COMPARISON OF THREE DIMENSIONAL ACCURACY FOR SURGICAL GUIDED TEMPLATE FABRICATION USING TWO DIFFERENT IMPLANT PLANNING SOFTWARE PROGRAMS

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การเปรียบเทียบความแม่นยำของการขึ้นรูปแผ่นจำลองนำทางผ่าตัดระหว่างชิ้นงานที่ได้จากการวางแผนฝังรากเทียมด้วยโปรแกรมคอมพิวเตอร์ช่วยเหลือสองระบบ

น.ส.ณัฐชยา ถิตะพาณิชย์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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ณัฐชยา ถิตะพาณิชย์ : การเปรียบเทียบความแม่นยำของการขึ้นรูปแผ่นจำลองนำทางผ่าตัดระหว่างชิ้นงานที่ได้จากการวางแผนฝังรากเทียมด้วยโปรแกรมคอมพิวเตอร์ช่วยเหลือสองระบบ. (COMPARISON OF THREE DIMENSIONAL ACCURACY FOR SURGICAL GUIDED TEMPLATE FABRICATION USING TWO DIFFERENT IMPLANT PLANNING SOFTWARE PROGRAMS) อ.ที่ปรึกษาหลัก : ผศ. ทพ.ประเวศ เสรีเชษฐพงษ์, อ.ที่ปรึกษาร่วม : ผศ. ทพ.อาทิพันธุ์ พิมพ์ขาวขำ

วัตถุประสงค์: เพื่อเปรียบเทียบความแม่นยำของตำแหน่งรากเทียมระหว่างแผ่นจำลองนำทางผ่าตัดที่ได้จากโปรแกรมคอมพิวเตอร์ช่วยเหลือระบบโคไดแอกโนสติค (coDiagnostiX™) และ ระบบอิมพล้านสตูดิโอ (Implant Studio™)

วิธีการศึกษา: แบบจำลองฟันที่สูญเสียฟันตัดบนคู่กลางด้านขวาจำนวน 30 ชิ้น ถูกแบ่งออกเป็น 2 กลุ่มตามโปรแกรมคอมพิวเตอร์ช่วยเหลือที่ใช้ ซึ่งได้แก่โปรแกรมโคไดแอกโนสติค (coDiagnostiX™) และ โปรแกรมอิมพล้านสตูดิโอ (Implant Studio™) จากนั้นตำแหน่งรากเทียมที่ได้จากการฝังผ่านแผ่นจำลองนำทางผ่าตัดที่ได้จาก 2 โปรแกรม จะถูกนำมาเปรียบเทียบกับตำแหน่งรากเทียมที่ได้วางแผนไว้จากแต่ละโปรแกรมคอพิวเตอร์ช่วยเหลือ ข้อมูลความเบี่ยงเบนของตำแหน่งรากเทียมที่ได้จะถูกนำไปวิเคราะห์ทางสถิติด้วยการทดสอบที (t-test) ที่ระดับนัยสำคัญ .05

ผลการศึกษา: การวิเคราะห์ทางสถิติพบว่าค่าเฉลี่ยของระยะเบี่ยงเบนของตำแหน่งรากเทียมที่ได้จากการใช้แผ่นจำลองนำทางผ่าตัดผ่านโปรแกรมโคไดแอกโนสติค (coDiagnostiX™)มีค่าตามแนวต่างๆดังนี้ มุมที่เบี่ยงเบนมีค่าเฉลี่ย 1.99 ± 0.96 องศา ระยะเบี่ยงเบนที่บริเวณบ่าของรากเทียมมีค่าเฉลี่ย 0.57 ± 0.15 มิลลิเมตร และระยะเบี่ยงเบนในแนวความลึกมีค่าเฉลี่ย -0.51 ± 0.18 มิลลิเมตร ในขณะที่ค่าเฉลี่ยของระยะเบี่ยงเบนของตำแหน่งรากเทียมที่ได้จากการใช้แผ่นจำลองนำทางผ่าตัดผ่านโปรแกรมอิมพล้านสตูดิโอ (Implant Studio™) มีค่าตามแนวต่างๆดังนี้ มุมที่เบี่ยงเบนมีค่าเฉลี่ย 2.43 ± 1.26 องศา ระยะเบี่ยงเบนที่บริเวณบ่าของรากเทียมมีค่าเฉลี่ย 0.51 ± 0.22 มิลลิเมตร และระยะเบี่ยงเบนในแนวความลึกมีค่าเฉลี่ย -0.49 ± 0.23 มิลลิเมตร อย่างไรก็ตามเมื่อวิเคราะห์ทางสถิติด้วยการทดสอบทีพบว่า ค่าเฉลี่ยของทั้งสองกลุ่มในทุกๆแนวไม่มีความแตกต่างอย่างมีนัยสำคัญทางสถิติ

สรุป: ความเบี่ยงเบนของตำแหน่งรากเทียมที่ได้จากแผ่นจำลองนำทางผ่าตัดจากโปรแกรมคอมพิวเตอร์ช่วยเหลือระบบโคไดแอกโนสติค (coDiagnostiX™) และ ระบบอิมพล้านสตูดิโอ (Implant Studio™) ไม่มีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติ

สาขาวิชา	ทันตกรรมบูรณะเพื่อความสวยงามและทันตกรรมรากเทียม	ลายมือชื่อนิสิต ....
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KEYWORD: Static computer assisted implant surgery, Accuracy of guided implant surgery, Dental implant, Anterior maxillary implant placement

Natchaya Thitaphanich : COMPARISON OF THREE DIMENSIONAL ACCURACY FOR SURGICAL GUIDED TEMPLATE FABRICATION USING TWO DIFFERENT IMPLANT PLANNING SOFTWARE PROGRAMS. Advisor: Assoc. Prof. PRAVEJ SERICHETAPHONGSE Co-advisor: Assoc. Prof. ATIPHAN PIMKHAOKHAM, DDS, Ph.D.

Statement of problem: Static computer-assisted implantation system (s-CAIS) has been introduced to implant dentistry for decades. According to previous studies, they were recognised the inaccuracies of actual implant position placed via using static computer-assisted implantation system. These inaccuracies result from an accumulation of every step in the workflow from planning to accuracy assessment. Recently, there are multiple implant planning softwares available. coDiagnostiX™ software and Implant Studio™ software are widely used third-party implant planning softwares which claimed to provide predictable implant placement outcome. However, the effect of softwares used on accuracy of guided surgery in anterior maxilla region has not been throughly reported.

Objective: This study intend to evaluate the accuracy of implant position between using coDiagnostiX™ and 3shape Implant studio software programs.

Materials and methods*:* 30 bone level tapered implants (Straumann) were placed on the single edentulous space maxilla model which has been planned with coDiagnostiX™ and Implant Studio™ software. The samples were divided into two groups according to the planning software used. Then the planned and placed implant position were superimposed. The deviation among two groups were recorded. Data was analyzed using *t*-test(α = .05).

