon who had been undergone with implantation more than ten years of experiences. Therefore the result are most likely applicable for veteran operator. Second, this experiment was done in vitro study which provide mostly ideal conditions and perceived clear visual field while working on the surgery hence the result may present better accuracy when compare with clinical situation also in clinical operation implantation may provide variable levels of accuracy rely on the location of implant placement and access ability of surgical field.

Chapter VII
Conclusion

The result of this study demonstrated the promising accuracy of static and dynamic CAIS system when delivered implant through different bone densities also the software offered predictable outcome when placing a single implant at the esthetic area which periodically had difficulty with defect of bone as well as a limitation of narrow bone and root proximity. Beside the application of CAIS system is useful when transfer a virtual plan of implant position to the clinical situation.

In case of surgical site involve bone type 3,4 densities, both CAIS systems consider to be used since the precision of both system are similar validity. In addition if surgical sites consists of bone types 1 and 2 densities, static CAIS is recommended. However dynamic CAIS should be involved in implantation, in case of critical anatomies are recognize as risk such as inferior alveolar canal, incisive canal or maxillary sinus since the dynamic CAIS contain real time visualization with the working drill in relation to intraosseous structure of CT image and real time adjustable. Beside cost effectiveness and beneficial of both systems should also be provided prior to begin the procedure.

Appendices

Static CAIS

Block no./ Bone type	Angle	Total offset platform (mm)	Mesial offset at platform (mm)	Buccal offset at platform (mm)	Platform apical (mm)	Total offset apex (mm)	Mesial offset at apex(mm)	Buccal offset at apex (mm)	Apex apical (mm)
1.1	0.00	0.91	-0.39	-0.41	-0.72	0.91	0.39	-0.41	-0.72
1.2	0.90	0.71	-0.13	-0.51	-0.48	0.84	0.13	-0.67	-0.48
1.3	1.00	1.67	0.04	-0.86	-1.44	1.67	-0.21	-0.82	-1.44
1.4	0.60	1.16	0.06	-0.34	-1.11	1.20	-0.06	-0.45	-1.11
1.5	0.80	1.04	0.08	-0.33	-0.98	1.09	-0.08	-0.48	-0.98
1.6	0.40	0.67	-0.19	-0.36	-0.54	0.71	0.19	-0.43	-0.54
1.7	0.70	0.80	-0.26	0.33	-0.68	0.86	0.25	0.46	-0.68
1.8	1.00	1.10	-0.04	0.09	-1.10	1.11	-0.14	0.09	-1.10
2.1	0.8	0.96	-0.26	-0.65	-0.65	1.06	0.26	-0.80	-0.65
2.2	0.60	1.34	-0.33	-0.69	-1.10	1.40	0.33	-0.80	-1.10
2.3	0.60	1.25	-0.07	-0.63	-1.07	1.30	0.07	-0.74	-1.07
2.4	1.00	0.74	-0.07	-0.69	-0.26	0.90	0.07	-0.86	-0.26
2.5	0.90	1.27	0.06	-1.11	-0.60	1.41	-0.06	-1.27	-0.60
2.6	0.50	0.90	-0.20	-0.77	-0.42	0.99	0.20	-0.87	-0.42
2.7	0.30	0.43	0.00	-0.12	-0.41	0.42	0.00	-0.07	-0.41
2.8	0.70	1.14	-0.07	-1.01	-0.53	1.25	0.07	-1.13	-0.53
3.1	1.00	0.76	-0.68	-0.31	-0.13	0.51	-0.51	-0.31	-0.13
3.2	0.80	1.05	-0.42	-0.57	-0.77	1.00	0.28	-0.57	-0.77
3.3	0.10	1.20	-0.83	-0.38	-0.78	1.21	0.83	-0.41	-0.78
3.4	0.80	0.96	-0.21	-0.57	-0.74	1.05	0.27	-0.69	-0.74
3.5	0.80	0.56	-0.47	-0.06	-0.30	0.65	0.55	-0.18	-0.30
3.6	0.70	1.15	-0.70	-0.58	-0.70	1.21	0.70	-0.70	-0.70
3.7	0.70	1.32	-0.40	0.78	-0.99	1.39	0.40	0.90	-0.99
3.8	0.40	0.94	-0.64	-0.46	-0.51	0.97	0.64	-0.54	-0.51
4.1	0.80	0.77	-0.53	0.20	-0.53	0.88	0.63	0.29	-0.53
4.2	0.90	0.79	-0.79	0.02	0.06	0.95	0.94	0.02	0.07
4.3	0.30	0.60	-0.46	0.01	0.38	0.56	0.41	0.01	0.38
4.4	0.90	0.79	-0.64	-0.45	-0.14	0.95	0.94	0.02	0.07
4.5	0.30	1.05	-1.05	0.04	-0.01	1.10	1.10	0.04	-0.01
4.6	0.00	0.28	0.18	-0.21	-0.06	0.28	-0.18	-0.21	-0.06
4.7	0.60	0.91	0.05	-0.75	0.52	0.92	-0.16	-0.75	0.52
4.8	0.00	0.62	0.19	-0.44	0.39	0.62	-0.19	-0.44	0.39

