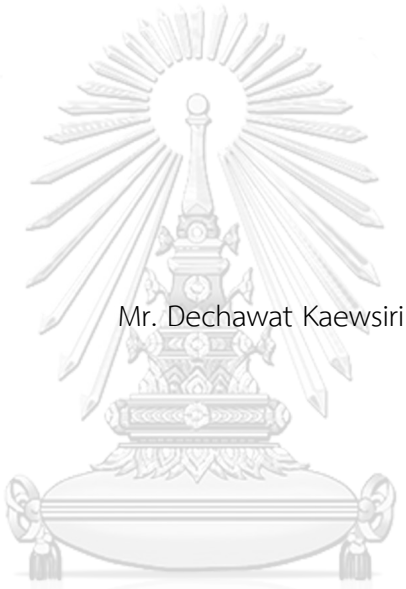
Comparison of the implant deviation between implants placed using static and dyna mic computer assisted surgery methods

Mr. Dechawat Kaewsiri



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Chulalongkorn University

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science in Oral and Maxillofacial Surgery
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การเปรียบเทียบความคลาดเคลื่อนของการฝังรากฟันเทียมโดยใช้คอมพิวเตอร์ช่วยแบบสถิตและแบบพลวัต

นายเดชาวัต แก้วศิริ

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CHULALONGKORN UNIVERSITY

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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เดชาวัต แก้วศิริ : การเปรียบเทียบความคลาดเคลื่อนของการฝังรากฟันเทียมโดยใช้คอมพิวเตอร์ช่วยแบบสถิตและแบบพลวัต. (
Comparison of the implant deviation between implants placed using static and dynamic computer assisted surgery methods) อ.ที่ปรึกษาหลัก : รศ. ทพ. ดร.อาทิ พันธุ์ พิมพ์ขาวขำ, อ.ที่ปรึกษาร่วม : รศ. ทพ. ดร.สุนทรา พันธ์มีเกียรติ

วัตถุประสงค์: งานวิจัยนี้มีวัตถุประสงค์เพื่อเปรียบเทียบความแม่นยำของการฝังรากฟันเทียมโดยวัดค่าความคลาดเคลื่อนของตำแหน่งรากฟันเทียมจากที่วางแผน ระหว่างการผ่าตัดฝังรากฟันเทียมโดยใช้คอมพิวเตอร์ช่วยแบบสถิตและแบบพลวัต ในสันเหงือกว่างที่สูญเสียฟัน 1 ซี่

วัสดุและวิธีการ: รากฟันเทียมจำนวน 60 ซี่ จะถูกฝังโดยผู้ผ่าตัด 1 คน โดยใช้ระบบคอมพิวเตอร์ช่วย 2 ระบบ ภาพถ่ายรังสีส่วนตัดอาศัยคอมพิวเตอร์แบบโคนบีมก่อนผ่าตัดจะถูกนำเข้าซอฟต์แวร์เพื่อจำลองตำแหน่งการฝังรากฟันเทียม ทำการฝังรากฟันเทียมโดยใช้แผ่นนำผ่าตัดสำหรับกลุ่มที่ใช้คอมพิวเตอร์ช่วยแบบสถิต (n = 30) หรือใช้ระบบนำทางผ่าตัดสำหรับกลุ่มที่ใช้คอมพิวเตอร์ช่วยแบบพลวัต (n = 30) ทำการถ่ายภาพรังสีส่วนตัดอาศัยคอมพิวเตอร์แบบโคนบีมหลังผ่าตัดและนำเข้าซอฟต์แวร์เพื่อทำการวิเคราะห์ความคลาดเคลื่อนของตำแหน่งรากฟันเทียม ผลลัพธ์หลักคือค่าความคลาดเคลื่อนที่ตำแหน่งขอบบนของรากเทียม, ปลายรากเทียม และความคลาดเคลื่อนเชิงมุม

ผลการศึกษา: ความคลาดเคลื่อนเฉลี่ยที่ตำแหน่งขอบบนของรากเทียมและปลายรากเทียมในกลุ่มที่ใช้คอมพิวเตอร์ช่วยแบบสถิตคือ 0.97 ± 0.44 มม. และ 1.28 ± 0.46 มม. ตามลำดับ ความคลาดเคลื่อนเฉลี่ยที่ตำแหน่งขอบบนของรากเทียมและปลายรากเทียมในกลุ่มที่ใช้คอมพิวเตอร์ช่วยแบบพลวัตคือ 1.05 ± 0.44 มม. และ 1.29 ± 0.50 มม. ตามลำดับ ความคลาดเคลื่อนเชิงมุมในกลุ่มที่ใช้คอมพิวเตอร์ช่วยแบบสถิตและแบบพลวัตคือ 2.84 ± 1.71 องศา และ 3.06 ± 1.37 องศา ตามลำดับ ไม่พบความแตกต่างอย่างมีนัยสำคัญระหว่างทั้ง 2 กลุ่ม

สรุปผลการศึกษา: การฝังรากฟันเทียมโดยใช้คอมพิวเตอร์ช่วยแบบพลวัตในสันเหงือกว่างที่สูญเสียฟัน 1 ซี่ ให้ความแม่นยำเทียบเท่ากับการใช้คอมพิวเตอร์ช่วยแบบสถิต

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

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5975811232 : MAJOR ORAL AND MAXILLOFACIAL SURGERY
KEYWORD: dental implant, accuracy, computer-assisted surgery, stereolithographic template, navigation

Dechawat Kaewsiri :

Comparison of the implant deviation between implants placed using static and dynamic computer assisted surgery methods. Advisor: Assoc. Prof. ATIPHAN PIMKHAOKHAM, D.D.S., Ph.D. Co-advisor: Assoc. Prof. SOONTRA PANMEKIATE, D.D.S., Ph.D.

Objectives: The aim of this study was to compare the accuracy of implant placement in terms of deviations related to the virtual plan between static and dynamic computer assisted implant surgery (CAIS) systems in single tooth space.

Materials & Methods: 60 single implants were randomly placed using two difference CAIS systems by one surgeon. Preoperative CBCT transferred to implant planning software were used to plan the virtual implant position. Implants were placed using either stereolithographic guide template for static CAIS group (n = 30) or implant navigation system for dynamic CAIS group (n = 30). Postoperative CBCT were taken to acquire the implant position and were imported to implant planning software in order to perform the implant deviation analysis. Primary outcomes were the deviations at implant platform, implant apex, and angular deviation.

Results: The mean deviations at implant platform and implant apex in static CAIS group were 0.97 ± 0.44 mm and 1.28 ± 0.46 mm respectively, while in dynamic CAIS group were 1.05 ± 0.44 mm and 1.29 ± 0.50 mm respectively. The angular deviation in static and dynamic CAIS group were 2.84 ± 1.71 degrees and 3.06 ± 1.37 degrees respectively. No significant differences between both groups was found.

Conclusions: Dynamic CAIS system provides the accuracy of implant placement in single tooth space similar to static CAIS system.

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Field of Study: Oral and Maxillofacial Surgery Student's Signature .....

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Dechawat Kaewsiri

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Chulalongkorn University

TABLE OF CONTENTS

Page

ABSTRACT (THAI) iii

ABSTRACT (ENGLISH) iv

ACKNOWLEDGEMENTS v

TABLE OF CONTENTS vi

LIST OF TABLES ix

LIST OF FIGURES x

CHAPTER I INTRODUCTION 1

CHAPTER II REVIEWS OF RELATED LITERATURES 4

2.1 Complications from malposition implant placement 4

2.2 Computer-Assisted Implant Surgery (CAIS) 5

2.2.1 Static Computer-Assisted Implant Surgery system (Static CAIS system) 7

2.2.1.1 Accuracy of static CAIS system 10

2.2.1.2 Factors influence the accuracy of static CAIS system 18

2.2.2 Dynamic Computer-Assisted Implant Surgery system (Dynamic CAIS system) 22

2.2.2.1 Accuracy of dynamic CAIS system 25

2.2.2.2 Factors influence the accuracy of dynamic CAIS system 29

2.3 Accuracy analysis 31

2.5 Objective 33

2.6 Hypothesis 33

2.7 Conceptual framework 33

Chulalongkorn University

CHAPTER III MATERIALS AND METHODS 34
3.1 Materials 34
3.1.1 Sample 34
3.2 Method 36
3.2.1 Ethical consideration 36
3.2.2 Sample size calculation 36
3.2.3 Sample assignment 36
3.2.4 Method for static CAIS system group 36
3.2.5 Method for dynamic CAIS system group 38
3.2.6 Accuracy analysis 41
3.2.7 Statistic analysis 41
3.2.8 Study schema 42
CHAPTER IV RESULTS 43
CHAPTER V DISCUSSION 50
CHAPTER VI CONCLUSION 55
APPENDICES 56
Appendix A Thai consent form 56
Appendix B Data recorded form 58
Appendix C Patient demographic and clinical data in static CAIS group 59
Appendix D Patient demographic and clinical data in dynamic CAIS group 60
Appendix E Implant deviations at platform, apex, and angle deviation in static CAIS group 61
Appendix F Implant deviations at platform, apex, and angle deviation in dynamic CAIS group 62

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Appendix G Statistical output 63

REFERENCES 69

VITA 77

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

LIST OF TABLES

Page

Table 1. Clinical studies on accuracy of the implants placed by static CAIS systems. 17

Table 2. Clinical studies on accuracy of the implants placed by dynamic CAIS system. 26

Table 3. Demographic and clinical data of patients 44

Table 4. Implant characteristic 45

Table 5. Deviations of implant position 45

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

LIST OF FIGURES

Page

Figure 1. Static CAIS system (CT-generated CAD/CAM guide stents with metal tube).. 2

Figure 2. Dynamic CAIS system (Navigation system) 3

Figure 3. Stereolithographic surgical template with metal sleeve. 8

Figure 4. Implant installation through stereolithographic surgical template. 9

Figure 5. Tracking camera of dynamic CAIS system 23

Figure 6. Implant headpiece attached with headpiece tracking sensor 23

Figure 7. Occlusal appliance that contain 4 fiducial markers for registration and patient tracking sensor attached with customized occlusal stent. 24

Figure 8. Handpiece registration plate. 24

Figure 9. Illustration of the parameters indicate the implant deviations. 32

Figure 10. Distribution of the deviation of each implants in mesio-distal VS bucco-lingual direction at implant platform. 47

Figure 11. Distribution of the deviation of each implants in mesio-distal VS apico-coronal direction at implant platform. 47

Figure 12. Distribution of the deviation of each implants in bucco-lingual VS apico-coronal direction at implant platform. 48

Figure 13. Distribution of the deviation of each implants in mesio-distal VS bucco-lingual direction at implant apex. 48

Figure 14. Distribution of the deviation of each implants in mesio-distal VS apico-coronal direction at implant apex. 49

Figure 15. Distribution of the deviation of each implants in bucco-lingual VS apico-coronal direction at implant apex. 49

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CHAPTER I
INTRODUCTION

The goal of implant placement is to place a restoration that provides function, esthetics and maintenance of oral health. Optimal implant position is an important factor for successful implant supported prosthetic restorations (1). Malposition of implants, caused by improper treatment planning and/or improper surgical procedures, may lead to biologic failure, esthetic failure and/or mechanical failure. These complications can be prevented by proper treatment planning, proper surgical procedure and a good understanding of the restorative aspects of implantology (2, 3).

Traditional methods for implant placement are including freehand approach and use of conventional surgical guide stents fabricated on study models. Even though conventional surgical templates allow guiding the bone entry position of the drill but the templates are fabricated on diagnostic casts which do not reveal underlying critical structures such as inferior alveolar canal or maxillary sinus (4, 5). Therefore, when traditional methods are applied, the clinical outcomes are often unpredictable and may lead to malposition of implants followed by unwanted complications (4).

Computer-Assisted Implant Surgery (CAIS) has been introduced to reduce the limitations of traditional implant placement methods (4-6). The development of Cone-Beam Computed Tomography (CBCT), 3D implant planning software, and Computer-Aided Design/Computer-Assisted Manufacturing (CAD/CAM) technology enable three-dimensional image reconstruction and simulation of virtual implant placement using computer software. The virtually planned implants can be transferred to the real surgical sites accurately by indirectly using static CAIS system or directly using dynamic CAIS system. These CAIS systems allow surgeons to place implants accurately and will reduce risk of damage to the underlying critical structures (1, 7-9).

The static CAIS systems are based on the use of CT-generated CAD/CAM guide templates with metal tubes and specific surgical instrument system (5, 10). CT scan, model / oral scan and implant planning software are used to design surgical guide templates. Subsequently, 3D acrylic resin surgical guide templates are fabricated by a computer-guided laser beam that polymerizes photosensitive liquid acrylic (stereolithography). The metal cylinders used as drill-guiding tubes are then placed

into the acrylic template spaces, and the templates are now ready for clinical use (Fig. 1) (11). However, static CAIS system is an indirect technique which operator cannot see directly when the drill is working which mean the position of the drill and the implant are depend on the virtual planning, so, surgeon has no room for adjustment of implant position.

Figure 1. Static CAIS system (CT-generated CAD/CAM guide stents with metal tube)

The dynamic CAIS system or navigation system is a technology that allows direct visualization of the implant drilling instruments related to patient's jaw position on a computer monitor in real time. Current navigation system is empowered by optical tracking technology, which continuously registers the position of handpiece and patient's jaw, and display them on the monitor superimpose with preoperative CBCT image (9, 10, 12). The ideal implant position is planned digitally by surgeon using 3D implant planning software. While the surgeon perform implant placement, tracking sensors attached on patient's jaw and handpiece will represent 3D positional information via an overhead tracking camera. Subsequently, the system immediately calculates and displays the actual position of the surgical instruments in the surgical area superimpose on the preoperative CBCT image on the monitor throughout the implant placement procedure (Fig. 2) (5).

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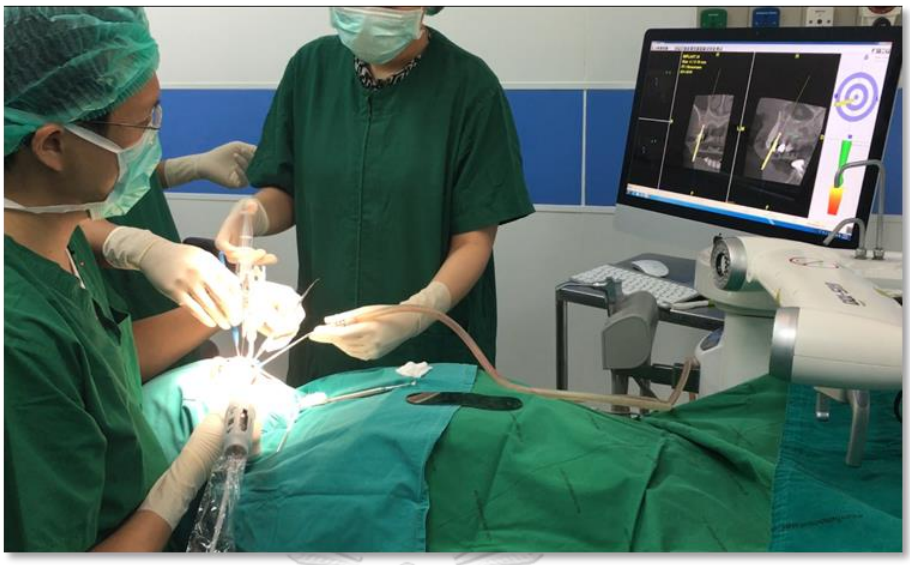

Figure 2. Dynamic CAIS system (Navigation system)

Many studies reported the advantages of using CAIS in dental implant placement over freehand approach (10, 13, 14) and using conventional surgical guide stent (1, 11, 15, 16). Some in vitro studies compared the deviation of implant position from virtual planning between using static and dynamic CAIS system, and reported that there are no significant differences (1, 17, 18). However, there are limited number of clinical studies that compare the implant deviation between implants placed using static and dynamic CAIS systems. The purpose of this study is to compare the accuracy of implant position (i.e. deviation at entry point, apex, and the axis) between the implants placed using static CAIS system (CT-generated CAD/CAM templates) and dynamic CAIS system (navigation system).

CHAPTER II
REVIEWS OF RELATED LITERATURES

2.1 Complications from malposition implant placement

Proper implant position together with optimum volume of hard and soft tissue support is the important factor to establish optimal function, esthetics and maintenance of oral health in implant prosthesis restorations. The implants should have sufficient volume of surrounding bone to compensate vertical and horizontal bone resorption around the implant shoulder (19). In mesiodistal aspect, the distance between implant and adjacent teeth should be at least 1.5 mm, for multiple implants placement, the inter-implant distance should be at least 3 mm. In buccolingual aspect, buccal and lingual bone thickness should be at least 2 mm (20). In apicocoronal aspect, the implant shoulder should be placed about 3 mm apical to the gingival margin at midfacial of the planned restoration (21).