Results*:* For coDiagnostiX™ software, statistic revealed mean angular deviations of 1.99 ± 0.96 degrees, mean coronal deviation of 0.57 ± 0.15 mm, and mean vertical deviation of -0.51 ± 0.18 mm. For Implant Studio™ software, mean angular deviations was 2.43 ± 1.26 degrees, mean coronal deviation of 0.51 ± 0.22 mm, and mean vertical deviation of -0.49 ± 0.23 mm. No significant differences were found between two planning software in all parameters, angular deviation, linear coronal deviation, and vertical deviation (P > 0.05)

Conclusions: There is no statistically significant difference between coDiagnostiX™ and Implant Studio™ software.

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

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Natchaya Thitaphanich

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CHAPTER I

INTRODUCTION

Background and rationale

Implant dentistry has been introduced into the field of dentistry to be one of the treatment options for replacing missing dentition for decades. Over the past twenty years, dental esthetic had become an essential issue in dental implant (1). Implant placement in the anterior maxillary region requires an accurate position in all dimension including faciolingual, mesiodistal and apicocoronal position in order to achieve sustainable functional and esthetic outcome (2, 3). However, placing the implant in anterior maxilla region was extremely critical and challenging for the clinician due to the limited bone architecture of this area and patients' esthetic satisfaction. The improper implant position in this region can lead to unsuccessful esthetic outcome and subsequent with implant removal in the eventually (2).

Correct implant insertion in three dimensional position is a prerequisite for successful esthetic outcome in anterior maxillary region (4). The facio-lingual direction of implant position affect emergence profile of the desired final restoration (5). The mesiodistal positioning of implant determines level of interproximal papillary support (6). The depth of the implant, apicocoronal direction, in anterior region is a significant factor for creating emergence profile of a final restoration (2). Moreover, implant axis is a significant factor to determine screw access and retrievability of the prostheses. Furthermore, presence of 1 mm. of facial bone wall is an importance factor for the long-term stability of peri-implant hard and soft tissue contour (4, 5). Consequently, all mentioned factors contribute to long-term favorable function and esthetic outcomes of implant placement in anterior maxillary region (7).

Conventionally, anterior implant placement technique can be done according to prosthetic driven technique by using radiographic template, fabricated from diagnostix wax up model, combines with CBCT image in order to provide the relationship between the expected final restoration and crestal bone (2). With this technique, the clinician place implants freehandedly, hence the precise three dimensional position of the implant can be achieved from the surgeon's skill. Correspond with the proposal of Buser et al. 2004, clinician's experience, skill and judgment are some of the importance factors which influence outcome of implant therapy (4). Moreover, the communication and agreement between restorative clinicians and surgeon can affect efficiency of implant placement process (2).

During the last few decades, computer assisted implantation systems (CAIS) had been introduced in the field of implant dentistry. CAIS is a technology which combine CT images with implant planning software and CAD/CAM technology. This technology allow the clinicians to transfer the planned implant position to the surgical field and exactly place the implant into the proper position in all dimension with respect to an individual patient’s anatomical structures and prosthetic aspect. Currently, CAIS can be divided in two type static and dynamic. Due to the

uncomplicated management, and lower investment cost, the static technique is more favorable as the technique of choice when guided surgery is indicate (7).

Recently, there are numerous static implant planning software programs such as Simplant™ (Materialise Dental Inc, Glen Burnie, MD, USA), Invivo5™ (Anatomage, San Jose, CA, USA), NobelClinician™ (Nobel Biocare, Goteborg, Sweden), OnDemand3D™ (Cybermed Inc, Seoul, Korea), Virtual Implant Placement software™

(BioHorizons, Inc, Birmingham, AL, USA), coDiagnostiX™ (Dental Wings Inc, Montreal, CA, USA), and Blue Sky Plan™ (BlueSkyBio, LLC, Grayslake, IL, USA), and Implant Studio™ (3Shape, Copenhagen, Denmark), which allow clinician to virtually plan treatment for the placement of implants according to an individual patient’s anatomy and restoration aspect (8).

Among various implant planning softwares, coDiagnostiX™ (Dental Wings Inc, Montreal, CA, USA) and Implant studio™ (3Shape, Copenhagen, Denmark) are the widely used third-party implant planing softwares which claimed to provided predictable implant placement outcome. However, there are few evidences to support the accuracy of these softwares in anterior maxilla region.

Implant placement in anterior maxilla region is critical to anatomical structures, the correct 3 dimensional position for esthetic outcome, and also require facial bone wall at least 1 mm. thickness to maintain soft tissue emergence profile, these complexity can be predictably established and considered before surgery with the usage of 3D visualization and the use of computer-guided implant surgical guides

(9, 10, 11, 12). However, the effect of softwares used on accuracy of guided surgery in anterior maxilla region has not been throughly reported.

Research question

Is there any difference in accuracy of implant position using coDiagnostiX^{TM} and Implant Studio^{TM} implant planning software?

Research objective

This study intend to evaluate the accuracy of implant position between using coDiagnostiX^{TM} and Implant studio^{TM} software programs.

Hypotheses

H0 = There is no differences in accuracy of implant position using coDiagnostiX^{TM} and Implant Studio^{TM} implant planning software.

Ha = There is a difference in accuracy of implant position using coDiagnostiX^{TM} and Implant Studio^{TM} implant planning software.

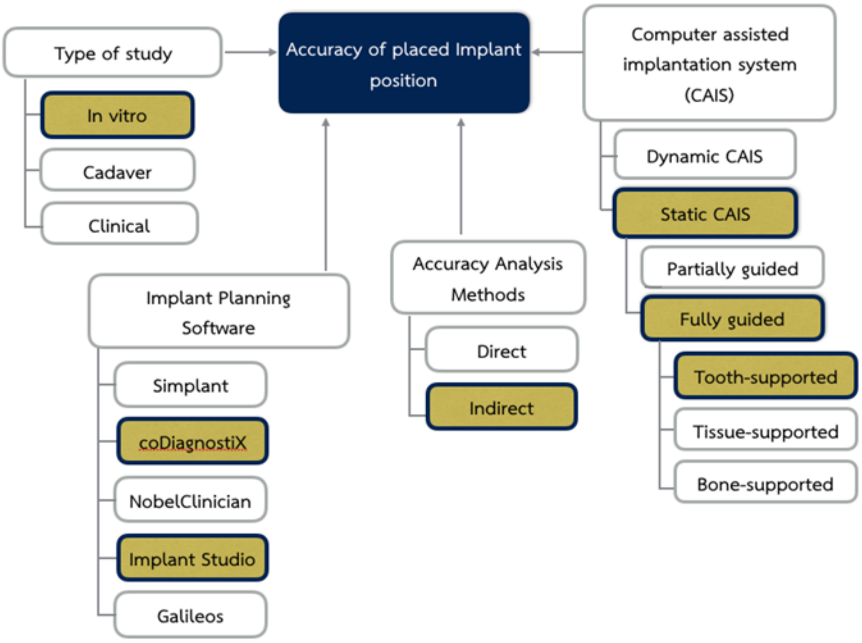

Figure 1 Diagram of Conceptual Framework

Keywords

Anterior maxillary implant placement, Static computer assisted implant surgery, Implant planning software, Accuracy of guided implant surgery.