Dynamic CAIS

Bllock no./ Bone type	Total angle	Total offset Platform(mm)	Mesial offset at platform (mm)	Bucaal offset at platform(mm)	Platform apical(mm)	Total offset Apex(mm)	Mesial offsetat apex(mm)	Buccal offset at apex(mm)	Apex apical (mm)
1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
1.2	1.85	1.29	1.08	0.51	0.4	1.33	1.76	-0.74	-0.337
1.3	1.32	1.23	0.92	0.67	-0.07	1.33	-0.82	0.94	-0.47
1.4	0.71	1.29	1.02	0.79	-0.07	1.38	-1.22	-0.65	0.09
1.5	1.98	0.80	-0.08	0.79	-0.08	1.34	-0.42	-1.26	0.13
1.6	1.03	1.33	0.64	0.75	-1.16	1.69	-0.98	-1.07	1.23
1.7	1.31	1.27	0.68	1.09	-0.67	1.63	-0.88	-1.19	0.7
1.8	1.10	1.56	1.23	0.91	-0.32	1.62	1.18	1.07	-0.32
2.1	1.11	1.19	-1.29	-1.67	-0.04	1.24	1.36	1.76	0.06
2.2	1.08	0.86	-0.47	0.61	0.37	1.31	0.91	-0.84	-0.42
2.3	1.26	0.93	-0.22	0.89	0.15	1.55	0.35	0.89	-0.23
2.4	1.33	0.89	0.64	0.57	-0.26	1.48	-0.68	-1.28	0.33
2.5	1.27	1.14	-0.14	0.05	-1.14	1.25	0.4	-0.28	1.14
2.6	1.31	0.98	0.25	0.94	-0.06	1.43	-0.95	-1.57	0.18
2.7	0.95	0.71	0.09	0.36	-0.61	1.51	-0.61	-1.18	0.7
2.8	1.36	0.87	0.21	0.54	0.35	1.35	0.94	0.84	-0.5
3.1	1.54	1.08	0.54	0.77	-0.54	0.79	-0.51	-0.31	0.51
3.2	1.47	1.34	0.88	0.98	-0.54	1.58	-0.98	1.33	0.59
3.3	1.5	0.94	0.17	0.9	-0.21	1.03	-1.05	-1.3	0.32
3.4	1.87	0.8	0.05	-0.67	-0.43	1.08	0.05	0.99	0.46
3.5	1.94	1.38	0.88	0.85	0.64	1.05	-1.08	-1.7	-0.53
3.6	1.04	0.71	0.41	0.54	-0.21	0.9	-0.91	-0.86	0.22
3.7	1.11	1.53	0.6	1.42	-0.18	2.04	-1.07	-1.72	0.26
3.8	0.86	0.03	0.02	0.01	-0.02	0.04	0.03	0.01	-0.01
4.1	1.85	1.53	0.6	1.33	0.44	2.21	-1.49	-1.69	-0.29
4.2	1.15	0.9	-0.18	0.47	-0.74	1.02	0.18	-0.67	0.75
4.3	0.34	0.44	-0.03	-0.21	-0.4	0.45	0.09	0.21	0.4
4.4	1.39	1.01	0.89	0.42	-0.25	1.59	-1.11	-1.08	0.33
4.5	2.12	0.99	0.18	0.85	-0.17	1.02	-0.82	-0.58	0.18
4.6	1.22	1.39	0.79	0.96	0.62	1.6	-1.1	-1.02	-0.58
4.7	2.1	1.06	0.86	0.28	0.56	1.25	1.13	0.11	-0.54
4.8	0.04	0.03	0.02	0.01	-0.02	0.04	-0.02	-0.02	0.02