Malposition of dental implant placement may cause the complications to implant and component in two ways. One is that malposed implants in relationship to bone and peri-implant mucosa may predispose the implant to biologic failure. The other way that malposition of dental implants relative to planned prosthesis position may result in esthetic failure, biologic failure (by difficult oral hygiene practice), and / or mechanical failure by increasing the improper forces acting within the prosthesis, abutment, abutment screw, implant fixture, implant–abutment interface or occasionally at the implant–bone interface (2).

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The complications associated with prostheses are, in part, caused by inappropriate location of implant, which affect both healing and loading environment of implant and prosthesis. Malposition of implant may compromises the integrity of surrounding bone, the strength of the prosthesis and the esthetic quality of final restorations. To prevent suboptimal implant location is the main strategy for overwhelming prosthetic complications. Consideration of the three dimensions that influence implant location in all clinical situations is required (2).

Complications that occur from implant malposition in buccolingual aspect are buccal bone dehiscence followed by peri-implant mucosal resorption, unrestorable implants due to excessive angulation, apical perforation of buccal alveolar ridge, and

lingual cingulum over contouring. Complications from mesiodistal malposition include insufficient inter-implant distance when placing multiple implants followed by interproximal marginal bone loss, restriction of implant or abutment impression by obstruction of impression copings, and damage to adjacent tooth. Complications from apicocoronal malposition occur when implant position is too shallow or too deep. Too shallow implant position may cause esthetic complications due to inability to place a restorative margin submucosally, unavoidable creation of short clinical crowns, insufficient space to mask screw access, and prosthesis fracture may be the result of reduced restorative dimension. Too deep implant position may compromises the biologic width followed by peri-implant mucosal recession, moreover, the impression coping or abutment is bounded by the crestal bone of the osteotomy lead to incomplete seating of impression and / or abutment (2).

Implant malposition problems can be prevented by volumetric implant planning procedures, site preparation and augmentation when necessary, clear communications between surgeon, prosthodontist and laboratory, and use of well-designed and fabricated surgical templates that determine optimal depth as well as the mesiodistal and buccolingual implant positions such as CAIS (2).

2.2 Computer-Assisted Implant Surgery (CAIS)

Traditional methods for implant placement include freehand approach and use of conventional surgical guide stent. Conventional plain film and panoramic tomography are generally used for treatment planning but they do not provide three dimensional data, therefore, 3D Computed Tomography (CT) was used in some cases. Even though conventional surgical template will allow guiding the bone entry position of the drill but they do not serve exact 3D guidance because the template was fabricated on the diagnostic stone cast without reference of the underlying anatomical structure. Therefore, when traditional methods are applied, the clinical outcomes are often unpredictable and may lead to malposition of implants follow by unwanted complications (4, 5).

CAIS has been introduced to overwhelm the limitations from freehand approach and using conventional surgical guide stent (4-6). The application of Cone-Beam Computed Tomography (CBCT) and 3D implant planning software have been

important achievements in this field. These technology enable 3D image reconstruction and simulation of virtual implant placement on computer software (1, 4, 10, 17).

CBCT, also known as Digital Volume Tomography (DVT), use cone-shape x-ray beam to achieve the image data. The process involves a single 360° scan in which x-ray source and 2D extended area receptor coordinately move around the patient's head. The basis images are obtained from single projection. These data can be converted and transferred to the software program which able to generate a 3D volumetric data set and provide primary reconstruction images in axial, sagittal and coronal planes (22). CBCT has been widely use in oral and maxillofacial procedures such as supporting complex surgery by intraoperative navigation, severe trauma, extensive tumors, removal of foreign body, and dental implantology (23). Advantages of CBCT scan include reduction of the size of exposed area that lead to minimize the radiation dose to the patient, high resolution of image, rapid scan time, reduced image artifact, and the image data can be converted and imported into several programs for further interpretation or analysis (22). Kobayashi et al. (2004) (24) evaluated the accuracy of distance measurement between reference points on 5 cadaver mandibles using measurement tool on the CBCT image viewer software compared with direct measure on the actual specimens. They reported that the measurement errors form CBCT image were 0.01 – 0.65 mm (0.1% - 5.2%) and concluded that CBCT was shown to be a useful device for preoperative assessment before dental implant surgery because the adequate accuracy for distance measurement and relatively limited patient's radiation exposer.

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Virtual implant planning system has been developed since 1996 to overwhelm the limitations from traditional implant placement methods. The system allows interactive administration of virtual implant in reformatted radiologic bone volume data. The surgeon can mimic implant placement on 2D reformatted images and confirm the relative positioning in a 3D scene. After patient receive CT scan with radiographic template that simulates optimal tooth position, the image data are transferred to the planning software and reformatted along a curve of axial plane (Multiplanar Reconstruction: MPR curve). This curve is placed at center of the teeth and the planned implant position on the axial plane 3 mm below the cemento-enamel junction of teeth, the panoramic view and 2D slice perpendicular to the curve are also

constructed. Implant planning software contains virtual representation of dental implants with long axis at center. Implant diameter, length and shape can be adjusted according to available products of the implant manufacturer. The virtual implants can be shown and tilted in any directions that allow surgeon to adjust in real time in any of the aforementioned views with simultaneous updating of all the other views or even the 3D spatial view. The perspective view and axial slice of the implants allows easy assessment of the parallelism and the space between the implants from different viewpoints (25).

In the clinical application of CAIS systems, two different approaches are used to transfer a CT-based planning onto the patient : static and dynamic CAIS systems (10).

2.2.1 Static Computer-Assisted Implant Surgery system (Static CAIS system)

Static CAIS system or computer-guided surgery uses Computer-Aided Design and Computer-Assisted Manufacturing (CAD/CAM) technology in combination with CBCT and 3D implant planning software. 3D image reconstruction from CBCT scan was performed using planning software, the virtual implant is planned digitally, and the relationship between the virtual implant position and radiographic template can be used to fabricate a surgical template that can fit intimately with the bone or tooth surface. Metal cylindrical tubes or sleeve are inserted into the drill guide template to assist in transferring the axis by orienting the drill in the exact planned direction (26). This computer-generated surgical template allows clinician to place the implant in the planned position more accurately than using a conventional guide template (7, 11).

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Computer-generated surgical template can be fabricated by various methods: stereolithographic rapid prototyping via polymerization of a photosensitive liquid acrylic through a series of layers (stereolithography or 3D printing), precision milling of radiographic template by CAD/CAM software, and a model-based technique using a special parallelometer that allows the dental technician to place the sleeves in the precise position in 3D space. Even though more studies on the stereolithography method have been published, there are no evidences to support the superiority of any of these techniques (13, 16).

The fabrication of a stereolithographic guide template starts with taking a CBCT scan. Digital Imaging and Communications in Medicine (DICOM) file converted from the

CBCT scan must be transfer into the implant planning software. Model scanning or intraoral scanning of the arch is needed to fabricate a surgical guide template that will seat intimately on the teeth or bone or mucosa surface (27). After finished treatment planning, the planned file will be uploaded to the stent manufacturer to fabricate a stereolithographic guide template by a computer-guided laser beam polymerizes a photosensitive liquid acrylic through a series of layers. The metal cylinders used as drill-guiding tubes are then forced into the spaces that closely matched to the diameter of the drills and/or implants, and the template are ready for clinical use (Fig. 3,4) (11).

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Figure 3. Stereolithographic surgical template with metal sleeve.

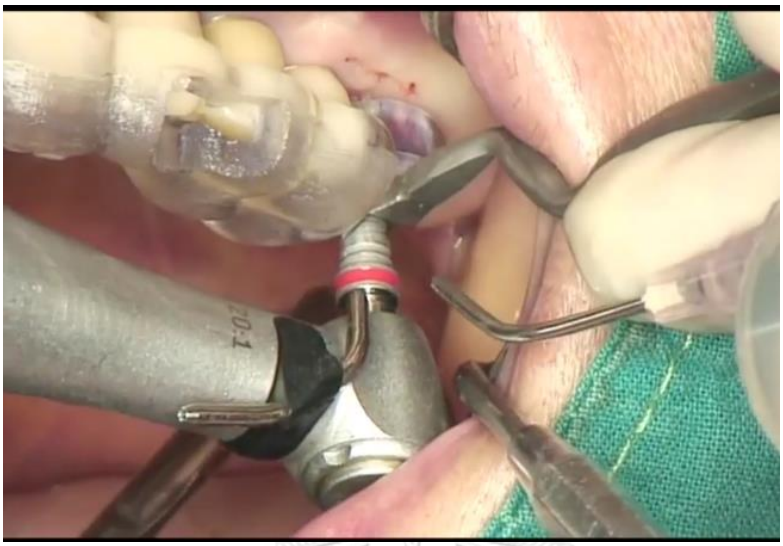

Figure 4. Implant installation through stereolithographic surgical template.

The advantages of using CT-generated guide template include accurate implant placement over freehand approach and using conventional guide stent, the possibility of operating with flapless approach that requires less-invasive surgery and results in less patient morbidity, the ability to integrate the virtual prosthesis into the planning software that allow production of a prosthesis before surgery, reduction of the error from technique-sensitive and operator-dependent surgical procedures which may significantly improve current implant surgical practices (27, 28).

In contrast, using CT-generated guided stent requires several preoperative steps. The complex treatment planning sequence lead to many potential sources of error, necessitate time delays and additional cost for fabricated stereolithographic guide template (14). Moreover, the use of the CT planning software requires training to gain proficiency with the planning software, creates a workflow barrier for the use of static CT-generated guide template (27). Intraoperative disadvantages of CT-generated template are the inability to change implant position or surgical plan as needed, limits the ability to irrigate the drill during the osteotomy that lead to increased heat production, and positioning problems caused by limited intermaxillary space when the patient has limited mouth opening and when placement is required in the second molar regions (5, 8, 10). During osteotomy and implant placement, the surgeon cannot get interactive feedback to visualize the position of the drill and the

implant in the underlying alveolar bone, therefore, the risk of perforation of critical structure such as inferior alveolar canal or maxillary sinus is increased (27). The surgical template stability is critical, particularly in case of total edentulous patient that is not possible to obtain a stable fit of surgical template during surgery. The clinician might need to repeat the process if the perioperative complications that make guided implant surgery less precise occur, such as surgical template does not seat intimately on the teeth or tissues, template fractures, template unstable (1). Additionally, the surgeon requires specific drill system, guided instruments, and specific implant fixture of various implant systems (10).

2.2.1.1 Accuracy of static CAIS system

Several clinical studies using static CAIS systems reported deviation of actual implant position from virtual planning position.

Di Giacomo et al. (2005) (29) studied the accuracy of 21 implants placed in 4 partial and total edentulous patients using stereolithographic templates (Simplant, CSI Materialise) and found that mean deviation of 21 implants were 1.45 ± 1.42 mm at entry point, 2.99 ± 1.77 mm at apex and 7.25 ± 2.67 degrees for angle deviation. They reported that the greatest deviation of implant position (7.1 mm at entry point, 4.5 mm at apex and 10.7 degrees of axis) occur in case of using bone-supported surgical template that was not possible to obtain the template stability during surgery. They suggested that the use of static CAIS system required improvement to obtain better surgical template stability during the surgery particularly in non-tooth supported templates.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Ersoy et al. (2008) (30) studied the accuracy of 94 implants placed in 21 patients (7 single tooth loss, 7 partial edentulous and 7 total edentulous) using stereolithographic templates (Stent Cad, Media Lab Software, La Spezia, Italy). They found that mean deviation at the entry point was 1.22 ± 0.85 mm, at the apex was 1.51 ± 1 mm and angle deviation was 4.9 ± 2.36 degrees. They reported significant differences in the deviation at the implant apex between single-tooth loss and partial edentulous patients and between single tooth loss and total edentulous patients while significant difference were not found between open flap and flapless techniques. They concluded that using stereolithographic templates may be reliable for implant placement and make flapless surgery possible.

Ozan et al. (2009) (31) studied the accuracy of 110 implants placed in 30 patients using static CAIS system (Stent Cad, Media Lab Software, La Spezia, Italy). 3 types of stereolithographic templates were used (tooth-supported for single-tooth loss, bone-supported for partial and total edentulous and mucosa-supported for total edentulous patients). They reported that mean deviation at entry point was 1.11 ± 0.7 mm, at apex was 1.41 ± 0.9 mm and angular deviation was 4.1 ± 2.3 degrees. Significant difference at implant apex were observed between tooth-supported and bone-supported groups and between tooth-supported and mucosa-supported groups. They concluded that tooth-supported templates were more accurate than bone-supported and mucosa-supported templates.

Arisan et al. (2010) (32) studied the accuracy of 279 implants placed in 54 patients using 2 static CAIS systems (Aytasarim, Classic and Otede systems, Kos-gep, ODTU, Ankara, Turkey and SimPlant, SurgiGuide and SAFE systems, Materialise Dental.) with tooth- , bone– or mucosa– supported surgical templates. They reported that highest mean deviation were found in bone–supported group (1.70 ± 0.52 mm at entry point, 1.99 ± 0.64 mm at apex, and 5.0 ± 1.66 for angle) whereas lowest mean deviation were found in mucosa–supported with fixation screws (0.7 ± 0.13 mm at entry point, 0.76 ± 0.15 mm at apex and 2.9 ± 0.39 degrees for angle). They concluded that uses of CBCT-derived CAD/CAM surgical templates combine with rigid screw fixation of surgical template minimized the implants deviation.

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Nickenig et al. (2010) (13) studied the accuracy of 23 implants placed in 10 lower jaws of patients with Kenedy class II defect using digital planning software (coDiagnostiX, IVS-solutions, Chemnitz, Germany) and surgical templates fabricated by model-based technique using a special parallelometer to transformed the radiographic templates to the surgical templates. They found that mean deviation at entry point was 0.9 ± 1.06 mm in bucco-lingual, 0.9 ± 1.22 mm in mesio-distal, at apex was 0.6 ± 0.57 mm in bucco-lingual, 0.9 ± 0.94 mm in mesio-distal, and angular deviation was 4.2 ± 3.04 degrees. The significant difference of all parameters were observed between surgical template group and freehand placement group that was performed in study models of the same patients. The authors concluded that the accuracy of implant placement using virtual planning software and surgical templates is high and significantly more accurate than freehand approach, however, the freehand approach group was only an in vitro study.

Ozan et al. (2011) (33) studied the angle deviation of implants placed by 2 static CAIS systems, only mucosa–supported surgical guides and flapless technique were used. They reported that the angle deviation of 94 implants placed through surgical guides (Stentcad Beyond, Ay-Design; Kos-gep, ODTU, Ankara, Turkey) were 3.73 ± 1.14 degrees whereas the angle deviation of 122 implants placed after removal of the surgical guides (Stentcad Classic; Kos-gep, ODTU) were 5.32 ± 1.96 degrees. They concluded that the lower quality of bone and the freehand placement of the implants led to the deviation of implants position.

Platzer et al. (2011) (34) studied the accuracy of 15 implants placed in 5 patients with partially edentulous mandible using planning software (SimPlant 12.0, Materialize Dental, Leuven, Belgium) and tooth-supported stereolithographic templates. They compared the implant positions of master casts with presurgical casts using 3D optical scanner (Laserscan 3D, Willytech, Feldkirchen-Westerham, Germany) and reported that mean bucco–lingual deviation was 0.27 ± 0.19 mm, mean mesio–distal deviation was 0.15 ± 0.13 mm, mean apico-coronal deviation was 0.28 ± 0.19 mm and mean rotational deviation was 14.04 ± 11.6°.

Vasak et al. (2011) (35) studied the accuracy of 56 implants placed in 18 partially edentulous patients using static CAIS system (NobelGuidet, Nobel Biocare, Gothenburg, Sweden) and reported that the deviations at implant shoulder were 0.43 mm (bucco-lingual), 0.46 mm (mesio-distal), and 0.53 mm (depth). The deviations at implant apex were 0.7 mm (bucco-lingual), 0.63 mm (mesio-distal), and 0.52 mm (depth). They also reported that the deviation of implants in anterior region were significantly lower than posterior region.

Arisan et al. (2012) (36) compared the deviations of implants placed between using CT- and CBCT–derived mucosa–supported stereolithographic templates (Simplant Pro, Materialise Dental, Leuven, Belgium) in 11 full edentulous patients. They reported that in the CT group, the deviations at implant platform and apex were 0.75 ± 0.32 mm and 0.8 ± 0.35 mm respectively, in the CBCT group, the deviations at implant platform and apex were 0.81 ± 0.32 mm and 0.81 ± 0.32 mm respectively. The angle deviation in CT and CBCT groups were 3.3 ± 1.08 degrees and 3.4 ± 1.14 degrees respectively. They concluded that implant placement using CT- or CBCT–

derived mucosa–supported stereolithographic templates yielded similar deviation values.

Pettersson et al. (2012) (37) studied the accuracy of 139 implants placed in 25 fully edentulous patients using static CAIS system (Procera software version 1.5 build 75; Nobel Biocare AB). The mean deviations at implant platform and apex were 0.80 mm (0.10-2.68) and 1.09 mm (0.24-3.62) respectively and the angle deviation was 2.26 degrees (0.24-11.74).