Expected Benefit of the Study

Outcome of this present study may provide useful information for clinicians, regarding influence of implant planning software on placed implant position.

CHAPTER II

REVIEW OF THE LITERATURES

The literatures in these following topic have been reviewed.

Implant placement in anterior maxillary region

Potential causes of esthetic implant failure

Complication relate to implant malposition in anterior maxillary region

Computer assisted implantation system (CAIS)

Factors influence the accuracy of static CAIS system

Accuracy of computer assisted implantation system

Accuracy analysis methods

Implant placement in anterior maxillary region

Implant placement in anterior maxilla is challenging for the clinician due to the esthetic demands of the patients and difficult pre-existing anatomy. Thicknesses of buccal and palatal cortical plates, buccal-lingual ridge dimensions, proximity to adjacent teeth, implant to root relationships, gingival and papilla support and contours, gingival exposure, gingival zenith, smile lines, and implant angulations and emergence are just a few of the many complex considerations in this region. Small variations in implant positions in this region can lead to difficult restorative dilemmas in these cases (5). The correct 3- dimensional implant positioning is a key to an esthetic treatment outcome regardless of implant system used (1). Moreover, appropriate 3-dimensional implant position is the crucial factor influenced the optimal final prostheses position, optimal occlusion which contribute to long term success of single tooth implant restoration.

Potential causes of esthetic implant failure

Anatomic Factors

It is important for the clinician to understand that ridge anatomy includes the soft tissues and the supporting bone in all dimensions, and that soft tissue contours around an implant are heavily influenced by the bone anatomy (2).

Maxillary anterior region may be the implant site that requires the most rigorous pre-operative assessment, because alveolar dimension and morphology will have a direct influence on aesthetic outcome and stability of implant placement. Previous experience has shown that adequate alveolar height is not the only prerequisite for a successful implant placement. Deficiency of transversal ridge width would lead to length reduction or even impossible implant insertion. Mean alveolar widths (mm) were: central incisor, 9.55; lateral incisor, 8.30; canine, 9.62. The lateral incisor had a significantly smaller alveolar width than the other anterior teeth. No significant difference in ridge height was noted among the teeth. Undercut locations from the alveolar crest (mm) were: central incisor, 5.84; lateral incisor, 3.59; canine, 5.11. Undercut depths (mm) were: central incisor, 0.76; lateral incisor, 0.87; canine, 0.73. The percentages of teeth with buccal undercuts were: central incisor, 41 %, lateral incisor, 77 %, and canine 33 % (13).

The underlying bone structure plays a significant role in the establishment of esthetic soft tissues in the anterior maxilla. Two anatomic structures are important: the bone height of the alveolar crest in the interproximal areas and the height and thickness of the facial bone wall. The interproximal crest height plays a role in the presence or absence of peri-implant papillae. A clinical study around teeth demonstrated that a distance of 6 mm or more from the alveolar crest to the contact point reduces the probability of intact papillae (2).

Presence of a facial bone wall of sufficient height and thickness is important for long-term stability of harmonious gingival margins around implants and adjacent teeth. In daily practice, implant patients frequently present with a bone wall that is missing or of insufficient height and/or thickness because of the various causes of tooth loss. Attempts to place implants in sites with facial bone defects in the absence of bone reconstruction will frequently result in soft tissue recession, potentially exposing implant collars and leading to loss of the harmonious gingival margin (2).

Iatrogenic Factors

Esthetic failures can also be caused by inappropriate implant positioning and/or improper implant selection (2). Placement of implants in a correct 3-

dimensional position is a key to an esthetic treatment outcome regardless of the implant system used. This position is dependent on the planned restoration that the implant will support. The relationship of the position between the implant and the proposed restoration should be based on the position of the implant shoulder, because this will influence the final hard and soft tissue response. The implant shoulder position can be viewed in 3 dimensions: orofacial, mesiodistal, and apicocoronal. In the orofacial direction, an implant shoulder placed too far facially will result in a potential risk for soft tissue recession, because the thickness of the facial bone wall is clearly reduced by the malpositioned implant. In addition, potential prosthetic complications could result in restoration–implant axis problems, making the implant difficult to restore.

Complication relate to implant malposition in anterior maxillary region

Appropriate implant position is a crucial factor for the long-term success of implant (14). Inadequate attention to analyzing the restorative space can lead to problems such as an over-contoured restoration, artificially opened occlusal vertical dimension, and the need to perform additional surgical and restorative procedures (15-18).

Mis-axis complication

Implants that are inclined too far facially are often associated with recession of the facial mucosa. If the axis problem is minor, the axis problem can usually be corrected by prosthetic means using angled abutments which are available for most implant systems. If the axis problem is severe and if it is combined with a facial malposition of the implant shoulder the esthetic complication is usually very difficult or impossible to resolve. However, in the majority of cases, the most effective treatment is to remove the implant, augment the site, and place a new implant in the correct position (4). Distribution of forces on implants is must be adhered remarkably along the implant (19-21). Off-axis inclination be capable of the factor that contribute to overloading prosthesis (22). Implant failure is a consideration if the axis change exceeds 25 degrees, because offset loading of this type may lead to shearing forces that the bone cannot tolerate (23).

Mesiodistal malposition

Implant, which is placed too close to an adjacent tooth, can cause a reduced papilla at the adjacent tooth, and was first described by Esposito et al. 1993 (24). This complication is mainly caused by the development of a crestal bone modeling process during healing and after implant restoration. This biologic phenomenon is routinely observed around commonly used implants such as the Brånemark system or the Straumann implant system, and results in what is often termed a “bone saucer”. This saucer has a horizontal component of 1.0–1.5 mm, whereas the vertical component measures around 2–3 mm. Thus, the clinician has to keep a distance of at least 1.0 mm or preferably 1.5 mm to the root surface to avoid such a complication. If an implant is placed too close to a root surface, a reduced papilla height will result, since there is not enough space for the soft tissues to develop. Such situations cause a disturbed emergence profile of the implant restoration, although the correct mesiodistal position is only altered by approximately 1 mm. When the mesiodistal malposition of the implant is extreme and differs by 2–3 mm from the ideal prosthetic position, this can lead to significant and permanent loss of hard- and soft-tissue support with extremely adverse esthetic outcomes. Moreover, William et al (25) performed a review of the literature to determine local risk factors for implant therapy. They concluded that when an implant is placed within 3 mm of the adjacent tooth, proximal bone is at risk. Two clinical studies (both prospective clinical trials) found statistically significant increase proximal bone loss at neighboring teeth following implant placement close to adjacent tooth (< 3 mm) (26, 27).

Buccolingual malposition

Buccolingual malposition of an implant can also cause two different complications. The first complication occurs if the implant is positioned too far palatally. This will often lead to a ridge-lap design of the implant crown. While this does not always lead to an esthetic complication, it may make it difficult for the patient to maintain optimum plaque control, with subsequent long-term implications for the health of the peri-implant tissues. If the palatal malposition is combined with deep placement, it can sometimes be difficult to seat the abutment because of the thick facial and palatal mucosa. Patients may also complain that the palatal surface of the implant crown feels bulky.