Over all angle Deviation (Degree)

Between-Subjects Factors

		Value Label	N
CAIS	1.00	static	32
	2.00	dynamic	32
bone_type	1.00		16
	2.00		16
	3.00		16
	4.00		16

Descriptive Statistics

Dependent Variable: angle

Tx	Bone type	Mean	Std. Deviation	N
static	1.00	.6750	.34122	8
	2.00	.6750	.22520	8
	3.00	.6625	.28253	8
	4.00	.4750	.37702	8
	Total	.6219	.30873	32
dynamic	1.00	1.2625	.45750	8
	2.00	1.2088	.14515	8
	3.00	1.4163	.38733	8
	4.00	1.2763	.77058	8
	Total	1.2909	.47544	32
Total	1.00	.9688	.49402	16
	2.00	.9419	.33086	16
	3.00	1.0394	.50869	16
	4.00	.8756	.71738	16
	Total	.9564	.52136	64

Levene's Test of Equality of Error Variancesa

Dependent Variable: Angle

F	df1	df2	Sig.
3.151	7	56	.007

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Tests of Between-Subjects Effects

Dependent Variable: Angle

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	7.581a	7	1.083	6.355	.000
Intercept	58.542	1	58.542	343.527	.000
Static/Dynamic	7.162	1	7.162	42.029	.000
Bone type	.220	3	.073	.431	.732
CAIS / bone type	.198	3	.066	.388	.762
Error	9.543	56	.170		
Total	75.666	64			
Corrected Total	17.124	63			

a. R Squared = .443 (Adjusted R Squared = .373)

Overall total offset at platform deviation (mm.)

Between-Subjects Factors

		Value Label	N
CAIS	1.00	static	32
	2.00	dynamic	32
Bone type	1.00		16
	2.00		16
	3.00		16
	4.00		16

Descriptive Statistics

Dependent Variable: Total offset platform

Tx	Bone type	Mean	Std. Deviation	N
static	1.00	1.0075	.32221	8
	2.00	1.0038	.31043	8
	3.00	.9925	.24592	8
	4.00	.7263	.23145	8
	Total	.9325	.29262	32
dynamic	1.00	1.2275	.22199	8
	2.00	.9462	.15611	8
	3.00	.9763	.47979	8
	4.00	.9188	.48528	8
	Total	1.0172	.37072	32
Total	1.00	1.1175	.29044	16
	2.00	.9750	.23922	16
	3.00	.9844	.36840	16
	4.00	.8225	.38050	16
	Total	.9748	.33404	64

Levene's Test of Equality of Error Variancesa

Dependent Variable: Total offset platform

F	df1	df2	Sig.
1.523	7	56	.178

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

Tests of Between-Subjects Effects

Dependent Variable: Total offset platform

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.055a	7	.151	1.412	.219
Intercept	60.821	1	60.821	570.025	.000
Static/Dynamic	.115	1	.115	1.075	.304
Bone type	.698	3	.233	2.182	.100
CAIS/ bone type	.241	3	.080	.754	.525
Error	5.975	56	.107		
Total	67.850	64			
Corrected Total	7.030	63			

a. R Squared = .150 (Adjusted R Squared = .044)

Over all total offset at apex (mm.)