Behneke et al. (2012) (14) studied the accuracy of 132 implants placed in 52 partially edentulous patients using virtual planning software (implant 3D ,med3D GmbH, Heidelberg, Germany) and tooth-borne laboratory-fabricated templates. The authors reported that mean deviations at entry point were 0.27 (0.03-0.92 mm) in maxilla, 0.28 (0.01-0.97 mm) in mandible, at apex were 0.5 (0.03-1.58 mm) in maxilla, 0.4 (0.03-1.15 mm) in mandible, angular deviations were 1.82 (0.14-6.26 degrees) in maxilla and 1.86 (0.07-5.82 degrees) in mandible. Significant difference were not observed between maxilla and mandible and between using open flap and flapless techniques but were observed between using full guidance and partial guidance protocals. They concluded that Implant placement through the surgical guide allowed a more accurate transfer of the virtual plan to the surgical site than freehand insertion or partial guidance protocals.

Cassetta et al. (2012) (38) studied the accuracy of implant placement using planning software (Simplant, CSI Materialise) and stereolithographic template (SurgiGuide, CSI Materialise). They found that mean deviation of 116 implants placed in 10 partial and total edentulous 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. They concluded that although the deviation value were high, they did not seem to have resulted in significant clinical complications.

Di Giacomo et al. (2012) (39) studied the accuracy of 60 implants placed in 12 partially edentulous patients using planning software (Rhino 4.0, McNeel, Seattle, WA.) and selective laser sintering (SLS) surgical template (Sinterstation HiQ, 3D Systems, Rock Hill, SC). They reported the mean deviation 1.35 ± 0.65 mm and 1.79 ± 1.01 mm at the implant platform and apex respectively and the angle deviation 6.53 ± 4.31

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degrees. They concluded that the CAIS for dental implant placement should be considered as in developmental stage and still required improvement.

D'Haese et al. (2012) (40) studied the accuracy of 77 implants placed in 13 patients with fully edentulous maxilla using static CAIS system (Facilitate software system, Astra Tech AB) and mucosa–supported stereolithographic surgical templates. They reported the mean deviation 0.91 ± 0.44 mm and 1.13 ± 0.52 mm at the implant platform and apex respectively and angle deviation 2.6 ± 1.61 degrees. They also reported that long implants show significantly higher deviation at the apex compared with shorter one.

Farley et al. (2013) (15) compared the accuracy of 20 implants placed in single tooth space in 10 patients. Each patient received two implants in symmetric locations using implant planning software (Implant Master software, iDent Imaging) and 2 difference surgical templates on each patient : CAD/CAM generated guide on one side and conventional guide on another side. They 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. They concluded that single implant placement using computer-generated surgical template were generally closer to the planned positions than using conventional template.

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A systematic review by Tahmaseb et al. (2014) (41) reported that total mean deviation of 1,517 dental implants placed by static CAIS from 14 human clinical studies in 2005 - 2012 was 1.04 mm (95% CI = 0.85-1.24) at entry point, 1.45 mm (95% CI = 1.18-1.73) at apex and 4.06 degrees (95% CI = 3.50-4.62) for angle deviation (table 2). Statistically significant differences were observed when compared between several type of template support (tooth-supported, bone-supported, mucosa-supported). Tooth-supported and mucosa-supported templates seem to have a better accuracy compared to the bone-supported templates. There are 14 studies (total of 1,941 implants) that reported survival and complication rates. After an observation period of at least 12 months, mean failure rate was 2.7% (0% to 10%). Intraoperative or prosthetic complications were reported in 36.4 %, which included: prosthetic misfit

(18.0 %), prosthesis fracture (10.2 %), prosthetic screw loosening (2.9 %), template fractures during the surgery (3.6 %), and change of surgical plan (2.0 %).

A systematic review by Bover-Ramos et al. (2018) (42) analyzed the deviation of 2,244 implants placed by static CAIS from 22 clinical studies in 2005 – 2014. They reported that mean horizontal platform deviation was 1.10 mm (95% CI = 0.91 – 1.28), mean horizontal apex deviation was 1.40 mm (95% CI = 1.16 – 1.64) and mean angle deviation was 3.98 degrees (95% CI = 3.31 – 4.64). They also reported that implant placement was more accurate using fully guidance protocol compared with partially guidance protocol when measure horizontal apex deviation (1.35 ± 0.12 mm VS 1.92 ± 0.25 mm, $p = 0.042$) and angular deviation (3.62 ± 0.29 degrees VS 5.82 ± 0.59 degrees, $p < 0.001$).

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Study	Study design	System	Implant (N)	Platform deviation (mm)	Apex deviation (mm)	Angle deviation (degree)
Di Giacomo et al. (2005)	PS	SimPlant	21	1.45 ± 1.42	2.99 ± 1.77	7.25 ± 2.67
Ersoy et al. (2008)	PS	StentCad	94	1.22 ± 0.85	1.51 ± 1	4.9 ± 2.36
Ozan et al. (2009)	CCT	StentCad	110	1.11 ± 0.7	1.41 ± 0.9	4.1 ± 2.3
Arisan et al. (2010)	PS	*Atasarim* Bone Mucosa Tooth *SimPlant* Bone Mucosa Tooth	279	 1.70 ± 0.52 1.24 ± 0.51 1.31 ± 0.59 1.56 ± 0.25 0.7 ± 0.13 0.81 ± 0.33	 1.99 ± 0.64 1.4 ± 0.47 1.62 ± 0.54 1.86 ± 0.4 0.76 ± 0.15 1.01 ± 0.40	 5.0 ± 1.66 4.23 ± 0.72 3.39 ± 0.84 4.73 ± 1.28 2.9 ± 0.39 3.39 ± 0.84
Nickenig et al. (2010)	CCT	coDiagnostiX	23	B-L 0.9 ± 1.06 M-D 0.9 ± 1.22	B-L 0.6 ± 0.57 M-D 0.9 ± 0.94	4.2 ± 3.04
Ozan et al. (2011)	CCT	StentCad Classic StentCad Beyond	94 122	-	-	3.73 ± 1.14 5.32 ± 1.96
Platzer et al. (2011)	PS	Simplant	15	BL 0.27 ± 0.19 MD 0.15 ± 0.13	-	-
Vasak et al. (2011)	PS	NobelGuide	86	BL 0.46 ± 0.35 MD 0.43 ± 0.32	BL 0.7 ± 0.49 MD 0.59 ± 0.44	3.53 ±1.77 (8.1)
Arisan et al. (2012)	CCT	Simplant	CBCT 52 CT 50	0.81 ± 0.32 0.75 ± 0.32	0.81 ± 0.32 0.8 ± 0.35	3.4 ± 1.14 3.3 ± 1.08

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Pettersson et al. (2012)	PS	NobelGuide	191	0.80 (0.10-2.68)	1.09 (0.24-3.62)	0.26 (0.24-11.74)
Behneke et al. (2012)	PS	Implant 3D	Max 87 Man 45	0.27 (0.03-0.92) 0.28 (0.01-0.97)	0.5 (0.03-1.58) 0.4 (0.03-1.15)	1.82 (0.14-6.26) 1.86 (0.07-5.82)
Cassetta et al. (2012)	PS	SimPlant	116	1.47 ± 0.68	1.83 ± 1.03	5.09 ± 3.7
Di Giacomo et al. (2012)	PS	Sinterstation	60	1.35 ± 0.65	1.35 ± 0.65	6.53 ± 4.31
D'Haese et al. (2012)	PS	Facilitate	72	0.91 ± 0.44	1.13 ± 0.52	2.6 ± 1.61
Farley et al. (2013)	RCT	iDent Conventional	10 10	1.45 ± 0.06 1.99 ± 1.00	1.82 ± 0.60 2.54 ± 1.23	3.68 ± 2.19 6.13 ± 4.04
Tahmaseb et al. (2014)	Systematic review	-	1,517	1.04 (0.85; 1.24)	1.45 (1.18; 1.73)	4.06 (3.50; 4.62)
Bover-Ramos et al. (2018)	Systematic review	-	2,244	1.10 (0.91; 1.28)	1.40 (1.16; 1.64)	3.98 (3.31; 4.64)

Table 1. Clinical studies on accuracy of the implants placed by static CAIS systems.

(PS = Prospective Study; CCT = Controlled Clinical Study; RS = Retrospective Study; RCT = Randomized Controlled Trial)

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Most of the clinical studies that using static CAIS systems for implant placement have shown that the deviation occurred less than 2 mm for linear deviation at entry point and apex and less than 6 degrees of angle deviation, however, there were difference in study design. Several factors such as type of dental arch, type of surgical template support, surgical technique and surgical guide application protocol may affect the accuracy of implant placement.

2.2.1.2 Factors influence the accuracy of static CAIS system

Several factors that may have an effect on the accuracy of implant placement using CT-generated guide has been studied : image acquisition, type of arch, type of template, surgical technique, number of sleeve-guided site preparation steps, and operator's skill.

Accuracy of the image acquisition

Multislice Computed Tomography (MSCT) is widely used for accurate preopertive implant position planning and navigation in maxillofacial surgery (4, 43). However, the development of 3D imaging led to the introduction of CBCT, also known as DVT (44). Kobayashi et al. (2004) (24) studied error from measurement of distances on 5 cadaver mandibles using Spiral Computed Tomography (SCT) and CBCT and reported significant difference between the 2 methods. The average measurement error was 0.36 ± 0.24 mm (2.2%) with SCT and 0.22 ± 0.15 mm (1.4%) with CBCT ($P<0001$). CBCT was shown to be a useful tool in preoperative evaluation for dental implant placement because of its high resolution and the relatively small field size of its images. CBCT has many advantages like significantly lower radiation exposure, reasonably short scanning times, compact design together with adequate accuracy compared with MSCT. These advantages lead to widely used of CBCT for the oral and maxillofacial imaging compared with the MSCT (44).

The image processing technique also affects the accuracy of 3D implant planning and implant placement. Mora et al. (2014) (45) described that orientation and cross-sectioning processes of CT image before implant planning have an effect to the reformatted images using in the planning procedure. Orientation errors will translate to the cross-sectional images follow by incorrect measurements of anatomical sites. The most important orientation of CT image is the sagittal tilt that should be leveled with occlusal plane of the operating arch antero-posteriorly on the horizontal axis. The

axial tilt should center the patient's midline in antero-posterior plane. The coronal tilt should level the occlusal plane horizontally so that the left and right side are aligned in the same level. The cross-sectional view of the operating arch was created after complete the orientation process. The principle is that cross-sectional image of the interested site must be perpendicular to the curve of the dental arch and level with the implant trajectory or occlusal plane.

Type of arch (maxilla / mandible)

Behneke et al. (2012) (14) studied 132 implants placed in 52 partially edentulous patients using virtual planning software and laboratory-fabricated templates. They reported a significant difference of the deviation between maxilla and mandible at apex which larger in maxilla (0.50 vs. 0.40 mm, P = 0.033) but no significant difference at implant platform and angle deviation. Though the apical deviation was larger in the upper jaw, the numerical difference amounted to only 0.1 mm in median, that is clinically not meaningful. Ozan et al (2009) (31) studied 110 implants placed in 30 subjects using stereolithographic surgical guides and reported significant difference between maxilla and mandible for the angle deviation (maxilla: 4.58 ± 2.4°, mandible: 3.32 ± 1.9°, p=0.001). A larger amount of maxillary deviations of implant position may be explained that upper jaw has lower bone density that is easier to transfer inaccuracies than the compact mandibular bone. The findings should be interpreted with caution because the differences between upper and lower jaws were low magnitude and therefore not clinically meaningful (14).

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Chulalongkorn University

Type of template (tooth-supported / bone-supported / mucosa-supported)

Ozan et al. (2009) (31) studied the deviation from virtual planning of 110 implants between using 3 types of Stereolithographic (SLA) surgical guide include tooth-supported (for single crown restoration), bone-supported (for partial or full edentulous) and mucosa supported (for full edentulous). They found that tooth-supported surgical templates were more precise than bone-supported and mucosa-supported surgical templates. For tooth-supported, bone-supported and mucosa-supported, the angular deviation was 2.91° ± 1.3°, 4.63° ± 2.6° and 4.51° ± 2.1° degrees respectively, the linear deviation at entry was 0.87 ± 0.4 mm, 1.28 ± 0.9 mm and 1.06 ± 0.6 mm respectively and the linear deviation at implant apex was 0.95 ± 0.6 mm, 1.57 ± 0.9 mm and 1.6 ± 1 mm respectively. Behneke et al. (2012) (14) reported that

significant differences were found when comparing the platform, apex, and angle deviations for the different template groups, most of the groups differences arose at the apex. The single-tooth gap template has smallest degrees of deviation and was almost similar to the interrupted dental arch group. There was a higher deviation values for reduced residual dentition group, as only few teeth could ensure the support. No significant differences could be found between the shortened dental arch with free-ending templates and the interrupted dental arch with bilateral anchored templates. This is unexpected because larger deviations for templates with unilateral anchorage could be found due to tilting and bending of the templates. It seems that using rigid template material in this study can prevent the tilting and bending of the templates.

Surgical technique (flapless / open flap)

Behneke et al. (2012) (14) reported A borderline significance difference between open flap and flapless approach for the deviation at entry point, which higher values for the flapless approach (0.36 vs 0.28 mm, P = 0.027). No significant differences were found for the linear deviation at the implant apex, and for the angular deviation. Most of the comparisons were nonsignificant or showed only a borderline difference. Therefore, it can be stated that the flap elevation did not negatively influence the positioning of the tooth-supported CT-generated guides that the natural dentition allowed a sufficient anchorage. Flapless implant surgery may have the advantage in reduces the postoperative discomfort and can further offer implant treatment to general medically compromised patients who would be excluded for conventional implant procedures.

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

Behneke et al. (2012) (14) studied the accuracy of CT-generated guide surgery for different sections of the implant surgery. For fully guided placement, the implants were inserted through the sleeves into the guided osteotomy using a special implant carrier which fit the internal diameter of the guide sleeves. For freehand placement, the templates were used for controlling all of the osteotomy procedure and the implants were inserted manually without a surgical template. For freehand final drill, the templates were used for supported osteotomy up to the standard diameter (4–

4.1 mm), then, the site development for implants with a wider diameter was performed manually and the implants were set without a surgical guidance. He reported that significant differences were found at all aspects of measurement (implant platform, apex and angle deviation). The highest deviations were found in the freehand final drilling group. Surgical guides may interfere with effective use of the drills in the posterior jaws segments especially in the patients with limited mouth opening till the placing of both surgical templates and drills are not possible. Therefore, the templates may be used as partial guides (only for the initial steps of osteotomy) but this can affect the accuracy of implant placement as seen in this study. Freehand final drilling, results in significantly higher deviation of implants than freehand placement and fully guided placement (platform deviation: 0.52 (0.97), 0.30 (0.78), and 0.21 (0.60) mm respectively, apex deviation: 0.81 (1.38), 0.47 (1.30), and 0.28 (0.77) mm respectively). The result shows that increasing in the number of sleeve-guided site preparation steps results in higher accuracy of implant placement.

Operator's skill (experienced / inexperienced)

Rungcharassaeng et al. (2015) (7) studied the effect of operator experience on the accuracy of implant placement in mandibular model. Each operator (10 experienced and 10 inexperienced) placed 1 dental implant on the model that had been planned with software by following a computer-guided surgery protocol (NobelGuide). They reported no significant differences were found in the angular and linear deviations at coronal and apical level between the experienced and in experienced operators (P>0.1). Though not statistically significant, the amount of vertical deviation in the coronal direction of the implants placed by the inexperienced operators was about twice that placed by the experienced operators (0.49 ± 0.21 VS 0.23 ± 0.22 mm at platform, 0.51 ± 0.21 VS 0.26 ± 0.23 mm at apex). Thus, the inexperienced operators might be more careful about the implant depth than the experienced group. Almost all implants were placed more coronally than the planned position because of the depth of the osteotomy, and implant is controlled by the contact between the flange of the drill / implant mount and the sleeve of the surgical template. Moreover, angular deviation would cause the premature contact of the surfaces that result in a more coronally placed implant position.

จุฬาลงกรณ์มหาวิทยาลัย
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2.2.2 Dynamic Computer-Assisted Implant Surgery system (Dynamic CAIS system)

Dynamic CAIS system or implant navigation system has been first introduced by Watzinger et al. (1999) (46) as a technology that allows direct visualization of the implant drills on a computer monitor in real time, based on information generated from the patient's CT image. Intraoperative navigation systems use computer digitizers to track the position of the instruments and patient's jaw in working space. Four different types of digitizer have been developed : i.e. optical, electromagnetic, electromechanical, and ultrasonographic (47). Current navigation systems for dental implant surgery are mostly empowered by optical tracking technology, which continuously registers the position of surgical instrument and patient's jaw by tracking cameras and displays them on the monitor as long as tracking sensors on handpiece and patient stay within the line of sight of the tracking cameras (5, 9, 12, 27, 47). This optical tracking digitizer were also used in simulation technology of Virtual Reality Dental Training System (VRDTS) but the registration procedure that provide the link between manikin and virtual patient is unavailable in most simulation systems, therefore, the position of instruments on the manikin are not precisely coordinate with the position of virtual instruments and virtual patients on monitor. The surgeon relies only on the position of instruments on the monitor whereas the manikin only serve as a reference frame (48).