The second complication is a recession of the facial mucosa if the implant is clearly positioned too far facially. This can cause severe esthetic complications, since the harmonious gingival course is significantly disturbed. These complications have frequently been observed in patients with immediately placed implant (28-33). Some of these studies clearly showed that the facial malposition is a risk factor for the development of a mucosal recession (30, 33).

Corono-apical malposition

Corono-apical malposition can cause two different esthetic complications. If the implant is not inserted deep enough into the tissues, the metal implant shoulder can be visible, causing an unpleasant esthetic outcome, although no recession of the mucosa is present.

The more common complication is an implant that is placed too deep into the tissues. This apical malposition can cause recession of the facial mucosa, if the implant only has a thin facial bone wall at implant placement. Following restoration, this thin bone wall is resorbed during the bone modeling process, since the already discussed bone saucer is a circumferential phenomenon. This leads to bone resorption not only at the mesial and distal aspect of the implants, as seen on the radiograph, but also on the facial and palatal aspect. Bone resorption on the facial aspect can lead within a few weeks to a recession of the facial mucosa. Small and Tarnow 2000 (34) reported the development of a mucosal recession in about 80% of the patients, on average of about 1 mm. The recession can be more pronounced if an apical malposition is combined with a facial malposition.

Furthermore, too deep implant position can cause violation of apical anatomical structures. Dental implants within the maxilla have unique and specific boundary conditions to be cautious. For anterior implants, the location and size of the nasopalatine canal and foramen should be identified at the midline. The nasal floor is most commonly seen in the anterior regions.

Computer assisted implantation system (CAIS)

Traditional surgical technique of dental implant placements involves careful preoperative planning (35), open flap access, and osteotomy of the site adhering to well-established surgical protocol, followed by proper wound closure. One of the major disadvantages of this method is that the systems always required a scanning template, with a radiopaque prosthetic design, to be made before the CBCT. On the other hand, computer assist surgery (CAS) for dental implant placement, clinician can decide implant position after a diagnostic CBCT to apply guided surgery. This term is also represented computer-aided dental implantology, computer-assisted dental implant intervention, image-guided surgery or guided implant surgery.

CAIS for dental implant placement includes static and dynamic systems (36-37). A static system uses computerized tomography (CT)–generated CAD/CAM stents, with sleeves (metal cylinders) and a surgical system that uses coordinated instrumentation to place implants with the help of the guide stent. Treatment planning is used in conjunction of three-dimensional CT images with surface scanning data. Computer software which allows visualization and manipulation of the images of the patient’s jaw bone and surrounding tissue makes possible the most accurate approach to implant surgery. Digital software will allow the user to place a virtual analog of the proposed implant and measure the optimum distance between the previously mentioned structures. This visualization allows for rapid site analysis and predictable treatment planning whereby the surgeon can order specific implant diameters and sizes, healing abutments, and provisional crowns. Implant position is dependent on the stent without the ability to change implant position. Static in this case is synonymous with a predetermined implant position without real-time visualization of the implant preparation site as the site is being developed. No intraoperative position changes can be made with a static system. This technique offers several benefits over the conventional approach. Computer-guided surgical templates allow surgeon to perform osteotomy site preparation in more accurate and efficiency (38-40). It is also reported that less patient discomfort than free hand method (41).

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 : type of arch, kind of template, surgical technique, number of sleeve-guided site preparation steps, operator’s skill and image acquisition.

• Type of arch (maxilla / mandible)

Behneke et al. (42) studied 132 implants placed in 52 partially edentulous patients using static guide stents. He reported a borderline significant difference was found between maxilla and mandible for the linear deviation between planned and placed implant position at apex which larger in maxilla (0.50 vs. 0.40 mm, P = 0.033) but not for the linear deviation at neck and angular deviation. Though the apical deviation was larger in the upper jaw, the numerical difference amounted to only 0.1 mm in median which is clinically not meaningful. Ozan et al. (43) studied 110 implants placed in 30 subjects using stereolithographic surgical guides and reported significant difference between maxilla and mandible for the angular deviation (maxilla: 4.58 ± 2.4°, mandible: 3.32 ± 1.9° , p=0.001) and linear deviation at neck (maxilla: 0.95 ± 0.5 mm ,mandible: 1.28 ± 0.9 mm, p=0.028) but not for the linear deviation at apex.

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 were low magnitude and therefore not clinically meaningful (42).

• Type of guide support template (tooth-supported / bone-supported / mucosa-supported)

Ozan et al.(43) studied the deviation of 110 implant position from virtual planning between 3 types of 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 SLA surgical guides were more precise than bone-supported and mucosa-supported SLA surgical guides. 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° respectively, the linear deviation at implant neck 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. (42) reported statistically significant differences were found when comparing the coronal, apical, and angular deviations for the different template groups, most of the groups differences arose at the apex. The single-tooth gap template has smallest degree of deviation and was almost similar to the interrupted dental arch group. There was a wider distribution of values for sites with a reduced residual dentition, 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 guides 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.(42) reported A borderline significance difference between the open flap and flapless approach for the shoulder linear deviation, which higher values for the flapless approach (0.36 and 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 non significant 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.(42) studied the accuracy of CT-generated guide surgery for different sections of the implant surgery. The fully guided placement meant that the implant were inserted through the sleeves into the guided osteotomy using a special implant carrier which fit the internal diameter of the guide sleeves. Freehand placement meant that the templates were used for controlling all of the osteotomy procedure and the implants were inserted manually without a surgical guide using a regular implant carrier. Freehand final drill meant that template were used for supported osteotomy up to the standard diameter (4–4.1mm). The site development for implants with a wider diameter was performed manually. The implants were set without a surgical guidance. He reported that significant differences were found at all aspects of measurement (implant coronal level, apex level, and angle). 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 patient with limited mouth opening. Therefore, the templates may be used 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 (at shoulder: 0.52 (0.97), 0.30 (0.78), and 0.21 (0.60) mm respectively, at apex: 0.81 (1.38), 0.47 (1.30), and 0.28 (0.77) mm respectively). The result shows that an increase in the number of sleeve-guided site preparation steps results in higher accuracy of implant placement.

• Operator’s skill (experienced / inexperienced)

Rungcharassaeng et al.(44) 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 (NobelGuide) protocol. 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. 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 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.

Gerlinde et al. found that when supervised by experienced dentists, inexperience of the surgeon had no influence on the accuracy of implant placement in fully edentulous jaws (45).

Accuracy of static CAIS system

Several clinical studies using static CAS system reported deviation of actual implant position from virtual planned position. According to two recent systematic review, mean entry deviation was 1.04 - 1.16 mm, mean apex deviation was 1.45 – 1.96 mm and mean angular deviation was 4.06 – 5.73 degrees (table 1) (38, 42, 43 49-53).