Between-Subjects Factors

		Value Label	N
CAIS	1.00	static	32
	2.00	dynamic	32
Bone type	1.00		16
	2.00		16
	3.00		16
	4.00		16

Descriptive Statistics

Dependent Variable: Total offset apex

Tx	Bone type	Mean	Std. Deviation	N
static	1.00	1.0487	.29940	8
	2.00	1.0913	.33039	8
	3.00	.9988	.29430	8
	4.00	.7825	.27091	8
	Total	.9803	.30918	32
dynamic	1.00	1.4363	.18578	8
	2.00	1.3900	.11940	8
	3.00	1.0638	.58199	8
	4.00	1.1475	.68510	8
	Total	1.2594	.46804	32
Total	1.00	1.2425	.31302	16
	2.00	1.2406	.28529	16
	3.00	1.0312	.44678	16
	4.00	.9650	.53741	16
	Total	1.1198	.41786	64

Levene's Test of Equality of Error Variances[a]

Dependent Variable: Total offset apex

F	df1	df2	Sig.
2.297	7	56	.039

Tests of Between-Subjects Effects

Dependent Variable: Total offset apex

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.491[a]	7	.356	2.342	.036
Intercept	80.259	1	80.259	528.174	.000
Static/Dynamic	1.246	1	1.246	8.200	.006
Bone type	.983	3	.328	2.157	.103
CAIS / bone type	.261	3	.087	.573	.635
Error	8.510	56	.152		
Total	91.260	64			
Corrected Total	11.000	63			

a. R Squared = .226 (Adjusted R Squared = .130)

Test between each bone type in static and dynamic CAIS

Angle deviation (degree)

Angle deviation of bone type 1

Group Statistics

	Tx	N	Mean	Std. Deviation	Std. Error Mean
Angle	static	8	.6750	.34122	.12064
	dynamic	8	1.2625	.45750	.16175

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Angle	Equal variances assumed	.682	.423	-2.912	14	.011	-.58750	.20178	-1.02028	-.15472
	Equal variances not assumed			-2.912	12.947	.012	-.58750	.20178	-1.02361	-.15139

Angle deviation of bone type 2

Group Statistics

	Tx	N	Mean	Std. Deviation	Std. Error Mean
Angle	static	8	.6750	.22520	.07962
	dynamic	8	1.2088	.14515	.05132

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Angle	Equal variances assumed	1.148	.302	-5.635	14	.000	-.53375	.09473	-.73692	-.33058
	Equal variances not assumed			-5.635	11.960	.000	-.53375	.09473	-.74022	-.32728

Angle deviation of bone type 3

Group Statistics

	Tx	N	Mean	Std. Deviation	Std. Error Mean
Angle	static	8	.6625	.28253	.09989
	dynamic	8	1.4162	.38733	.13694

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Angle	Equal variances assumed	1.195	.293	-4.447	14	.001	-.75375	.16950	-1.11730	-.39020
	Equal variances not assumed			-4.447	12.805	.001	-.75375	.16950	-1.12050	-.38700

Angle deviation of bone type4

Group Statistics

	Tx	N	Mean	Std. Deviation	Std. Error Mean
Angle	static	8	.4750	.37702	.13330
	dynamic	8	1.2762	.77058	.27244

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Angle	Equal variances assumed	2.540	.133	-2.642	14	.019	-.80125	.30330	-1.45177	-.15073
	Equal variances not assumed			-2.642	10.170	.024	-.80125	.30330	-1.47553	-.12697

Test between each bone type in static and dynamic CAIS

Total offset at platform deviation of each bone type

Total offset at platform deviation of bone type 1

Group Statistics

	Tx	N	Mean	Std. Deviation	Std. Error Mean
Offset platform	static	8	1.0075	.32221	.11392
	dynamic	8	1.2275	.22199	.07848