The main components of dynamic CAIS system are tracking cameras, surgical instrument tracking sensors, and patient tracking sensors with registration markers (Fig.5 -7). The workflow for dynamic navigation begins with attaching the fiducial markers, the radiopaque objects uses as reference point, to the patient's jaw. A prefabricated occlusal appliance, which contains metallic fiducial markers, is attached onto the patient's teeth using a customized occlusal stent on the patient's arch that will undergo surgery, and CBCT scan was taken. Then, the occlusal appliance is removed and stores for use during the surgery. The DICOM data of patient's CBCT image is transferred into the navigation system's computer. A virtual implant is then generated using commercial implants database, the implant type, platform diameter, apical diameter, and length can be selected and the implant position can be oriented as needed (27). At time of surgery, two tracking sensors are attached to the occlusal appliance and the handpiece. The occlusal appliance should be accurately

repositioned onto the patient arch and both tracking sensors which attached on the occlusal appliance and the handpiece will be registered to the navigation system using a registration plate (Fig. 8). Then, the surgeon arranges the position of patient and both tracking sensors for straight line of sight to the tracking cameras. Each drill length should have been registered during the osteotomy procedure. The drills should be oriented in agreement with the 3D images on the screen. And then, the surgeon performs the osteotomy and implant placement under the navigation (27).

Figure 5. Tracking camera of dynamic CAIS system

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Figure 6. Implant headpiece attached with headpiece tracking sensor

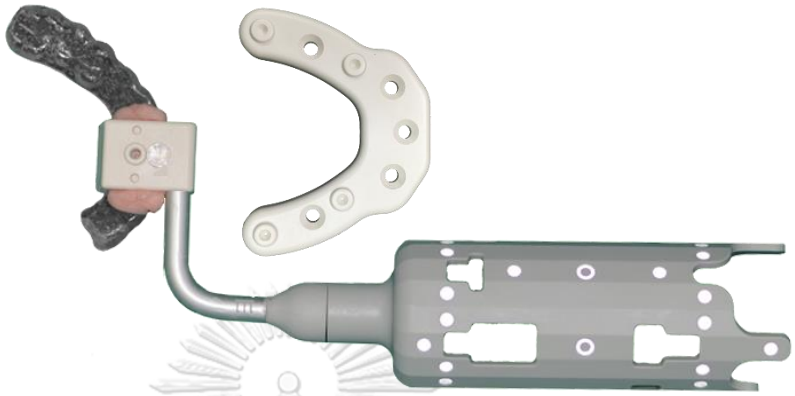

Figure 7. Occlusal appliance that contain 4 fiducial markers for registration and patient tracking sensor attached with customized occlusal stent.

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Figure 8. Handpiece registration plate.

The advantages of the dynamic CAIS method include its accuracy over the freehand approach (10) and using conventional guide stent (1), the ability to change the implant size, system, location, and surgical plan as the clinical situation enforces during the surgical procedure. The surgical procedure requires less-invasive flap reflection compared with free-hand approaches. It also improves surgeon ergonomics during surgery, with less back and neck bending, results in less morbidity to the surgeon. Dynamic navigation allows for implant placement in patient who has limited mouth opening or requires an implant at a second molar site, which can be difficult to access. The surgeon relies on the navigation screen to guide the drills without need

for direct visualization in the patient's mouth. Additionally, it also requires no complicated laboratory work, thus allowing for immediate scanning, planning, and guidance surgery in one day (10).

In contrast, application of dynamic navigation system requires the registration sequences that contain many potential sources of error. Using optical tracking system require a free line of sight between patient sensor, handpiece sensor, and tracking cameras to prevent the loss of tracking. Furthermore, some mechanical problems such as loosening of registration template or loose fit of the implant drill may reduce the precision of the procedure (4). Dynamic navigation system requires a learning curve of the clinician to gain proficiency, this could requires additional time for training, simulation, and practice on models. This system also requires a team approach. Both surgeon and assistant must learn to work together for efficient use of a dynamic navigation system (10).

2.2.2.1 Accuracy of dynamic CAIS system

Several clinical studies reported the accuracy of implant placement with dynamic CAIS systems. Mean platform deviation was 0.89 – 1.37 mm, mean apex deviation was 0.8 – 1.56 mm and mean angular deviation was 3.62 – 6.4 degrees (Table 2) (10, 49-51).

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Study	Study design	System	Implant (N)	Platform deviation (mm)	Apex deviation (mm)	Angle deviation (degree)
Wagner et al. (2003)	PS	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
Wittwer et al. (2005)	PS	Treon	78	1.1 ± 0.7	0.8 ± 0.6	-
Wittwer et al. (2007)	RCT	Treon VISIT	16 16	La 1.0 ± 0.5 Li 1.2 ± 0.8 La 1.0 ± 0.5 Li 0.7 ± 0.3	La 0.8 ± 0.6 Li 0.7 ± 0.5 La 0.6 ± 0.2 Li 0.7 ± 0.3	-
Elian et al. (2008)	Case series	IGI	6	0.89 ± 0.53	0.96 ± 0.50	3.78 ± 2.76
Block et al. (2017)	PS	X-Guide 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
Block et al. (2017)	PS	X-Guide X-Guide -	Full guide 219 Partialguide 373 Freehand 122	1.16 ± 0.59 1.31 ± 0.68 1.78 ± 0.77	1.29 ± 0.65 1.52 ± 0.78 2.27 ± 1.02	2.97 ± 2.09 3.43 ± 2.33 6.50 ± 4.21

Table 2. Clinical studies on accuracy of the implants placed by dynamic CAIS system. (PS = Prospective Study, RCT = Randomized Controlled Trial, La = deviation in labial / buccal direction, Li = deviation in lingual / palatal direction)

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Wagner et al. (2003) (51) studied the accuracy of 32 implants placed using novel dynamic navigation system (VISIT navigation system, University of Vienna, Vienna, Austria) in 5 partially edentulous patients after microvascular bony reconstruction due to tumor surgery. The mean deviation in lingual and vestibular direction was larger at the implant apex (1.3 ± 0.9 mm in lingual, 1.1 ± 0.9 mm in vestibular direction at the apex vs 1.0 ± 0.7 mm in lingual, 0.8 ± 0.5 mm in vestibular direction at the platform) and mean angle deviation was 6.4 ± 3.6 degrees (0.4 – 17.4 degrees). They concluded that sufficient accuracy in placing oral implants can be performed in patients with difficult anatomical situations.

Wittwer et al. (2005) (49) studied the accuracy of 78 implants placed in 20 full edentulous patients using dynamic navigation system (The StealthStation Treon navigation system, Medtronic, Minneapolis, MN) without flap reflection or mucosal punching. Mean deviation of 1.1 ± 0.7 mm at implant platform and 0.8 ± 0.6 mm at implant apex were reported. They concluded that using dynamic CAIS system combine with transmucosal implant placement can be done without mucosal punching and is a predictable and accurate procedure with suitable patient selection.

Wittwer et al. (2007) (50) also compared the accuracy of implants placed in 16 full edentulous patient between 2 dynamic navigation systems (The StealthStation Treon navigation system, Medtronic, Minnesota, MN versus VISIT navigation system, University of Vienna, Vienna, Austria). They reported that the labio-lingual deviation at the implant platform and the implant apex in both system were similar (VISIT : 1.0 ± 0.5 mm in labial , 0.7 ± 0.3 mm in lingual direction at the implant platform and 0.6 ± 0.2 mm in labial, 0.7 ± 0.3 mm in lingual direction at the implant apex versus Treon : 1.0 ± 0.5 mm in labial , 1.2 ± 0.8 mm in lingual direction at the implant platform and 0.8 ± 0.6 mm in labial, 0.7 ± 0.5 mm in lingual direction at the implant apex)

Elian et al. (52) (2008) studied the accuracy of 14 implants placed by flapless surgery in 3 single-tooth loss patients and 3 partial edentulous patients using dynamic navigation system (IGI, DenX Advanced Dental Systems, Moshav Ora, Israel). They reported that the mean deviations were 0.89 ± 0.53 mm at platform, 0.96 ± 0.50 mm at apex and 3.78 ± 2.76 degrees for angle deviation. They concluded that navigation system using optical tracker was sensitive to technological and technical errors and

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suggested that less than 1 mm of linear deviation and 4 degrees of angular deviation might be achievable.

Block et al. (2017) (10) 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-loss space. They concluded that the accuracy of navigation system was superior compared to freehand approach. Using navigation system, mean platform deviation, apex deviation and angle deviation were 1.37 ± 0.55 mm, 1.56 ± 0.69 mm and 3.62 ± 2.73 degrees respectively while in freehand were 2.51 ± 0.86 mm, 1.67 ± 0.43 mm and 7.69 ± 4.92 degrees respectively.

Block et al. (2017) (53) compared the accuracy of implant placement between fully guidance (FG) and partially guidance (PG) protocol using dynamic CAIS (X-Guide, X–Nav Technologies) and freehand placement (FP) in 478 single and / or partially edentulous patients involving 714 implants. They found that implant placement using dynamic CAIS with fully guidance or partially guidance protocol was more accurate than using freehand placement method. Mean platform deviation in FG, PG, and FP groups were 1.16 ± 0.59 mm, 1.31 ± 0.68 mm, and 1.78 ± 0.77 mm respectively. Mean apex deviation in FG, PG, and FP groups were 1.29 ± 0.65 mm, 1.52 ± 0.78 mm, and 2.27 ± 1.02 mm respectively. Mean angle deviation in FG, PG, and FP groups were 2.97 ± 2.09 degrees, 3.43 ± 2.33 degrees, and 6.50 ± 4.21 degrees respectively. They concluded that using dynamic CAIS will improve accuracy and precision of implant placement.

จุฬาลงกรณ์มหาวิทยาลัย
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Some laboratory studies compared the accuracy of implant placement between using several methods. Ruppin et al. (2008) (17) compared the accuracy of implants placed on 20 human cadaver mandibles between using three difference CAIS system : two dynamic CAIS systems (Artma virtual patient and RoboDent LapAccedos) and one static CAIS system (Materialise SurgiGuide). No significant difference was found between these three CAIS systems with average lateral deviation less than 1.5 mm, depth deviation less than 0.8 mm and angle deviation less than 8.1 degrees.

Somogyi-Gnass et al. (2015) (1) compared the accuracy of implant site preparation in mandibular models between using a novel dynamic CAIS system (Claron Technology Inc., Toronto, ON, Canada), 3 commercial static CAIS systems : Simplant (Materialise Dental, Leuven, Belgium), Straumann Guided Surgery (Institut Straumann

AG, Basel, Switzerland), NobelClinician, (Nobel Biocare AG, Zurich, Switzerland), and using conventional laboratory guide stent. They reported that average error from both dynamic and static CAIS systems were less than 1.91 mm for platform and apex deviation and 4.24 degrees for angle deviation whereas average errors from using conventional guide stent were less than 2.32 mm for platform and apex deviation and 8.95 degrees for angle deviation. The dynamic and static CAIS systems provide superior accuracy for implant site preparation compared to using conventional guide stent.

Most of the clinical studies that using dynamic CAIS system for implant placement have shown that the deviations occurred less than 1.56 mm for linear deviation at platform and apex and less than 3.82 degrees for angle deviation, however, there were difference study designs and the number of clinical studies were limited. Several factors such as type of dental arch, type of sensor frame support, and registration procedure may affect the accuracy of implant placement.

2.2.2.2 Factors influence the accuracy of dynamic CAIS system

Many factors have an effect on the precise transfer of virtual planning to the surgical site when using navigation system. These factors include the resolution of image, registration errors, type of fiducial markers and reference sensor frame support, and human error

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Accuracy of the image acquisition

CBCT has many advantages like significantly lower radiation exposure, reasonably short scanning times, compact design together with adequate accuracy compared with MSCT as mentioned before in factors influence the accuracy of static CAIS system.

Accuracy of the registration

The accurate transfer of virtual planning to the surgical site relies on the precisely of the registration procedure, the matching of the coordinated points between patient's jaw and CT image. Errors in registration procedure include Fiducial Localization Error (FLE), the error in locating the fiducial points by a measurement

hardware, is measured by locating two fiducial markers on patient's jaw by the measure probe. Fiducial Registration Error (FRE), the root-mean square distance between corresponding fiducial points in CT and surgical site after registration, is computed by the registration algorithm. Target Registration Error (TRE), the distance between corresponding points in CT and surgical site other than the fiducial points after registration, is the critical value and is the direct measurement of registration error. TRE is measured after registration by transform the position of specific points on the jaw back to CT-space and comparing these positions to the corresponding points on the original image (4, 54, 55).

Type of fiducial markers and reference sensor frame support

Casap et al. (2008) (12) compared registration error (TRE) in mandibular surgery procedure between two dynamic CAIS systems that use difference fiducial markers and reference sensor frame support. IGI system (DenX Advanced Dental Systems, Moshav Ora, Israel), which designed for dental implant placement, used teeth-supported fiducial markers that attached on the removable occlusal guide and teeth-mounted reference sensor frame. LanmarX system (Medtronic Xomed, Inc., Jacksonville, FL) which designed for ENT surgery, used facial skin-supported fiducial markers and head-mounted reference sensor frame. They reported that the registration error (TRE) from the IGI system (< 0.5 mm) is less than the LanmarX system (3-4 mm) and concluded that the dynamic CAIS system using teeth-supported fiducial markers and teeth-mounted reference sensor frame provides more accurate navigation for lower jaw surgery.

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Chulalongkorn University

Widmann et al. (2010) compared the TRE between invasive (bone markers) and non-invasive (occlusal splint with markers) registration methods in maxilla and mandible stone casts using StealthStation Treon Plus (Medtronic Inc) navigation system. They reported that no significant difference of TRE was found between the two registration methods with mean TRE 0.94 ± 0.37 mm for invasive method and 0.93 ± 0.36 mm for non-invasive method. Moreover, they found that increasing the number of registration markers from five to seven did not yield significant difference TRE. They concluded that non-invasive registration method using occlusal registration template can achieve an accuracy similar to that of invasive registration method and using five registration markers was sufficient.

Operator's skill and learning curve

Block et al. (2016) (10) studied the accuracy of implants placed in 80 patients using navigation system (X-Guide, X–Nav Technologies) operated by 3 difference experience surgeons. One surgeon had prior experience with dynamic navigation system while the others had no prior dynamic navigation experience. The results showed that implant placed by experienced surgeon had minimal deviation and flat learning curve while the other two showed more deviation for the first 20 cases, and then their learning curve flattened. They concluded that the proficiency from using navigation system is obtained by the 20th surgical procedures.

2.3 Accuracy analysis

Accuracy of implant placement using CAIS 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 image data to calculate the position and angle deviation between the planned and the actual implant position (10, 41). Several measuring parameters were used in the previous systematic reviews for the comparison of these positions (5, 41, 56, 57) :

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Linear deviation

- 3D deviation at implant platform: the displacement between the planned and placed implants at the implant platform in total direction, measure at the center of implant platform.

- 3D deviation at implant apex: the displacement between the planned and placed implants at the implant apex in total direction, measure at the center of implant apex

Angle deviation

- Deviation of implant axis: the largest angle in 3D space between the planned and placed implants center axis line.

For the deviation at the platform and apex, the most common method was to measure deviation between the planned and actual point by one distance in 3D (10, 13, 15, 28-31, 38, 41, 49, 56) while some studies reported by two individual vectors with a buccolingual (x-axis) and mesiodistal (y-axis) distance (14, 17) or reported as the difference of the distances between planned and placed implant at the platform and apex to the lingual and vestibular cortex (50, 51). For the deviation in height / depth, there was reported as a negative number if the implant was not inserted as deeply as planned, however, this type of deviation was not often measured (17, 38). For the deviation of the axis, the comparison was less complicated, since every study reported by degrees of deviation of the imaginary long axis line that cross center of the implant shoulder and the implant apex (1, 10, 13-15, 17, 28-31, 38, 41, 51, 56). Figure 9 illustrates the different parameters for describing the deviations.