Study	Study design	System	Implant (N)	Error entry (mm)	Error apex (mm)	Error angle (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
Valente et al. (2009)	RS	SimPlant	89	1.4 ± 1.3	1.6 ± 1.2	7.9 ± 4.7
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
Behneke et al. (2012)	PS	Implant 3D	Max 87 Mand 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)

Study	Study design	System	Implant (N)	Error entry (mm)	Error apex (mm)	Error angle (degree)
Cassetta et al. (2012)	PS	SimPlant	116	1.47 ± 0.68	1.83 ± 1.03	1.83 ± 1.03
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
George et al. (2017)	Case Report	3shape Implant Studio	10	Facio-lingual 0.49 ± 0.22 Mesio-distal 0.28 ± 0.19		Facio-lingual 3.37 ± 2.58 Mesio-distal 0.84 ± 1.53
Jacques et al. (2017)	Case Report	SimPlant	80	Freehand 1.27 Guided 0.42	Free hand 1.28 Guided 0.52	Freehand 7.63 Guided 2.19
Schneider et al. (2009)	Systematic review	-	269	1.16 (0.92, 1.39)	1.96 (1.33, 2.58)	5.73 (3.96, 7.49)
Tahmaseb et al. (2014)	Systematic review	-	2,355	1.04 (0.85, 1.24)	1.45 (1.18, 1.73)	4.06 (3.50, 4.62)
Tahmaseb et al. (2018)	Systematic review and meta analysis	-	2,238	1.2 (1.04, 1.44)	1.4 (1.28, 1.58)	3.5 (3.0, 3.96)

Study	Study design	System	Implant (N)	Error entry (mm)	Error apex (mm)	Error angle (degree)
Bover-Ramos et al. (2018)	Systematic review	-	in vitro 543 cadaver 246 clinical 2,244	0.77 ± 0.15 1.18 ± 0.12 1.10 ± 0.09	0.17 ± 0.85 1.52 ± 0.18 1.40 ± 0.12	2.39 ± 0.35 2.82 ± 0.40 3.98 ± 0.33

Table 1 The accuracy of the implant placed by static computer-assisted system.

Di Giacomo et al.(59) studied the accuracy of implant placement using static CAS system (Simplant, CSI Materialise) and found that mean deviation of 21 implants placed in 4 patients 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.

Ersoy et al.(50) studied the accuracy of implant placement using static CAS system (Stent Cad, Media Lab Software, La Spezia, Italy). They found that mean deviation of 94 implants placed in 21 patients 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.

Ozan et al(43). studied the accuracy of 110 implants in 30 patients using static CAS system (Stent Cad, Media Lab Software, La Spezia, Italy) and found 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. They also reported that tooth-supported guides were more accurate than bone-supported and mucosa-supported guides.

Valente et al.(49) studied the accuracy of implant placement using static CAS system (Simplant, CSI Materialise) and found that mean deviation of 89 implants placed in 28 patients were 1.4 ± 1.3 mm at entry point, 1.6 ± 1.2 mm at apex and 7.9 ± 4.7 degrees for angle deviation.

Nickening et al. (38) studied the accuracy of 23 implants in 10 lower jaws of patients with Kenedy class II defect using static CAS system (coDiagnostiXTM, IVS-solutions, Chemnitz, Germany) and 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.

Behneke et al (42). studied the accuracy of 132 implants in 52 partially edentulous patients using static CAS system (implant 3D ,med3D GmbH, Heidelberg, Germany) and found that mean deviation at entry point was 0.27 (0.03-0.92 mm) in maxilla, 0.28 (0.01-0.97 mm) in mandible, at apex was 0.5 (0.03-1.58 mm) in maxilla, 0.4 (0.03-1.15 mm) in mandible, angular deviation was 1.82 (0.14-6.26 degrees) in maxilla and 1.86 (0.07-5.82 degrees) in mandible. There was no statistical significant between maxilla and mandible.

Cassetta et al. (52) studied the accuracy of implant placement using static CAS system (Simplant, CSI Materialise). They found that mean deviation of 116 implants placed in 10 patients at the entry point was 1.47 ± 0.68 mm, at the apex was 1.83 ± 1.03 mm and angle deviation was 5.09 ± 3.7 degrees.

Farley et al.(40) compared the accuracy of 20 implants in 10 patients between using static CAS system (Implant Master software, iDent Imaging) and conventional guide. 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

George et al. (54) used 3shape Implant Studio to determine the accuracy of in office- printed implant surgical guides. They reported that the mean difference in mesiodistal direction at the alveolar crest between planned implants and placed implants was 0.28 ± 0.19 mm and the difference in the faciolingual direction was 0.49 ± 0.22 mm. The mean mesiodistal angulation deviation was 0.84 ± 1.53 mm. and the mean faciolingual angulation deviation was 3.37 ± 2.58 mm.

Jacques Vermeulen (55) compared the accuracy between freehand and guided single-implant placement in situations with one or more missing teeth as performed by experienced surgeons. The 80 implants were placed in the anterior site of maxillary models. They found that angular deviation was 7.63 degrees for the freehand method and 2.19 degrees for guided surgery. Lateral deviation at the coronal level of the implants was 0.42 mm and 1.27 mm for the guided and freehand methods, respectively, and at the apical level was 0.52 mm and 1.28 mm for the guided and freehand methods, respectively; the deviation at the coronal and apical levels was significantly smaller for guided surgery than for the freehand method (P = .001). Differences in the depth deviation at the apical and coronal levels were smaller (guided vs freehand surgery at the coronal level: 0.54 mm vs 0.78 mm; apical level: 0.54 mm vs 0.73 mm) but also of statistical significance (P = .05). Differences in angular, global, and lateral deviations between the clinical situations (single vs multiple missing teeth) were also significantly smaller for guided surgery, whereas the deviations in depth did not reveal any statistically significant difference between both methods for the single-spaced units.

A systematic review by Tahmaseb et al.(51) reported that total mean deviation of 2,355 dental implants 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.

A systematic review by Schneider et al.(9) reported that total mean deviation of 269 dental implants from 3 human clinical studies in 2003 - 2009 was 1.16 mm (95% CI = 0.92, 1.39) at entry point, 1.96 mm (95% CI = 1.33, 2.58) at apex and 5.73 degrees (95% CI = 3.96, 7.49) for angle deviation.

A systematic review and meta-analysis by Tahmaseb et al.(11) showed a total mean error of 1.2 mm (1.04 mm to 1.44 mm) at the entry point, 1.4 mm (1.28 mm to

1.58 mm) at the apical point and deviation of 3.5°(3.0° to 3.96°). When compared partial edentulous with full edentulous cases, there was a significant difference in accuracy.

A systematic review and meta-analysis by Bover-Ramos (12) intended to compare planned and placed implant position in relation to study type (in vitro, clinical, or cadaver). Thy reported that there were significant less horizontal apical deviation and angular deviation were observed in in vitro studies compared to clinical and cadaver studies. However, there were no statistically significant differences in vertical deviation between the groups.