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Offset platform	Equal variances assumed	.879	.364	-1.590	14	.134	-.22000	.13834	-.51671	.07671
	Equal variances not assumed			-1.590	12.423	.137	-.22000	.13834	-.52028	.08028

Total offset at platform deviation of bone type 2

Group Statistics

	Tx	N	Mean	Std. Deviation	Std. Error Mean
Offset platform	static	8	1.0038	.31043	.10976
	dynamic	8	.9463	.15611	.05519

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Offset platform	Equal variances assumed	3.710	.075	.468	14	.647	.05750	.12285	-.20599	.32099
	Equal variances not assumed			.468	10.327	.649	.05750	.12285	-.21506	.33006

Total offset at platform deviation of bone type 3

Group Statistics

	Tx	N	Mean	Std. Deviation	Std. Error Mean
Offset platform	static	8	.9925	.24592	.08695
	dynamic	8	.9763	.47979	.16963

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Offset platform	Equal variances assumed	2.160	.164	.085	14	.933	.01625	.19062	-.39258	.42508
	Equal variances not assumed			.085	10.441	.934	.01625	.19062	-.40605	.43855

Total offset at platform deviation of bone type 4

Group Statistics

	Tx	N	Mean	Std. Deviation	Std. Error Mean
Offset platform	static	8	.7263	.23145	.08183
	dynamic	8	.9188	.48528	.17157

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Offset platform	Equal variances assumed	2.105	.169	-1.013	14	.328	-.19250	.19009	-.60020	.21520
	Equal variances not assumed			-1.013	10.028	.335	-.19250	.19009	-.61588	.23088

Test between each bone type in static and dynamic CAIS

Total offset at apex deviation of each bone type

Total offset at apex deviation of bone type 1

Group Statistics

	Tx	N	Mean	Std. Deviation	Std. Error Mean
Offset apex	Static	8	1.0488	.29940	.10585
	Dynamic	8	1.4363	.18578	.06568

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Offset apex	Equal variances assumed	.725	.409	-3.111	14	.008	-.38750	.12458	-.65469	-.12031
	Equal variances not assumed			-3.111	11.694	.009	-.38750	.12458	-.65972	-.11528

Total offset at apex deviation of bone type 2

Group Statistics

	Tx	N	Mean	Std. Deviation	Std. Error Mean
Offset apex	Static	8	1.0913	.33039	.11681
	Dynamic	8	1.3900	.11940	.04222

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Offset apex	Equal variances assumed	4.205	.060	-2.405	14	.031	-.29875	.12420	-.56514	-.03236
	Equal variances not assumed			-2.405	8.798	.040	-.29875	.12420	-.58071	-.01679

Total offset at apex deviation of bone type 3

Group Statistics

	Tx	N	Mean	Std. Deviation	Std. Error Mean
Offset apex	Static	8	.9987	.29430	.10405
	Dynamic	8	1.0638	.58199	.20576

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Offset apex	Equal variances assumed	.987	.337	-.282	14	.782	-.06500	.23058	-.55954	.42954
	Equal variances not assumed			-.282	10.360	.784	-.06500	.23058	-.57635	.44635

Total offset at apex deviation of bone type 4

Group Statistics

	Tx	N	Mean	Std. Deviation	Std. Error Mean
Offset apex	Static	8	.7825	.27091	.09578
	Dynamic	8	1.1475	.68510	.24222

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Offset apex	Equal variances assumed	3.748	.073	-1.401	14	.183	-.36500	.26047	-.92365	.19365
	Equal variances not assumed			-1.401	9.137	.194	-.36500	.26047	-.95288	.22288

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VITA

NAME	Phloi Chaisuwannarak
DATE OF BIRTH	19 October 1988
PLACE OF BIRTH	Thailand
INSTITUTIONS ATTENDED	Chiangmai University
HOME ADDRESS	17/1 Changror rd. Muang Chiang mai