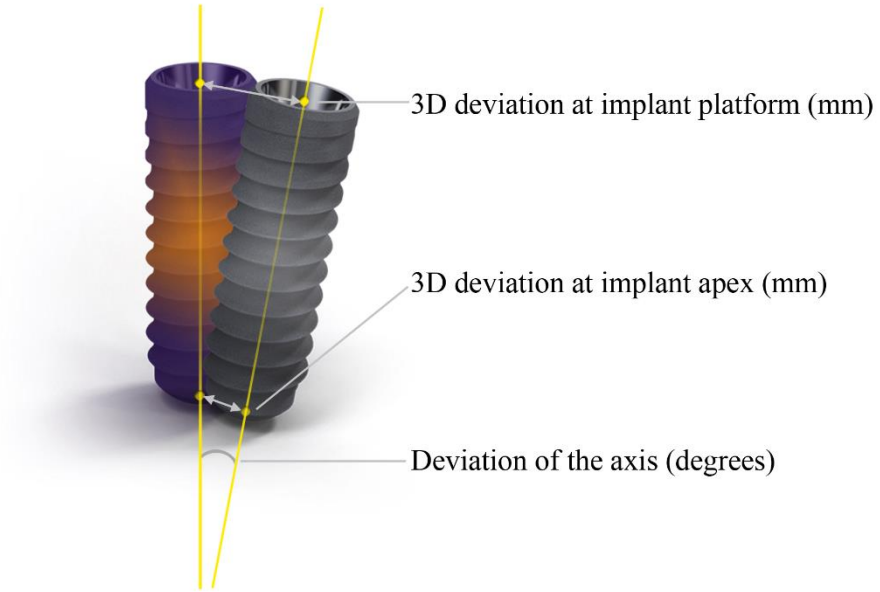


Figure 9. Illustration of the parameters indicate the implant deviations. The purple implant represents the planned virtual implant. The grey implant represents the placed implant. The yellow line represents the central axis of each implants.

2.4 Research question

Are there any differences in accuracy of implant position between using static CAIS system and dynamic CAIS system in patient who receive dental implant placement in single tooth space?

2.5 Objective

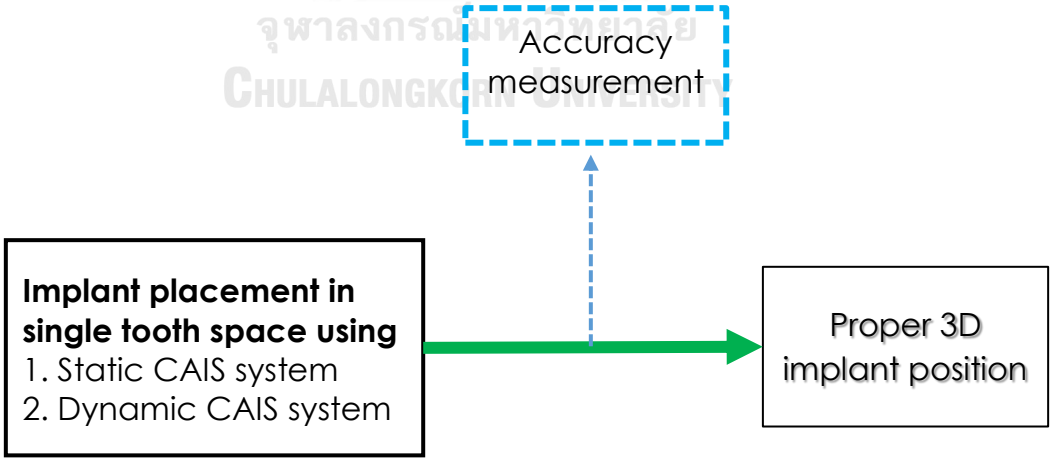
To compare the accuracy of implant placement in terms of deviations relative to virtual plan between implants placed using static and dynamic CAIS systems in single tooth space.

2.6 Hypothesis

H_0 : Linear deviation at implant platform and apex, and angle deviation between static and dynamic CAIS groups are not different.

H_1 : Linear deviation at implant platform and apex, and angle deviation between static and dynamic CAIS groups are different.

2.7 Conceptual framework



CHAPTER III
MATERIALS AND METHODS

3.1 Materials

3.1.1 Sample

The study is randomized controlled trial study. Patients who require dental implant prostheses were enrolled in this study.

Inclusion criteria

1.) Subjects with at least one single tooth space in upper and / or lower jaws needing single tooth implants. This allows us to use tooth-supported surgical guides, which provide more stable and better fit than tissue-supported guides.
2.) Extractions completed at least 3 months prior to implant placement. This is for adequate bone healing to support implants.
3.) CBCT radiograph and clinical examination reveal sufficient bone volume to support the implants (including simultaneously implant placement with bone augmentation)
4.) Age 20 years and over that able to sign consent form.

Exclusion criteria

1.) Patients with uncontrolled systemic diseases or conditions that would compromised osseointegration and / or postoperative healing process.
2.) Clinical or radiographic signs presents any pathology in the jaw bone.
3.) Patients on orthodontic appliance that interfere placing of surgical template.
4.) Patients with periodontal pocket formation and / or mobility of adjacent teeth.
5.) Patients with limited mouth opening (inter-incisal range less than 40 mm)
6.) Patients sustained perioperative complications that make guided implant surgery less precise, such as template fractures.

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3.1.2 Sample size calculation software

G*Power version 3.1 software (Faul, Erdfelder, Buchner & Lang, 2009)

3.1.3 Cone Beam Computed Tomography (CBCT) scanner

Accuitomo 3D machine (J. Morita Inc., Kyoto, Japan)

3.1.4 Implant

Screw type implant (Straumann, institute Straumann AG, Basel, Switzerland)

- type: bone level, bone level taper, tissue level
- diameter: 3.3 mm, 4.1 mm, 4.8 mm
- length: 8 mm, 10 mm, 12 mm

3.1.5 Static CAIS system

3.1.5.1 Planning and accuracy analysis software

coDiagnostiX software version 9.7 (Dental Wings Inc, GmbH, Germany)

3.1.5.2 Surface scanner

Model scanner (D900L, 3shape, Copenhagen, Denmark)

Intraoral scanner (TRIOS, 3shape, Copenhagen, Denmark)

3.1.5.3 Surgical guide stents

Stereolithographic *(SLA)* surgical template (VisiJet MP200, VisiJet M3 Stone Plast, 3D Systems, Inc., South Carolina, USA)

3.1.6 Dynamic CAIS system

3.1.6.1 Planning and accuracy analysis software

Iris–100 software (EPED Inc., Taiwan)

3.1.6.2 Occlusal stent for registration

Plastic splint sheet (3A MEDES, South Korea)

Vacuum former machine (Ultraform, Ultradent Products, Inc., Utah, USA)

3.1.6.3 Occlusal appliance set for registration

Iris–100 (EPED Inc., Taiwan)

3.1.6.4 Navigation machine

Iris–100, (EPED Inc., Taiwan)

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3.1.7 Statistic analysis software

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

3.2 Method

3.2.1 Ethical consideration

This study has been approved by the Human Research Ethics Committee of the Faculty of Dentistry, Chulalongkorn University, study code: HREC-DCU 2017-052. Informed consent was achieved from all patients.

3.2.2 Sample size calculation

Based on the implant deviation values of static and dynamic CAIS reported in previous studies (1.35 ± 1.11 degrees and 3.62 ± 2.73 degrees) (10, 14), the minimum required sample size for independent t test of 46 implants was calculated using a statistical software (G*Power software version 3.1, Erdfelder, Faul, & Buchner, 1996) with 95% of study power and significant level over 95%. Total number of 60 implants were used in this study.

3.2.3 Sample assignment

Patients were randomly divided into 2 groups: static CAIS group and dynamic CAIS group using block randomization method.

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3.2.4 Method for static CAIS system group

3.2.4.1 Presurgical stage

3.2.4.1.1 Patient was taken an impression with irreversible hydrocolloid and poured with stone for making a diagnostic model for surface scanning procedure or use intraoral scanner (TRIOS, 3shape, Copenhagen, Denmark) to record the configuration of the patient's dentition, edentulous area and mucosa.

3.2.4.1.2 In case without intraoral scanning was not performed, the diagnostic model was scanned by model scanner (D900L, 3shape, Copenhagen, Denmark) to record the configuration of the patient's dentition, edentulous area and mucosa.

3.2.4.1.3 Patient was taken CBCT scan by 3D Accuitomo 170 machine (J.Morita Inc., Kyoto, Japan). The settings were 5 mA, 90 kV, 0.25 x 0.25 x 0.25 mm voxel size, field of view 10 x 5 cm for implant placement in single jaw and 10 x 10 cm for implant placement in both jaws.

3.2.4.1.4 The Digital Imaging and Communications in Medicine (DICOM) format file of CBCT image and the Standard Tessellation Language (STL) files of model / intraoral scanning data were imported to the coDiagnostiX software version 9.7 (Dental Wings Inc, GmbH, Germany). The STL file was merged to the CBCT image to create alignment between treatment plan and tooth borne surgical guided template.

3.2.4.1.5 The virtual crown and implant (Straumann implant system, institute Straumann AG, Basel, Switzerland) with proper dimeter and length was placed superimpose on the multiplanar reconstruction images from CBCT scan and aligned to the proper position based on the restorative and biologic driven concepts.

3.2.4.1.6 After complete planning, a 3 mm thick teeth-supported digital surgical template with sleeve was designed. The anchorage location starts from the most posterior tooth on the ipsilateral side of implant placement to the same tooth position on the contralateral side.

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3.2.4.1.7 Finished design of digital surgical template was sent to dental manufacturing to fabricate stereolithographic surgical guide template (VisiJet MP200, VisiJet M3 Stone Plast, 3D Systems, Inc., South Carolina, USA)

3.2.4.2 Surgical stage

3.2.4.2.1 Before the surgical procedure start, a 5 mm diameter Straumann T – sleeve was inserted to the surgical template in the planned implant position and the fit of surgical template was verified via inspection windows and adjust manually.

3.2.4.2.2 Fully guided surgery protocol under local anesthesia was performed by one surgeon. Implant bed preparation was done according to the guidance protocal of Straumann guided surgery system. The implant fixture (Straumann, institute Straumann AG, Basel, Switzerland) diameter 3.3 - 4.8 mm, lengh 8 – 10 mm was inserted through the sleeves into the prepared site. In case with adequate keratinized mucosa was defined, flapless approach was applied

3.2.4.2.3 The closure screw or healing abutment was inserted

3.2.4.3 Postsurgical stage

3.2.4.3.1 Patient was given antibiotics (amoxicillin 1 g twice a day for 5 days) and analgesic drugs (mefenamic acid 500 mg 3 times a day for 5 days)

3.2.4.3.2 Patient was taken CBCT scan 2 weeks after implant placement with 3D Accuitomo 170 machine (J.Morita Inc., Kyoto, Japan) with the same settings as previously.

3.2.4.3.3 Preoperative CBCT with the planned virtual implant was fused onto the postoperative CBCT image using surface-based registration provided by treatment evaluation tool in the coDiagnostiX software version 9.7 (Dental Wings Inc, GmbH, Germany). The second virtual implant were placed intimately onto the placed implant image volume on the postoperative CBCT image to represent the location of the placed implant. The deviations of the placed implant related to the virtual planned implant were automatically calculated

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3.2.5 Method for dynamic CAIS system group

3.2.5.1 Presurgical stage

3.2.5.1.1 Patient was taken an impression with irreversible hydrocolloid and poured with stone for making a diagnostic model.

3.2.5.1.2 The model was used for fabricate an occlusal stent with a 1.5 mm thick plastic splint sheet (3A MEDES, South Korea) and vacuum former machine (Ultraform, Ultradent Products, Inc., Utah, USA). The occlusal stent border will be trimmed at gingival margin and leave a space on edentulous area for place implant.

3.2.5.1.3 The occlusal guide appliance that contains 4 radiopaque fiducial markers (Iris – 100, EPED Inc., Taiwan) was connected to the occlusal stent by acrylic resin.

3.2.5.1.4 Patient was taken CBCT scan by 3D Accuitomo 170 machine (J.Morita Inc., Kyoto, Japan). The settings were 5 mA, 90 kV, 0.25 x 0.25 x 0.25 mm voxel size, field of view 10 x 5 cm for implant placement in single jaw and 10 x 10 cm for implant placement in both jaws. During the scan, the occlusal stent, connected with radiopaque marker, was inserted to the operating arch and was stored for later used as registration stent at time of surgery.

3.2.5.1.5 The DICOM format file of CBCT image was imported to the navigation planning software (Iris – 100, EPED Inc., Taiwan)

3.2.5.1.6 The virtual implant (Straumann implant system, institute Straumann AG, Basel, Switzerland) with proper dimeter and length was placed superimpose on the multiplanar reconstruction images from CBCT scan and aligned to the proper position based on the restorative and biologic driven concepts. The drilling sequence with difference diameter and length of burs was also determined and the 4 radiopaque fiducial markers that appear on the CBCT image was marked.

3.2.5.2 Surgical stage

3.2.5.2.1 The surgical procedure was performed using the dynamic navigation system machine and accessories (Iris – 100, EPED Inc., Taiwan). Before the procedure, an infrared tracking camera was set and two tracking sensors were connected to the handpiece and the registration stent.

3.2.5.2.2 Handpiece registration was performed by set the tracking camera to identify the position and orientation of the handpiece and the drill.

3.2.5.2.3 The occlusal stent connected with radiopaque markers was inserted on the teeth in the same position as during CBCT scan. An extraoral patient tracking sensor was connected to the occlusal stent.

3.2.5.2.4 Registration of the patient's jaw position was performed to provide a synergistic movement between the position of 4 fiducial markers image on preoperative CBCT scan and real position of these markers in the surgical site by touch

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the registration probe to 4 markers on the occlusal appliance. After complete the registration process, the occlusal stent and patient tracking sensor were remained in place during surgery, only the occlusal guide appliance was remove.

3.2.5.2.5 The surgery was performed under local anesthesia by one surgeon. Implant bed preparation and implant placement (Straumann, institute Straumann AG, Basel, Switzerland) were performed under visual guidance as provided by the navigation system (Iris – 100, EPED Inc., Taiwan). The system will continuously track the headpiece tracking sensor and patient tracking sensor and display the position of virtual drill superimposed onto the preoperative CBCT image with virtual planning of implant on the monitor as a live video. Surgical team can get interactive feedback from the system to visualize drilling procedure and implant placement and adjust the position to match the treatment plan. In case with adequate keratinized mucosa was defined, flapless approach was applied

3.2.5.2.6 The closure screw or healing abutment was inserted.

3.2.5.3 Postsurgical stage

3.2.5.3.1 Patient was given antibiotics (amoxicillin 1 g twice a day for 5 days) and analgesic drugs (mefenamic acid 500 mg 3 times a day for 5 days)

3.2.5.3.2 Patient was taken CBCT scan 2 weeks after implant placement with 3D Accuitomo 170 machine (J.Morita Inc., Kyoto, Japan) with the same settings as previously. The same occlusal stent connected with radiopaque markers will be placed at the same position during the scan.

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3.2.5.3.3 Preoperative CBCT with the planned virtual implant was fused onto the postoperative CBCT image using marker-based registration provided by IRIS – 100 software (Iris – 100, EPED Inc., Taiwan). The second virtual implant were placed intimately onto the placed implant image volume on the postoperative CBCT image to represent the location of the placed implant. The deviations of the placed implant related to the virtual planned implant were automatically calculated

3.2.6 Accuracy analysis

For analyzing the accuracy, the planned position of the implant was compared with the actual position of the implant after insertion by coDiagnostiX software (Dental wings inc, Montreal, CA) for static CAIS system group and IRIS-100 software (EPED Inc., Taiwan) for dynamic CAIS system group. The data collection includes (see Fig.9) :

- 3D deviation at implant platform: displacement between the planned and placed implant at the implant platform in total direction, measure at the center of implant platform.

- 3D deviation at apex: displacement between the planned and placed implant at the implant apex in total direction, measure at the center of implant apex

- Divergence of implant axis: angle difference of the implant imaginary axis line that cross the center of the implant platform and the center of the implant apex between the planned and placed implant.

3.2.7 Statistic analysis

Measurements were imported into IBM SPSS Statistics software version 22 (SPSS Inc., Chicago, IL). Mean 3D deviation at implant platform, implant apex and angular deviation were compared between static CAIS and dynamic CAIS groups using independent t test. Platform and apex deviation of implants that deviated to mesial, distal, buccal, lingual, apical, and coronal directions were compared between two groups using Mann-Whitney U test. P-value < 0.05 was considered as statistically significant.