Accuracy analysis methods

Accuracy of implant placement using computer-assisted surgery is obtained by measure the deviation of the actual implant position from the virtual planning position. The image data of postoperative CBCT scan are surerimposed on the virtual planning image automatically by implant planning software. A mathematical algorithm was implemented on both image data to calculate the positional and angular deviation between the planned and the actual implant position (51). Several measuring parameters were used in the previous systematic reviews for the comparison of these positions (9, 51, 56, and 57):

• Deviation at the entry point of the implant (mm), measured at the center of the implant

• Deviation at the apex of the implant (mm), measured at the center of the implant

• Deviation of the axis of the implant (degree)

• Deviation in height/depth of the implant (mm)

For the first two parameters, the most common method was to measure deviation between the planned and actual point by one distance in 3D. For deviation of the axis, the comparison was less complicated, since every study reported by degrees of deviation. For the deviation in height/depth, there was often reported as a negative number if the implant was not inserted as deeply as planned. Figure 2 illustrates the different parameters for describing the deviations.

Accuracy analysis method can be categorized into two main method as direct and indirect method. The direct method can be performed by superimposition of pre-operative CBCT image with a planned implant and post-operative CBCT image with an actual placed implant. On the other hand, the indirect method determines deviation by using pre-operative CBCT image to superimpose onto the implant position which generated from impression or intraoral scanning through the impression coping or scan body. The advantage of this method over the direct method is the patients do not have to expose the CBCT after implant surgery. However, this method could create error from the inaccuracy of intraoral scanner or from not correctly connect between the impression coping or scan body to the implant. According to Pyo et al., accuracy analysis method claimed to be one of the influencing factors lead to deviation in implant position. Thus the more procedures of accuracy analysis method, can lead to the more total deviation (58).

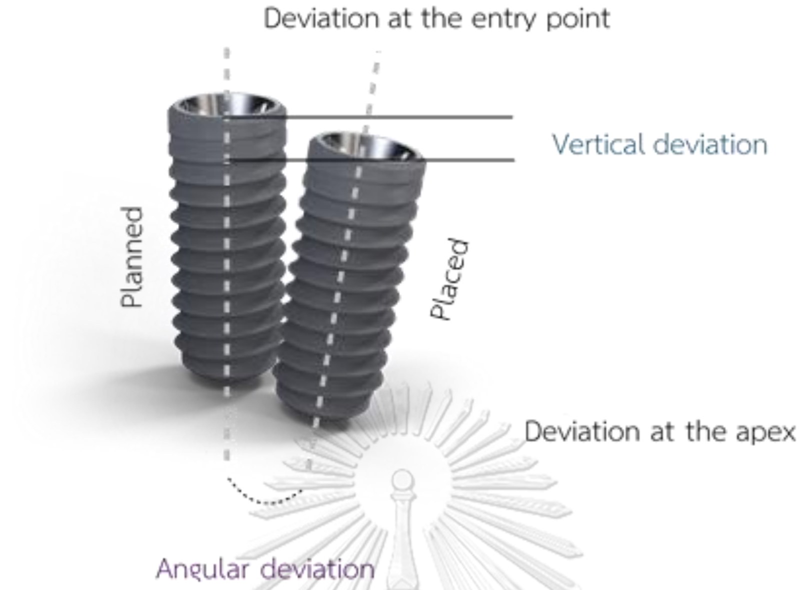

Figure 2 Illustration of the different parameters for describing the deviations

CHAPTER III

MATERIALS AND METHODS

Materials

Cone Beam Computed Tomography (CBCT) scanner

iCAT^{TM} (Imaging Science International, Hatfield, PA, USA) with a 170x130 mm. field of view

Surface scanner

TRIOS (3shape, Copenhagen, Denmark)

Implant planning and accuracy analysis software

coDiagnostiX^{TM} software version 9.7 (Dental Wings inc, Montreal, CA) and 3shape Implant Studio^{TM} version 2015 (3Shape, Copenhagen, Denmark)

Implant

Bone level implant (Straumann, institute Straumann AG, Basel, Switzerland)

Surgical kit

Guided BLT Surgical kit (Straumann, institute Straumann AG, Basel, Switzerland)

3D printer

Dental Primes (Stratasys, Rehovot, Israel)

Sample size

Sample size was calculated using means and standard deviations obtained from a pilot study. The calculation was performed using G*Power application. Based on 5% Type I Error, 80% study power. The sample size from calculations was 11 subjects. Thus total of 30 subjects were needed (15 per group).

Methods

Model preparation

A total of thirty drillable polyurethane maxillary models from left to right second molar with edentulous space on right central incisor were fabricated (figure 3). The samples were divided into 2 groups according to the implant planning software used which are coDiagnostiX^{TM} (version 9.10, Dental Wings Inc, Montreal, CA) and Implant studio (version 2015, 3 shape, Copenhegen, Denmark).

Planning procedure and surgical template fabrication

Digital Imaging and Communication in Medicine (DICOM) files of the CBCT images (iCAT^{TM} , Imaging Science International, Hatfield, PA, USA) and Stereolithography (STL) file derived from intraoral scan (TRIOS, 3 shape, Copenhegen, Denmark) of each models were transferred to the coDiagnostiX and Implant studio softwares. In each software, Straumann 3.3*10 mm BLT implants were planned at the edentulous space. The surgical guide templates were designed to incorporate full maxillary arch with H4 protocol and 4 inspecting windows (figure 4). Then the surgical guided templates were fabricated by 3D printing (Dental Primes, Stratasys, Rehovot, Israel).

Implant placement

Prior the implant placement procedure, the adaptability of surgical guide templates were examined via inspecting windows. The tip of explorer was not allowed to penetrate through each inspecting window. The models were attached to mannequin head to simulate clinical situation (figure 5). One operator randomly placed thirty implants into each model according to a guided surgery protocol (Straumann) using Straumann BLT guided surgery kit (figure 6).

Implant Position Accuracy Analysis

After the implants were placed, each model was scanned using an intraoral scanner (TRIOS, 3 shape, Copenhegen, Denmark) with scan body (CARES® NC Mono Scan body, Straumann, Basel, Switzerland) attachedto the implant. The adaptability of implant platform and scan body was examined. Then STL file of 3D cast was superimposed onto the original startup treatment plan.

For the implants which had been planned with codiagnostiX™ software, the STL files of placed implants were superimposed with the planned. The superimposition was performed by 3-point registration. The deviation of planned and placed implant were evaluated automatically in linear and angular via Tx Evaluation tool. The values of deviation in linear and angular were recorded.

For the implants which had been planned with Implant Studio™ software, the STL files of placed implants were superimposed with the original planned. The superimposition was performed by 3-point registration. The deviation of planned and placed implant were evaluated manually in linear and angular via Dental System software (3 shape, Copenhegen, Denmark).

Data collection

In each assessment method, three measuring points were used to compare the deviation between virtual planned and actual placed implant positions. :

- Angulation deviation of the axis of the implant (degree)
- Linear deviation at platform of the implant (mm)
- Linear deviation in height/depth of the implant (mm)

All measuring points were measured at the center of the implant (figure 1). If placed implants were shallower than the planned implants, the data will be recorded as negative value. If placed implants were deeper than the planned implants, the data will be recorded as positive value.

Data Analysis

All measurement data was gathered and entered in IBM SPSS Statistics software (version22 software SPSS Inc., Chicago, IL). All data was normally distributed, t-test with 95% confidence interval (CI) was used to compare each parameter.

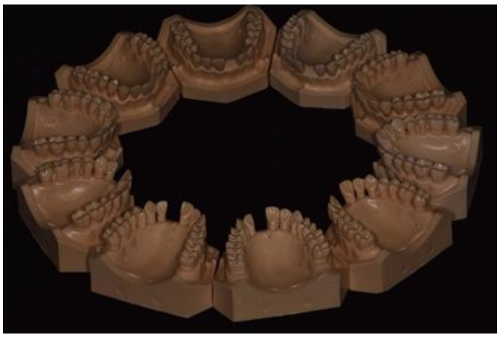

Figure 3 Maxillary models from left to right second molar with edentulous space on right central incisor

Figure 4 Surgical guided template

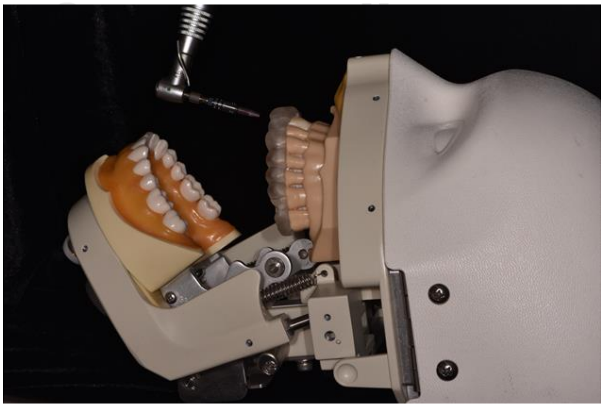

Figure 5 The model was mounted with Mannequin head in order to stimulate clinical situation

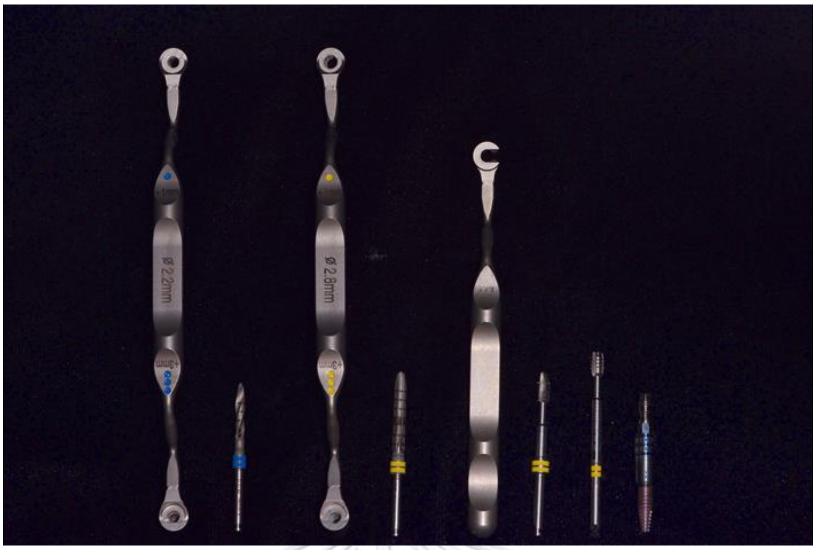

Figure 6 Guided BLT surgical kit (Straumann, institute Straumann AG, Basel, Switzerland)

CHAPTER IV

RESULTS

Results

In each assessment method, three following measuring points were collected for comparison the deviation between virtual planned and actual placed implant positions. :

- Angulation deviation of the axis of the implant (degree)
- Linear deviation at platform of the implant (mm)
- Linear deviation in height/depth of the implant (mm)

The maximum, minimum, mean and standard deviation of linear and angular deviation obtained from two implant planning softwares, coDiagnostiX and Implant studio, were demonstrated and compared in Table 2.

Parameter	coDiagnostiX^{TM}			Implant Studio^{TM}		
	Maximum	Minimum	Mean ± SD	Maximum	Minimum	Mean ± SD
Angulation (degree)	3.60	0.6	1.99 ± 0.96	5.14	0.89	2.43 ± 1.26
Deviation at platform (mm)	0.95	0.37	0.57 ± 0.15	0.93	0.17	0.51 ± 0.22
Vertical Deviation (mm)	-0.64	-0.18	-0.51 ± 0.18	-0.90	-0.17	-0.49 ± 0.23

Table 2 Mean, maximum, minimum, standard deviation of different parameters evaluated for coDiagnostiX and Implant Studio groups

No statistically significant differences were found in all parameters, angular deviation, deviation at platform and vertical deviation between two experiments groups (P > 0.05). P-value of all measuring points, angular deviation, deviation at platform, and vertical deviation were demonstrated in Table 3.

Parameter	P-value
Angulation	0.298
Deviation at platform	0.414
Vertical Deviation	0.830

Table 3 P-value of the comparison of the accuracy in different analyzed parameters

CHAPTER V

DISCUSSION AND CONCLUSION

Discussion

This study was performed to investigate whether there is any differences in accuracy of implant position using coDiagnostiX^{TM} and Implant Studio implant planning software. The null hypothesis was accepted, there is no differences in accuracy of implant position using coDiagnostiX^{TM} and Implant Studio^{TM} implant planning software.

This study was conducted in models, which claimed to achieve most precise when compare to invivo and cadaver studies (58). Moreover, the type of guided templates used in this present study were tooth-support, which showed less deviation when compared to soft tissue-supported and bone supported guided templates.(58) There are multiple systematic reviews showed deviation of guided template. However, the systematic review by Bover-Ramos et al. compared guided template precision in relation to study type (in vivo, in vitro and cadaver studies). In the aspect of in vitro study, they found that the angular deviation was 2.39 ± 0.35 degrees. While the mean horizontal coronal, the deviation was 0.77 ± 0.15 mm. And vertical deviation was 0.61 ± 0.149 mm. When compared results obtained from this experiment to the results from Bover-Ramos et al., the mean angular deviation, horizontal coronal deviation and vertical deviation of this study are in line with Bover-Ramos et al. study.

It is surprising that all of the placed implant positions achieved from this study were shallower than the planned. However, the implants were placed according to the depth which specified in guided protocol (figure 7). Previous studies reported vertical deviation at 0.61 ± 0.149 mm for in vitro studies (). While Tahmasep et al.(11) reported Error in implant height at the entry point at 0.2 mm, CI 95%, [−0.25 to 0.57 mm]. However, these systematic reviews included result from multiple software. There are scant of evidences of the error in height of coDiagnostiX and Implant Studio software. The depth of the implant platform is crucial factor for anterior implant placement. Too shallow implant position effect a zenith and gingival margin of final restoration which can be result in a short clinical crown when compared to a natural adjacent tooth. Moreover, too shallow implant with screw retained implant position can lead to a ridge-lap prosthetic design. Too shallow implant position can be corrected by planning implant deeper or overdrill.