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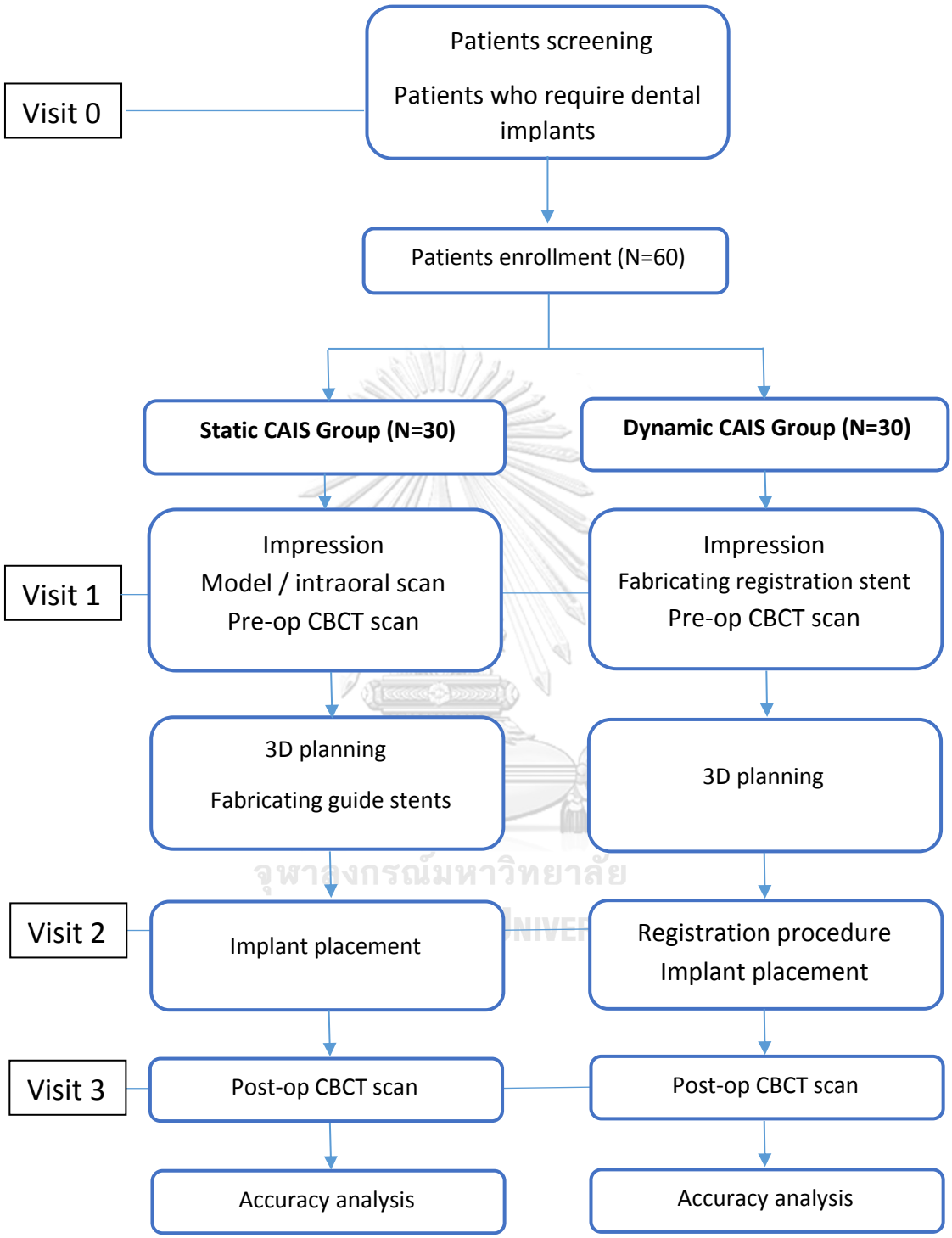
3.2.8 Study schema



CHAPTER IV
RESULTS

Sixty patients needing single implants were enrolled and equally randomized into two groups. The population includes 16 males and 44 females with mean age of 53 years (range 21 – 74). Most implants were placed in posterior region (83.3 %) with adequate bone volume to support implant without augmentation procedure (58.3 %). 25 implants (41.7 %) were placed simultaneously with bone augmentation procedure (18 implants with GBR procedure, 7 implants with transcrestal sinus augmentation). Flapless approach was applied in 10 implants (17.2%). All patients were completed the treatment protocol and all data were analyzed. Patient demographic and clinical data of each group are shown in Table 3. Implant characteristics of each group are shown in Table 4. There were no statistical significant difference of all demographic (mean age, position of implant, bone augmentation, and flap technique) between groups. Moreover, no significant difference were found for the implant type, diameter, and length

The surgeries were well tolerated by all patients. Only mild pain and swelling were observed. No major intraoperative and postoperative complications were found. Mean implant deviations at platform and apex in static CAIS group were 0.97 ± 0.44 mm and 1.28 ± 0.46 mm respectively, while in dynamic CAIS group were 1.05 ± 0.44 mm and 1.29 ± 0.50 mm respectively. Angular deviation in static and dynamic CAIS groups were 2.84 ± 1.71 degrees and 3.06 ± 1.37 degrees respectively. No significant differences were found between the two groups (Table 5). The intraclass correlations coefficient of the examiner who performed accuracy analysis using two difference software was 0.99, that indicated very good reliability.

The surgical time, measure from incision was made until suturing was finished, of both groups were also reported. The average surgical time in case with and without GBR procedure was performed in static CAIS group were 15 minutes (12-20 minutes) and 40 minutes (30-45 minutes), while in dynamic CAIS group were 18 minutes (12-25 minutes) and 48 minutes (30-90 minutes) respectively.

Group	Static CAIS (n=30)	Dynamic CAIS (n=30)	p–value (Chi-square test)
Mean age (year)	57 (28 - 74)	50 (21 - 70)	0.12
Gender (n)			
Male	9	7	0.56
Female	21	23	
Position (n)			
Anterior	6	4	0.49
Posterior	24	26	
Left side	13	15	0.61
Right side	17	15	
Maxilla	21	16	0.18
Mandible	9	14	
Bone augmentation (n)			
Yes	15	10	0.19
No	15	20	
Surgical technique (n)			
Open flap	25	25	1.00
Flapless	5	5	
Timing of placement (n)			
Early (≤4 months)	6	6	1.00
Late (>4 months)	24	24	

Table 3. Demographic and clinical data of patients

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Group	Static CAIS (n=30)	Dynamic CAIS (n-=30)	p–value (Chi-square test)
Implant type (n)			
Bone level	24	18	0.23
Bone level taper	4	9	
Tissue level	2	3	
Implant diameter (n)			
3.3 mm	5	8	0.63
4.1 mm	13	12	
4.8 mm	12	10	
Implant length (n)			
8 mm	7	5	0.61
10 mm	21	21	
12 mm	2	4	

Table 4. Implant characteristic

Group	Static CAIS (n = 30)	Dynamic CAIS (n = 30)	p-value (Independent-t test)
Deviation at platform (mm)			
Mean ± SD	0.97 ± 0.44	1.05 ± 0.44	0.47
Min - Max	0.18 – 1.83	0.37 – 2.04	
Deviation at apex (mm)			
Mean ± SD	1.28 ± 0.46	1.29 ± 0.50	0.94
Min - Max	0.49 – 2.13	0.61 – 2.31	
Angular deviation (degrees)			
Mean ± SD	2.84 ± 1.71	3.06 ± 1.37	0.60
Min - Max	0.20 – 6.60	0.43 – 6.54	

Table 5. Deviations of implant position

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Interestingly, when measure the platform and apex deviation in mesio-distal, bucco-lingual, and apico-coronal directions, we found that significant difference between the two groups was found only at the platform of implants that deviated to mesial direction while other directions were not significant difference. The vector and magnitude of deviation to each direction of all implants were showed in Figure 10. Dots and lines represent magnitude and direction of the deviation. The triangle markers represent median value of the deviation in millimeter of each direction (mesial, distal, buccal, lingual, apical, coronal). The number in ( ) represent the amount of implants that deviate in each directions. Blue color represents static CAIS group. Orange color represents dynamic CAIS group.

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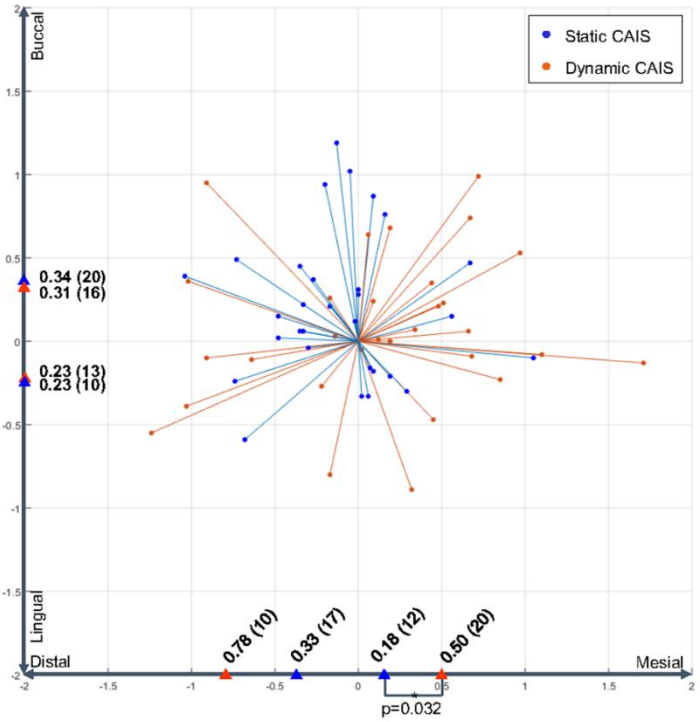

Figure 10. Distribution of the deviation of each implants in mesio-distal VS bucco-lingual direction at implant platform.

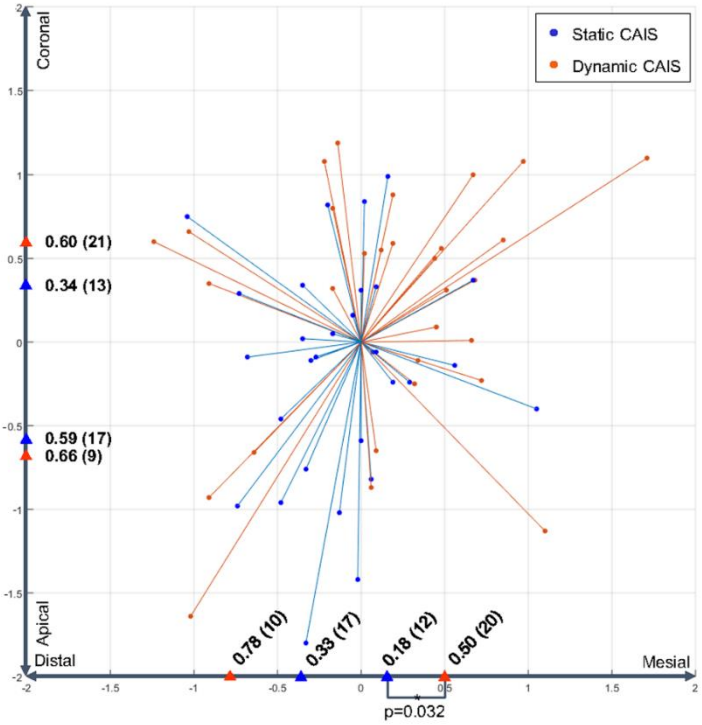

Figure 11. Distribution of the deviation of each implants in mesio-distal VS apico-coronal direction at implant platform.

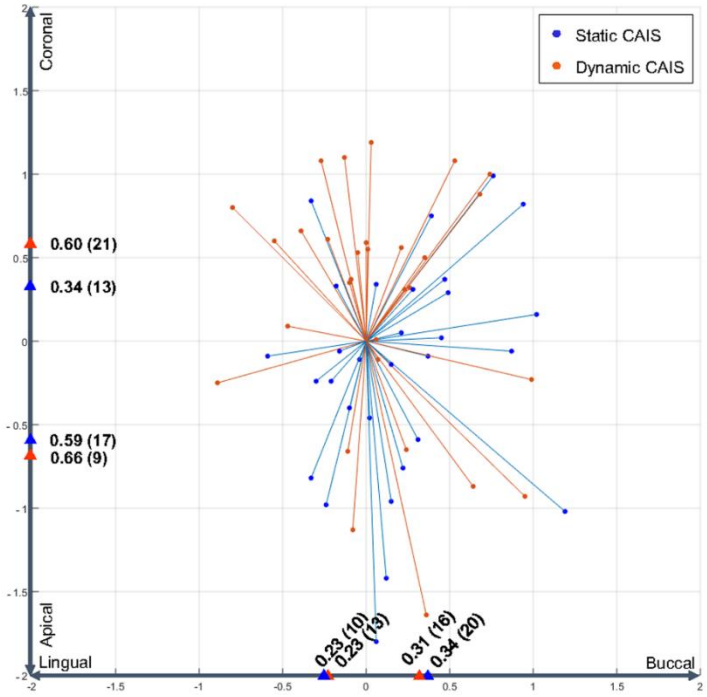

Figure 12. Distribution of the deviation of each implants in bucco-lingual VS apico-coronal direction at implant platform.

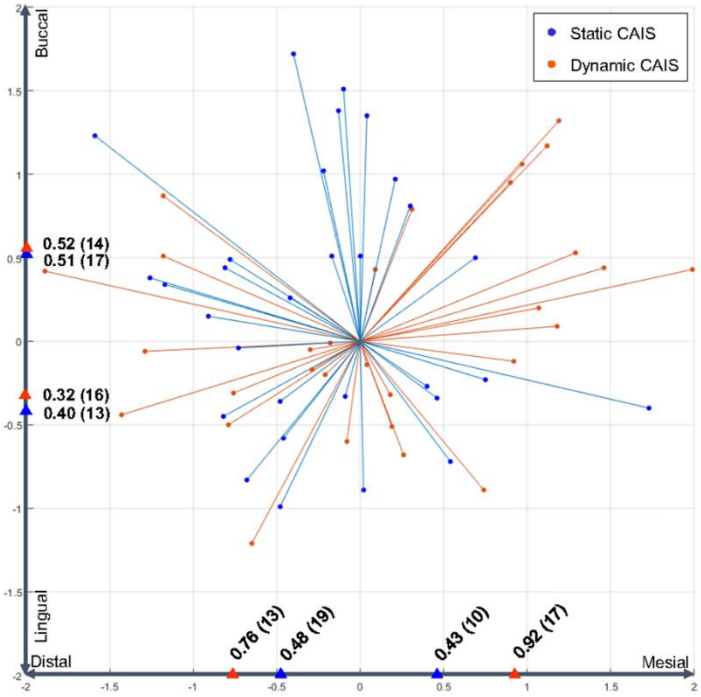

Figure 13. Distribution of the deviation of each implants in mesio-distal VS bucco-lingual direction at implant apex.

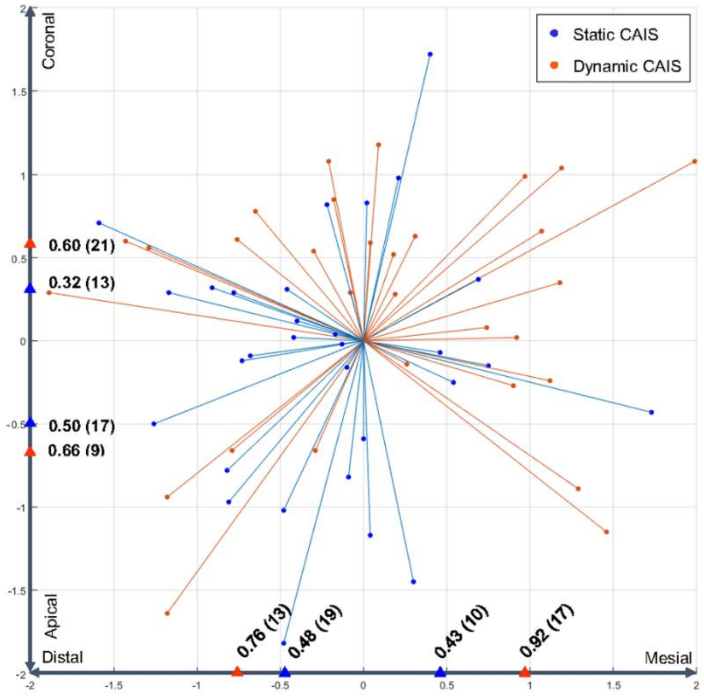

Figure 14. Distribution of the deviation of each implants in mesio-distal VS apico-coronal direction at implant apex.

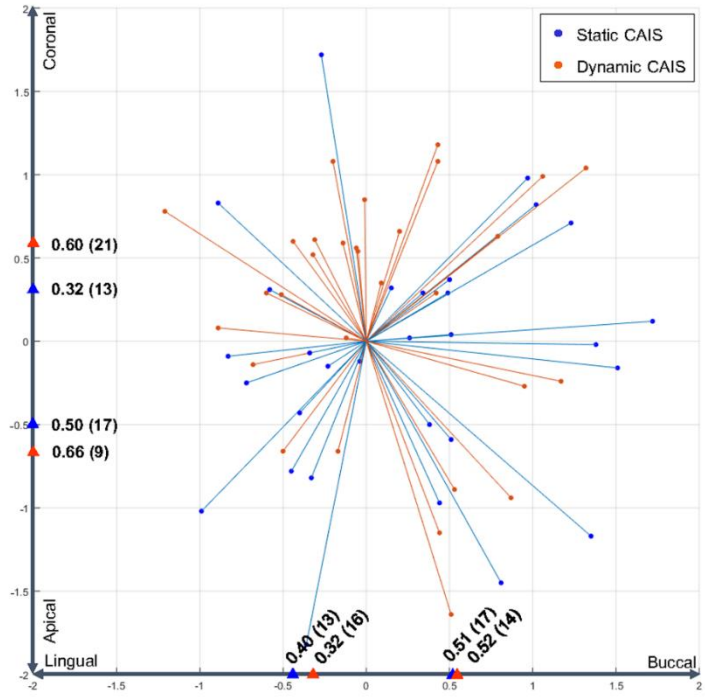

Figure 15. Distribution of the deviation of each implants in bucco-lingual VS apico-coronal direction at implant apex.

CHAPTER V
DISCUSSION

The ideal 3D implant position should be achieved in single dental implant restoration in order to provide proper function, esthetic, and long term success to the implant prostheses (58-60). CAIS systems were developed in order to accurately transfer the virtual ideal 3D implant position to the surgical site. Several authors reported that implants placed using CAIS systems were more accurate than those using traditional methods (1, 15, 17, 61, 62) thus this study desired left the traditional implant placement behind.

In this study, no significant differences of the implant deviations were found between the two groups. Both static and dynamic CAIS systems provide the accurate single implant placement related to the plan with mean platform and apex deviations less than 1.1 mm and mean angular deviation less than 3.1 degrees. The deviations of both groups were less than the results from in vitro studies by Ruppin et al. (2008) (17) that compare the deviation of implant placement from preoperative and postoperative CT scan in partially and fully edentulous human cadaver mandibles using static and dynamic CAIS systems. They reported that no significant difference were found between these CAIS system with the mean platform deviation of less than 1.5 mm and mean angular deviation of less than 8.1 degrees. Somogyi-Gnass et al. (2015) (1) compared the deviations of implant bed preparation between using static and dynamic CAIS systems in partially edentulous maxilla and mandible models and reported that no significant differences were found between the two systems with mean platform and apex deviation of less than 1.91 mm and 1.14 mm respectively and mean angular deviation of less than 4.24 degrees for both systems. However, these in vitro studies performed in cadavers and study models that provided better access, better visual control, no patient movement, and absent of soft tissue, saliva and blood that can increase the deviation of implant in clinical study. Therefore, it is assume that in vitro studies would yielded lower implant deviation than clinical studies as shown in several systematic reviews. Our results also consistent with several systematic

reviews and meta-analyses that reported the accuracy of CAIS systems in clinical studies, the deviation were less than 1.22 mm and 1.45 mm at platform and apex respectively and less than 4.06 degrees for angular deviation (5, 41, 42, 57, 63). However, these systematic reviews contain various study designs, implant systems, and CAIS systems so the lack of homogeneity between studies in these systematic reviews were observed (I^2 = 71.6 – 99%).

When analyze the vector of the deviation at implant platform and apex of both groups, there were no significant difference in bucco-lingual and apico-coronal directions between groups. Interestingly, in mesio-distal direction, the median value of implants that deviated to mesial direction in static CAIS group was significant difference to dynamic CAIS group when measure at implant platform. This phenomenon might be caused by poorer visualization because implant placement using dynamic CAIS system relies in visual control that allow the blind spot to be happen at mesial side of edentulous area due to hindering of mesial tooth particularly in posterior region. Most of the implants in this study were placed in posterior edentulous area, so the mesial deviation value can be larger in dynamic CAIS group. Moreover, the rotational movement of human hand and wrist might also affect the mesial deviation in dynamic CAIS group compared with static CAIS group that using mechanical positioning method. However, this mesial deviation in dynamic CAIS group was smaller comparing to the conventional implant placement in previous studies (1, 10, 15).

Implant deviation is the sum of possible errors from image acquisition, image data processing, surgical template manufacturing, type of surgical template support, level of guidance in osteotomy and implant placement procedure, registration procedure, and human error (4, 45). The resolution of the digital image volume affects the accuracy of the virtual planning procedure follow by the deviation of final implant position transferred from the virtual plan. The resolution of data depends on the voxel size, the smaller the voxel size, the higher the resolution and the measurement accuracy are (4). CBCT was shown to be a useful tool in preoperative evaluation for dental implant placement because of its higher resolution, lower radiation exposure, and shorter scanning times compared to conventional CT. Kobayashi et al. (2004) (24) compared the accuracy of distance measurement in mandible between using spiral CT

and CBCT and reported that mean measurement error of spiral CT (0.36 ± 0.24 mm) was significantly higher than CBCT (0.22 ± 0.15 mm). In our study, all patients were receive CBCT scan using the same machine performed by one experienced radiologist with the voxel size of 0.25 x 0.25 x 0.25 mm that provided comparable resolution with previous studies (10, 15, 17, 61) and the image data processing was followed the orientation and cross-sectional principles described by Mora et al. (2014) (45) so the image acquisition and processing could be reliable.

In static CAIS group, although the position of the drill and implant were controlled by teeth-supported surgical template which provide better accuracy for implant placement compared to mucosa- and bone-supported template, however, the deviation of the drill and implant could be occurred (14, 30, 31, 41). The error can caused by movement of the template during surgery, misfit of the guided instruments and drill, the interference of the opposing dentition that hinder the correct positioning of the drill and implant especially in molar area or in restrict mouth opening patient. In this study, however, the surgical templates were fabricated by stereolithographic rapid prototyping method using photosensitive liquid acrylic that has been used in previous studies and provide accurate transfer of implant position (1, 15, 17, 30, 31). The stability and intimate fit of the template was also confirmed through the observation window on the template before the surgery was performed. All patients have proper mouth opening (at least 40 mm of inter-incisal distance) to perform implant placement with the surgical template in place. Therefore, errors from surgical template manufacturing and application were reduced.

Several factors influence the accuracy of dynamic CAIS system. Error from tracking system can be reported as Target Registration Error (TRE) which refer to the deviation between the corresponding points on CT image and surgical site other than the fiducial points after registration (4). In this study, we used the occlusal stent with fiducial markers as the registration device which is the non-invasive technique, provide acceptable accuracy, and easy to perform particularly in patient who has sufficient teeth to support the stent. Luebbers et al. (2007) (64) reported that when using an occlusal stent as the registration method, the minimum TRE measuring closed to maxillary teeth was 0.4 mm and the TRE increases with the distance from the plane of fiducial markers on maxillary teeth. The result is consistent with Casap et al. (2008) (12) that reported the TRE of less than 0.5 mm when using teeth-supported fiducial

markers as the registration method for lower jaw surgery. In our study, the registration procedure was performed by one clinician who was done the reliability test of the accuracy of registration in study models before. The intraclass correlations coefficient was 0.84, that indicated good reliability, therefore, the procedure were not affected by human error.

Human error also has an effect on the accuracy of implant placement especially in dynamic CAIS system. In this system, the position and angulation of the drill and implant were controlled by surgeon's hand without any mechanical guidance instruments. The procedure involves hand tremor and perception inaccuracy that can cause the deviations of about 0.25 mm and 0.5 degrees (4). The success of transferring the virtual implant position to the surgical site relies on the eye-hand coordination skill of the surgeon to interpret the data on navigation monitor together with handling of the drill and implant during surgery (1, 4). In this study, only one surgeon who have more than ten years of experiences in implant performed the surgery in both group, so the accuracy of freehand implant placement under guidance by the navigation system could be reliable.

Implant bed preparation in an area with asymmetric bone density also leads to the deviation of the drill to the least resistance area (10). In the present study, the maximum implant deviations were found in dynamic CAIS group with the platform and apex deviation of 2.04 mm and 2.31 mm respectively. In this case, the implant was placed into mandibular molar area which has been extracted for 3 months prior surgery. Asymmetric bone density due to remaining bony septum was observed and the implant was deviated mesially from the virtual plan. We recommend that in case with implant placement will be performed in molar area which the dense interradicular septum could be observed, the implant placement procedure should be performed more than 3 months after extraction to obtain symmetric bone density.

CAIS systems provide many advantages for implant placement over traditional methods. Dynamic CAIS system provides real-time visualization of the implant drill related to the preoperative CT scan. This process helps the clinician to aware the presence of the important structures and the surgical plan can be adjusted at any time to avoid damage of these structures. This ability might be useful in varieties of implant placement such as when implant placed closed to the inferior alveolar nerve, maxillary

sinus, and in narrow edentulous space with proximity of adjacent tooth roots, etc. In contrast, although the planning was perform in 3D space of CT image, the static CAIS system can provide only passive guidance. The clinician relies on the CT-derived surgical template without intraoperative visualization of intraosseous structure and adjustment of implant position cannot be performed (27). However, no sign and symptom of damage to these structures were found in this study. Other advantages of dynamic CAIS over static CAIS include the ability to directly observe and irrigate the surgical site without interference of surgical template. The surgery can be performed using traditional instrument of several implant systems that included in the database, whereas static CAIS system requires specific drill system, guided instruments, and specific implant fixture of various implant systems that require additional laboratory cost and time.

In contrast, static CAIS system requires less surgical time compared with dynamic CAIS system because the surgical template provides mechanical guidance of the drill and implant position without additional time for adjustment is needed. Dynamic CAIS system requires the learning curve of the surgeon to gain proficiency from using this system. Block et al. (2016) (10) reported that implant placement using dynamic CAIS system performed by experienced surgeon was more accurate than unexperienced surgeon. In contrast, Rungcharassaeng et al. (2015) (7) reported that the accuracy of implant placement using static CAIS system was not significant difference between experienced and unexperienced surgeons. Implant placement in our study was performed by one experienced surgeon, so the reliability of implant placement in both group could be controlled.

CHAPTER VI

CONCLUSION

Implant placement in single tooth space is straightforward situation and considered as the simple treatment procedure in dental implantology especially in non-esthetic zone. With the limitation of the study, implant placement in single tooth space using dynamic CAIS system is as accurate as using static CAIS system. From our experience and clinical observation, we recommend to use dynamic CAIS system in case of implant placement close to the important structure such as inferior alveolar canal or maxillary sinus. The ability to visualize the working drill related to intraosseous structure in CT image and real-time adjustment is the advantages of dynamic CAIS system. Further studies should be performed to compare the accuracy of these systems in more advance anatomical situation such as in partially and fully edentulous patient. Comparison of cost-benefits and cost-effectiveness between static and dynamic CAIS systems should also be done.

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APPENDICES

Appendix A Thai consent form

เอกสารยินยอมเข้าร่วมการวิจัย (Consent Form)

การวิจัยเรื่อง การเปรียบเทียบความคลาดเคลื่อนของการฝังรากฟันเทียมโดยใช้คอมพิวเตอร์ช่วยแบบสถิตและแบบพลวัต

ข้าพเจ้า (นาย/ นาง/ นางสาว/ เด็กชาย/

เด็กหญิง).....

อยู่บ้านเลขที่.....ถนน.....ตำบล/แขวง

.....

อำเภอ/เขต.....จังหวัด.....รหัสไปรษณีย์

.....

ก่อนที่จะลงนามในใบยินยอมให้ทำการวิจัยนี้

1. ข้าพเจ้าได้รับทราบรายละเอียดข้อมูลคำอธิบายสำหรับอาสาสมัครที่เข้าร่วมในการวิจัย รวมทั้งได้รับการ

อธิบายจากผู้วิจัยถึงวัตถุประสงค์ของการวิจัย วิธีการทำวิจัย อันตรายหรืออาการที่อาจเกิดขึ้นจากการทำวิจัย

หรือจากยาที่ใช้รวมทั้งประโยชน์ที่จะเกิดขึ้นจากการวิจัยอย่างละเอียดและมีความเข้าใจดีแล้ว

2. ผู้วิจัยรับรองว่าจะตอบคำถามต่างๆ ที่ข้าพเจ้าสงสัยด้วยความเต็มใจไม่ปิดบังซ่อนเร้นจนข้าพเจ้าพอใจ

3. ผู้วิจัยรับรองว่าจะเก็บข้อมูลเฉพาะเกี่ยวกับตัวข้าพเจ้าเป็นความลับและจะเปิดเผยได้เฉพาะในรูปที่เป็นสรุป

ผลการวิจัย การเปิดเผยข้อมูลเกี่ยวกับตัวข้าพเจ้าต่อหน่วยงานต่างๆ ที่เกี่ยวข้องกระทำได้เฉพาะกรณีจำเป็น

ด้วยเหตุผลทางวิชาการเท่านั้น และผู้วิจัยรับรองว่าหากเกิดอันตรายใดๆ จากการวิจัยดังกล่าว ข้าพเจ้าจะได้รับ

การรักษาพยาบาลโดยไม่คิดมูลค่า

4. ข้าพเจ้ามีสิทธิที่จะบอกเลิกการเข้าร่วมในโครงการวิจัยนี้เมื่อใดก็ได้และการบอกเลิกการเข้าร่วมการวิจัยนี้จะไม่

มีผลต่อการรักษาโรคที่ข้าพเจ้าจะพึงได้รับต่อไป

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

ข้าพเจ้าจึงสมัครใจเข้าร่วมโครงการวิจัยนี้ตามที่ระบุในเอกสารข้อมูลคำอธิบายสำหรับอาสาสมัครและได้ลง นามในใบยินยอมนี้ด้วยความเต็มใจ และได้รับสำเนาเอกสารใบยินยอมที่ข้าพเจ้าลงนามและลงวันที่ และเอกสารยกเลิกการเข้าร่วมวิจัย อย่างละ 1 ฉบับ เป็นที่เรียบร้อยแล้ว ในกรณีที่อาสาสมัครยังไม่บรรลุนิติภาวะจะต้องได้รับการยินยอมจากผู้ปกครองด้วย

ลงนาม..... (อาสาสมัคร) (.....) วันที่...../...../.....	ลงนาม..... (ผู้ปกครอง) (.....) วันที่...../...../.....
ลงนาม..... (ผู้วิจัยหลัก) (.....) วันที่...../...../.....	ลงนาม..... (พยาน) (.....) วันที่...../...../.....

ข้าพเจ้าไม่สามารถอ่านหนังสือได้ แต่ผู้วิจัยได้อ่านข้อความในใบยินยอมนี้ให้แก่ข้าพเจ้าฟังจนเข้าใจดีแล้ว ข้าพเจ้าจึงลงนาม หรือประทับลายนิ้วหัวแม่มือขวาของข้าพเจ้าในใบยินยอมนี้ด้วยความเต็มใจ

ลงนาม..... (อาสาสมัคร) (.....) วันที่...../...../.....	ลงนาม..... (ผู้ปกครอง) (.....) วันที่...../...../.....
ลงนาม..... (ผู้วิจัยหลัก) (.....) วันที่...../...../.....	ลงนาม..... (พยาน) (.....) วันที่...../...../.....

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Appendix B Data recorded form

Group ☐ Static CAIS ☐ Dynamic CAIS

Name..... HN.....

Age..... Gender..... Tel.....

Underlying disease.....

Current medication.....

Drug allergy.....

Tooth No..... Extraction date..... Implant placement date.....

Timing of placement ☐ Early (3 - 4 months) ☐ Late (> 4 months)

Implant type ☐ Bone level ☐ Bone level taper ☐ Tissue level

Implant diameter ☐ 3.3 mm ☐ 4.1 mm ☐ 4.8 mm

Implant length ☐ 8 mm ☐ 10 mm ☐ 12 mm

Surgical technique ☐ Flap opening ☐ Flapless

Bone augmentation ☐ No ☐ GBR technique ☐ Transcrestal sinus lift

☐ Other .....

Insertion torque (N/cm)..... RFA value (ISQ) Buccal..... Mesial.....

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Implant deviation

Angle deviation (degrees)	Platform deviation (mm)				Apex deviation (mm)			
	3D	Mesial	Buccal	Apical	3D	Mesial	Buccal	Apical

Complications.....