Furthermore, after the implants were placed the clinicians should verify whether the depth of the implants were at the expecting level.

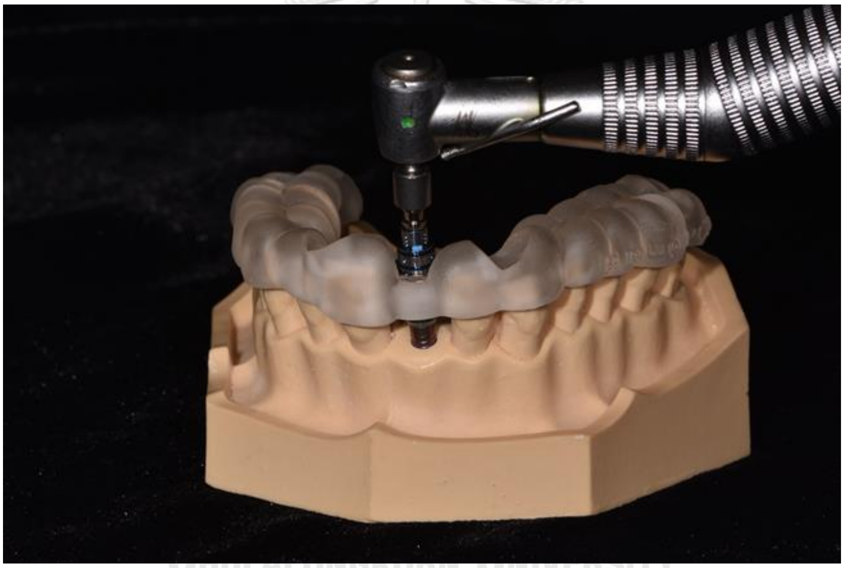

Figure 7 H4 protocol depth

Currently, there are multiple available software programs in the field of computer-guided implantation system (8). The first type is third-party implant planning software programs, such as Simplant (Materialise Dental Inc, Glen Burnie, MD, USA), Implant studio (3 Shape, Copenhagen, Denmark), Invivo5 (Anatomage, San Jose, CA, USA), NobelClinician (Nobel Biocare, Goteborg, Sweden), OnDemand3D (Cybermed Inc, Seoul, Korea), Virtual Implant Placement software (BioHorizons, Inc, Birmingham, AL, USA), coDiagnostiX (Dental Wings Inc, Montreal, CA, USA), and Blue Sky Plan (BlueSkyBio, LLC, Grayslake, IL, USA). Another type of planning software is provided by CBCT units such as Galileos system (Sirona Dental Systems, Inc, Charlotte, NC, USA), TxSTUDIO software (i-CAT!, Imaging Sciences International LLC, Hatfield, PA) and NewTom implant planning software (NewTom, Verona, Italy). One of the concerning factors when clinicians decided to use any softwares is the availability of each software in each specific region.

Recently, there are several methods to assess the accuracy of dental implant position in Computer assisted implant placement. They can be divided into two main categories (58). The first method can be done directly by superimposition between pre-operative CBCT images and postoperative CBCT images with a planned and placed implant in position respectively. While the second technique is using impression method, which could be achieved via impression coping or scan body in order to acquire implant position indirectly. As the deviation of implant position result from the accumulation error of every step in the process. Thus the more steps used to evaluate accuracy of implant position can lead to creation of the more total deviation. The concerning factor to select method for implant position evaluation is the implant planning software used. coDiagnostiX has both direct and indirect method available. While Implant studio has only indirect method available. For the coDiagnostiX, author had compared between direct and indirect method with paired t-test. No statistically significant different were found between direct and indirect method. Hence, indirect method was use in order to control factor between coDiagnostiX and Implant studio group. Clinically, the advantage of the direct method over the indirect method is it could be perform at any time, while the indirect method could be conducted on the same day of surgery or after healing period. Because the impression coping or scan body has to connect with the fixture, the osseointegration should be completed prior the connection to prevent the loss of osseointegration while connecting the scan body to the fixture. However, this article was performed in vitro, the time of data collection was not the concerned factor. Apart from the time of data collection, in clinical situation which implant had been placed deeper than in this experiment, it is improbable to examine the adaptability between scan body and implant platform.

Computer assisted implantation system involved multiple sequences from data registration, planning, therapeutic step to the accuracy analysis step. The reported deviation is the total error derived from the accumulation error of every single step in the process (12, 42, 59). Several factors have been reported influencing the deviation of implant position achieved from static computer assisted implantation systems. These include type of study, type of supporting template, and experience of the operator. Firstly, type of study (ie, cadaver, in vivo, or in vitro) had been reported to be one of the influencing factors for the implant accuracy. In vitro study seem to have the most accuracy result from the better access. Second influencing factors is type of template support which are tooth-supported, mucosa-supported, and bone-supported template. Behneke et al. (2011) reported that tooth supported template has the lowest deviation. Lastly, operator experience can be one of the factors contribute to implant deviation (Rungcharassaeng et al., 2015). While Gerlinde et al. found that when supervised by experienced dentists, inexperience of the surgeon had no influence on the accuracy of implant placement in fully edentulous jaws (45).

The differences between two groups of this study were the software used and the method to achieve STL files. The quality of STL files influence the adaptability of the guided templates. However, the adaptability of the guided templates on models were verified and adapted perfectly. Thus, it can be assumed that the results achieved from this study were influence from the implant planning softwares.

From the perspective of the author, there are three key steps to achieve accurate outcomes when using guided surgery template. Firstly, the adaptability of STL file with Dicom file. Thus when superimposed DICOM files to STL files, clinicians should verify adaptability between CBCT image and surface scan image. Secondly, the adaptability of the guided template on patient arch. According to Giacomo et al., the most deviation were found when stability of template cannot be achieved (59).

Lastly, the adaptability of each instrument to the guided cylindrical sleeve on the template.

Limitations

The limitations of this investigation was that the accuracy evaluation of coDiagnostiX and Implant Studio software were done differently. The available tool of coDiagnostiX was automatic calculate accuracy between planned and placed implant position. While 3 Shape provide manual evaluation tool. However the intra correlation test was done. No statistically significant difference was found in the person who evaluate the accuracy of Implant Studio software. Additionally, Dental System software showed the center of the implant only at the apical. Thus the data of the accuracy at the apical was unable to validate.

Suggested further studies

This study investigated influencing of coDiagnostiX and Implant Studio software on accuracy of implant position. Therefore, further studies should evaluate other factors which influenced deviation of static CAIS. These factor could be surgical kit, surgical template design.

Conclusion

Under the conditions of this in vitro study, the following conclusion was drawn:

there is no statistically significant difference between coDiagnostiX and Implant Studio software in anterior implant placement.

Declaration of Conflicting Interest

The authors declare that there is no conflict of interest.

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