Appendix C Patient demographic and clinical data in static CAIS group

ID	Age	Sex	Tooth	Diameter	Type	H	Flap	Timing	Augment	Torque	RFA (B)	RFA (M)
S01	58	M	46	4.8	SP	10	Flap	Delay	No	N/A	N/A	N/A
S02	67	F	16	4.8	SP	10	Flap	Delay	No	N/A	N/A	N/A
S03	63	F	13	3.3	BL	10	Flap	Delay	Yes	35	56	56
S04	53	F	36	4.8	BL	10	Flapless	Early	No	15	63	59
S05	59	F	26	4.8	BL	10	Flap	Delay	No	35	73	74
S06	70	M	45	3.3	BL	10	Flap	Delay	Yes	20	62	67
S07	55	F	26	4.8	BL	8	Flap	Delay	Yes	35	70	71
S08	59	F	26	4.8	BL	8	Flapless	Delay	Yes	15	53	44
S09	58	F	46	4.1	BL	8	Flap	Delay	Yes	N/A	80	85
S10	61	M	16	4.8	BL	8	Flap	Early	Yes	35	61	61
S11	29	F	12	3.3	BL	12	Flap	Delay	Yes	35	62	64
S12	63	F	23	3.3	BL	10	Flap	Delay	Yes	35	57	62
S13	63	M	24	4.1	BL	12	Flap	Delay	No	15	30	30
S14	74	M	45	4.1	BL	10	Flapless	Early	No	35	69	71
S15	53	F	15	4.1	BL	10	Flapless	Delay	No	35	74	72
S16	48	F	36	4.8	BL	10	Flap	Delay	No	10	74	74
S17	66	M	25	4.1	BL	10	Flapless	Delay	Yes	35	81	82
S18	66	M	47	4.8	BL	10	Flap	Delay	No	20	61	63
S19	61	F	21	4.1	BL	10	Flap	Early	No	N/A	20	14
S20	46	F	36	4.1	BL	10	Flap	Delay	No	30	60	59
S21	59	M	15	4.1	BL	10	Flap	Delay	Yes	25	59	58
S22	57	F	16	4.8	BL	8	Flap	Delay	Yes	N/A	N/A	N/A
S23	28	F	11	3.3	BLT	10	Flap	Delay	Yes	15	22	30
S24	43	F	21	4.1	BL	10	Flap	Early	Yes	10	10	10
S25	56	F	14	4.1	BL	10	Flap	Early	No	25	75	75
S26	66	F	14	4.1	BLT	10	Flap	Delay	No	N/A	N/A	N/A
S27	66	F	25	4.1	BLT	10	Flap	Delay	No	N/A	N/A	N/A
S28	36	M	46	4.1	BLT	10	Flap	Delay	No	15	57	53
S29	57	F	16	4.8	BL	8	Flap	Delay	Yes	15	N/A	N/A
S30	57	F	26	4.8	BL	8	Flap	Delay	Yes	15	N/A	N/A

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Appendix D Patient demographic and clinical data in dynamic CAIS group

ID	Age	Sex	Tooth	Diameter	Type	H	Flap	Timing	Augment	Torque	RFA (B)	RFA (M)
D01	66	F	24	4.1	BL	10	Flap	Early	No	35	80	78
D02	45	F	36	4.1	BLT	10	Flap	Delay	No	15	49	37
D03	43	F	24	4.1	BLT	10	Flap	Early	No	25	76	76
D04	41	F	25	3.3	BL	12	Flap	Delay	No	20	74	73
D05	49	M	42	3.3	BLT	12	Flap	Delay	Yes	35	N/A	N/A
D06	36	M	36	3.3	BL	10	Flap	Delay	No	35	85	85
D07	64	F	14	3.3	BL	10	Flap	Delay	Yes	15	69	72
D08	65	M	16	4.8	BL	8	Flap	Delay	No	15	66	66
D09	55	F	21	4.1	BL	10	Flap	Delay	Yes	35	78	81
D10	34	M	42	3.3	BL	12	Flap	Delay	Yes	35	70	73
D11	63	F	46	4.8	BL	10	Flap	Delay	No	35	86	85
D12	41	F	15	3.3	SP	12	Flap	Early	No	15	60	63
D13	55	F	36	4.8	BL	10	Flap	Early	No	35	69	72
D14	55	F	46	4.8	BL	10	Flap	Early	No	35	82	79
D15	38	F	14	3.3	BL	10	Flap	Delay	Yes	25	71	73
D16	70	M	16	4.8	BL	10	Flapless	Delay	No	35	80	82
D17	61	F	14	3.3	BL	8	Flapless	Delay	No	15	61	61
D18	60	F	26	4.8	BL	10	Flapless	Delay	No	25	64	69
D19	30	M	44	4.1	BL	10	Flap	Delay	Yes	35	80	77
D20	65	F	25	4.1	BLT	10	Flapless	Delay	No	35	75	75
D21	60	F	26	4.8	BL	8	Flapless	Delay	Yes	25	79	79
D22	50	F	46	4.8	BLT	10	Flap	Delay	No	35	85	85
D23	44	F	25	4.1	BLT	10	Flap	Delay	No	25	72	72
D24	44	F	46	4.8	BLT	10	Flap	Delay	No	35	80	81
D25	60	F	16	4.1	BL	8	Flap	Delay	No	N/A	N/A	N/A
D26	32	F	35	4.1	BL	10	Flap	Early	Yes	25	71	72
D27	50	F	34	4.1	BLT	10	Flap	Delay	Yes	35	78	85
D28	38	F	36	4.8	SP	8	Flap	Delay	No	35	84	77
D29	21	F	21	4.1	BLT	10	Flap	Delay	Yes	15	44	65
D30	59	M	36	4.1	SP	10	Flap	Delay	No	35	65	71

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Appendix E Implant deviations at platform, apex, and angle deviation in static CAIS group

ID	Angle deviation (degrees)	Platform deviation (mm)				Apex deviation (mm)			
		3D	Mesial	Buccal	Apical	3D	Mesial	B-L	Apical
S01	0.50	1.26	- 0.20	0.94	- 0.82	1.33	- 0.22	1.02	- 0.82
S02	2.40	0.59	0.56	0.15	0.14	0.80	0.75	- 0.23	0.15
S03	1.20	1.75	0.19	-0.21	- 1.72	1.78	0.40	- 0.27	- 1.72
S04	2.80	0.48	0.29	- 0.30	0.24	0.94	0.54	- 0.72	0.25
S05	6.60	0.47	- 0.27	0.37	0.09	1.52	- 0.10	1.51	0.16
S06	3.90	0.70	0.09	- 0.18	- 0.33	1.02	- 0.46	- 0.58	- 0.31
S07	3.10	1.08	- 0.48	0.15	0.96	1.33	- 0.81	0.44	0.97
S08	2.10	0.28	- 0.17	0.21	- 0.05	0.54	- 0.17	0.51	- 0.04
S09	1.40	1.57	- 0.13	1.19	1.02	1.72	- 0.13	1.38	0.02
S10	1.50	1.26	0.16	0.76	- 0.99	1.40	0.21	0.97	- 0.98
S11	3.90	0.85	- 0.33	0.22	0.76	1.22	- 0.82	- 0.45	0.78
S12	1.40	0.90	- 0.68	- 0.59	0.09	1.07	- 0.68	- 0.83	0.09
S13	4.80	1.34	- 1.04	0.39	- 0.75	2.13	- 1.59	1.23	- 0.71
S14	1.10	0.57	- 0.35	0.45	- 0.02	0.49	- 0.42	0.26	- 0.02
S15	2.50	0.32	- 0.30	- 0.04	0.11	0.75	- 0.73	- 0.04	0.12
S16	0.80	0.89	0.06	- 0.33	0.82	0.89	- 0.09	- 0.33	0.82
S17	1.20	0.66	0.00	0.31	0.59	0.78	0.00	0.51	0.59
S18	3.20	0.49	- 0.35	0.06	- 0.34	0.97	- 0.91	0.15	- 0.32
S19	3.80	0.90	0.00	0.28	- 0.31	1.42	- 1.17	0.34	- 0.29
S20	3.20	0.90	0.02	- 0.33	- 0.84	1.22	0.02	- 0.89	- 0.83
S21	5.00	1.54	- 0.47	0.02	0.46	1.99	- 1.26	0.38	0.50
S22	5.60	1.04	- 0.05	1.02	- 0.16	1.77	- 0.40	1.72	- 0.12
S23	2.50	0.18	0.07	- 0.16	0.06	0.58	0.46	- 0.34	0.07
S24	2.80	1.45	0.09	0.87	1.16	1.78	0.04	1.35	1.17
S25	0.30	0.93	- 0.73	0.49	- 0.29	0.97	- 0.78	0.49	- 0.29
S26	4.30	1.42	- 0.02	0.12	1.42	1.68	0.30	0.81	1.45
S27	4.30	1.13	1.05	- 0.10	0.40	1.83	1.73	- 0.40	0.43
S28	0.20	1.03	0.67	0.47	- 0.37	1.06	0.69	0.50	- 0.37
S29	5.70	1.25	- 0.74	- 0.24	0.98	1.50	- 0.48	- 0.99	1.02
S30	3.20	1.83	- 0.33	0.06	1.80	1.91	- 0.48	- 0.36	1.82

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Appendix F Implant deviations at platform, apex, and angle deviation in dynamic CAIS group

ID	Angle deviation (degrees)	Platform deviation (mm)				Apex deviation (mm)			
		3D	Mesial	Buccal	Apical	3D	Mesial	Buccal	Apical
D01	3.98	1.23	0.60	0.64	0.87	1.66	1.29	0.53	0.89
D02	2.90	1.58	1.10	- 0.08	1.13	1.90	1.46	0.44	1.15
D03	0.43	1.14	- 0.22	- 0.27	- 1.08	1.12	- 0.21	- 0.20	- 1.08
D04	1.37	0.62	0.19	0.00	- 0.59	0.61	0.04	- 0.14	- 0.59
D05	3.79	1.12	0.19	0.68	- 0.88	0.87	- 0.18	- 0.01	- 0.85
D06	3.34	1.07	0.85	- 0.23	- 0.61	1.02	- 0.76	- 0.31	- 0.61
D07	2.38	0.56	0.12	0.01	- 0.55	0.62	- 0.30	- 0.05	- 0.54
D08	2.28	0.53	0.02	- 0.05	- 0.53	0.64	0.18	- 0.32	- 0.52
D09	2.61	1.20	- 0.14	0.03	- 1.19	1.26	0.09	0.43	- 1.18
D10	4.31	0.75	0.44	0.35	- 0.50	1.41	- 1.29	- 0.06	- 0.56
D11	3.19	0.69	0.09	0.24	0.65	0.74	- 0.29	- 0.17	0.66
D12	0.94	1.29	- 1.03	- 0.39	- 0.66	1.28	1.07	0.20	- 0.66
D13	4.57	0.64	0.51	0.23	- 0.31	0.61	0.19	- 0.51	- 0.28
D14	3.80	2.04	1.71	- 0.13	- 1.10	2.31	1.99	0.43	- 1.08
D15	2.91	0.78	0.68	- 0.09	0.37	1.24	1.18	0.09	- 0.35
D16	3.52	0.83	0.48	0.21	- 0.65	1.06	0.31	0.79	- 0.63
D17	5.60	1.55	0.97	0.53	- 1.08	2.06	1.19	1.32	- 1.04
D18	1.37	1.48	- 1.24	- 0.55	- 0.60	1.61	- 1.43	- 0.44	- 0.60
D19	4.36	0.37	0.34	0.07	0.11	0.75	0.26	- 0.68	0.14
D20	2.58	1.41	0.67	0.74	- 1.01	1.75	0.97	1.06	- 0.99
D21	1.96	1.62	- 0.91	0.95	0.93	1.74	- 1.18	0.87	0.94
D22	6.54	0.98	- 0.91	- 0.10	- 0.35	1.96	- 1.89	0.42	- 0.29
D23	1.15	1.97	- 1.02	0.36	1.64	2.08	- 1.18	0.51	1.64
D24	2.79	0.98	0.32	- 0.89	0.25	1.27	0.90	0.95	0.27
D25	3.00	1.25	0.72	0.99	0.23	1.64	1.12	1.17	0.24
D26	4.91	0.45	- 0.17	- 0.26	- 0.32	0.67	- 0.08	- 0.60	- 0.29
D27	3.56	1.14	- 0.17	- 0.80	- 0.80	1.58	- 0.65	- 1.21	- 0.78
D28	2.24	0.66	0.66	0.06	- 0.01	0.93	0.92	- 0.12	- 0.02
D29	2.41	0.92	- 0.64	- 0.11	0.66	1.14	- 0.79	- 0.50	0.66
D30	2.91	0.66	0.45	- 0.47	- 0.09	1.16	0.74	- 0.89	- 0.08

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Appendix G Statistical output

Descriptive statistics of 3D implant deviation at platform in static and dynamic CAIS groups

	Group			Statistic	Std. Error
Platform3D	static	Mean		.9687	.08058
		95% Confidence Interval for Mean	Lower Bound	.8039	
			Upper Bound	1.1335	
		5% Trimmed Mean		.9643	
		Median		.9150	
		Variance		.195	
		Std. Deviation		.44136	
		Minimum		.18	
		Maximum		1.83	
		Range		1.65	
		Interquartile Range		.70	
		Skewness		.104	.427
		Kurtosis		-.747	.833
	dynamic	Mean		1.0503	.07972
		95% Confidence Interval for Mean	Lower Bound	.8873	
			Upper Bound	1.2134	
		5% Trimmed Mean		1.0330	
		Median		1.0250	
		Variance		.191	
		Std. Deviation		.43662	
		Minimum		.37	
		Maximum		2.04	
		Range		1.67	
		Interquartile Range		.66	
		Skewness		.532	.427
		Kurtosis		-.308	.833

Descriptive statistics of 3D implant deviation at apex in static and dynamic CAIS groups

	Group			Statistic	Std. Error
Apex3D	static	Mean		1.2797	.08452
		95% Confidence Interval for Mean	Lower Bound	1.1068	
			Upper Bound	1.4525	
		5% Trimmed Mean		1.2780	
		Median		1.2750	
		Variance		.214	
		Std. Deviation		.46293	
		Minimum		.49	
		Maximum		2.13	
		Range		1.64	
		Interquartile Range		.80	
		Skewness		.044	.427
		Kurtosis		-1.060	.833
	dynamic	Mean		1.2897	.09117
		95% Confidence Interval for Mean	Lower Bound	1.1032	
			Upper Bound	1.4761	
		5% Trimmed Mean		1.2750	
		Median		1.2500	
		Variance		.249	
		Std. Deviation		.49936	
		Minimum		.61	
		Maximum		2.31	
		Range		1.70	
		Interquartile Range		.84	
		Skewness		.284	.427
		Kurtosis		-.955	.833

Descriptive statistics of implant angle deviation in static and dynamic CAIS groups

	Group			Statistic	Std. Error
Angle	static	Mean		2.8433	.31204
		95% Confidence Interval for Mean	Lower Bound	2.2051	
			Upper Bound	3.4815	
		5% Trimmed Mean		2.7963	
		Median		2.8000	
		Variance		2.921	
		Std. Deviation		1.70914	
		Minimum		.20	
		Maximum		6.60	
		Range		6.40	
		Interquartile Range		2.65	
		Skewness		.332	.427
		Kurtosis		-.620	.833
	dynamic	Mean		3.0567	.25081
		95% Confidence Interval for Mean	Lower Bound	2.5437	
			Upper Bound	3.5696	
		5% Trimmed Mean		3.0170	
		Median		2.9100	
		Variance		1.887	
		Std. Deviation		1.37374	
		Minimum		.43	
		Maximum		6.54	
		Range		6.11	
		Interquartile Range		1.57	
		Skewness		.389	.427
		Kurtosis		.387	.833

Mean and standard deviation of the implant deviations in static and dynamic CAIS group

Group Statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
Platform3D	static	30	.9687	.44136	.08058
	dynamic	30	1.0503	.43662	.07972
Apex3D	static	30	1.2797	.46293	.08452
	dynamic	30	1.2897	.49936	.09117
Angle	static	30	2.8433	1.70914	.31204
	dynamic	30	3.0567	1.37374	.25081

Normality test of 3D implant deviation at platform, apex and angle deviation in static and dynamic CAIS groups

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Group	Statistic	df	Sig.	Statistic	df	Sig.
Platform3D	static	.071	30	.200*	.979	30	.785
	dynamic	.110	25	.200*	.962	25	.466
Apex3D	static	.108	30	.200*	.965	30	.405
	dynamic	.124	25	.200*	.936	25	.121
Angle	static	.117	30	.200*	.968	30	.488
	dynamic	.088	25	.200*	.987	25	.984

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

a. Lilliefors Significance Correction

Comparison of 3D platform deviation, 3D apex deviation, and angle deviation between static and dynamic CAIS group.

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
Platform3D	Equal variances assumed	.003	.955	-.720	58	.474	-.08167	.11335	-.30856	.14522
	Equal variances not assumed			-.720	57.99	.474	-.08167	.11335	-.30856	.14523
Apex3D	Equal variances assumed	.115	.736	-.080	58	.936	-.01000	.12432	-.25885	.23885
	Equal variances not assumed			-.080	57.67	.936	-.01000	.12432	-.25889	.23889
Angle	Equal variances assumed	2.029	.160	-.533	58	.596	-.21333	.40035	-1.01471	.58805
	Equal variances not assumed			-.533	55.43	.596	-.21333	.40035	-1.01550	.58884

Comparison of platform and apex deviation in implants that deviated to mesial, distal, buccal, lingual, coronal, and apical direction between static and dynamic CAIS group.

Platform deviation Test Statistics[a]

	mesialP	distalP	buccalP	lingualP	apicalP	coronalP
Mann-Whitney U	65.000	61.000	152.500	63.500	68.500	103.000
Wilcoxon W	143.000	214.000	288.500	118.500	221.500	194.000
Z	-2.143	-1.206	-.239	-.093	-.431	-1.187
Asymp. Sig. (2-tailed)	.032	.228	.811	.926	.666	.235
Exact Sig. [2*(1-tailed Sig.)]	.032[b]	.243[b]	.814[b]	.927[b]	.672[b]	.246[b]

a. Grouping Variable: group

b. Not corrected for ties.

Apical deviation Test Statistics[a]

	mesialA	distalA	buccalA	lingualA	apicalA	coronalA
Mann-Whitney U	56.500	105.000	100.500	77.500	62.000	108.500
Wilcoxon W	111.500	295.000	205.500	213.500	215.000	199.500
Z	-1.431	-.710	-.735	-1.162	-.782	-.993
Asymp. Sig. (2-tailed)	.152	.478	.462	.245	.434	.321
Exact Sig. [2*(1-tailed Sig.)]	.155[b]	.495[b]	.468[b]	.249[b]	.458[b]	.326[b]

a. Grouping Variable: group

b. Not corrected for ties.

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Chulalongkorn University

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