ARCH FORM AND ALVEOLAR BONE THICKNESS IN MAXILLARY ANTERIOR ESTHETIC REGION: A CONE BEAM COMPUTED TOMOGRAPHY ASSESSMENT

Miss Atcharee Bulyalert

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Esthetic Restorative and Implant Dentistry
Faculty of Dentistry
Chulalongkorn University
Academic Year 2015

รูปแบบความโค้งและความหนาของกระดูกเบ้าฟันในขากรรไกรบนส่วนหน้าที่สวยงาม: ประเมินโดยการถ่ายภาพรังสีส่วนตัดอาศัยคอมพิวเตอร์ชนิดโคนบีม

นางสาวอัจฉรีย์ บุลยเลิศ

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาทันตกรรมบูรณะเพื่อความสวยงามและทันตกรรมรากเทียม
คณะทันตแพทยศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2558

Thesis Title	ARCH FORM AND ALVEOLAR BONE THICKNESS IN MAXILLARY ANTERIOR ESTHETIC REGION: A CONE BEAM COMPUTED TOMOGRAPHY ASSESSMENT
By	Miss Atcharee Bulyalert
Field of Study	Esthetic Restorative and Implant Dentistry
Thesis Advisor	Associate Professor Atiphan Pimkhaokham, Ph.D.

Accepted by the Faculty of Dentistry, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

....Dean of the Faculty of Dentistry

(Assistant Professor Suchit Poolthong, Ph.D.)

THESIS COMMITTEE

....Chairman

(Associate Professor Chalermpol Leevailoj)

....Thesis Advisor

(Associate Professor Atiphan Pimkhaokham, Ph.D.)

....External Examiner

(Assistant Professor Lertrit Sarinnaphakorn, Ph.D.)

อัจฉรีย์ บุลยเลิศ : รูปแบบความโค้งและความหนาของกระดูกเบ้าฟันในขากรรไกรบนส่วนหน้าที่สวยงาม: ประเมินโดยการถ่ายภาพรังสีส่วนตัดอาศัยคอมพิวเตอร์ชนิดโคนบีม (ARCH FORM AND ALVEOLAR BONE THICKNESS IN MAXILLARY ANTERIOR ESTHETIC REGION: A CONE BEAM COMPUTED TOMOGRAPHY ASSESSMENT) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: รศ. ทพ. ดร. อาทิพันธุ์ พิมพ์ขาวขำ, 89 หน้า.

วัตถุประสงค์: เพื่อค้นหาสอบรูปแบบความโค้งของกระดูกเบ้าฟันในขากรรไกรบนส่วนหน้าบริเวณที่สวยงามและตรวจสอบหาความแตกต่างความหนาของกระดูกเบ้าฟันในแต่ละรูปแบบความโค้งโดยใช้ภาพรังสีชนิดโคนบีม

วิธีการศึกษา: ประเมินภาพถ่ายรังสีส่วนตัดอาศัยคอมพิวเตอร์ชนิดโคนบีมจำนวน 113 ภาพ ในแนวระนาบที่ระดับต่ำกว่ารอยต่อเคลือบรากฟันเขี้ยวในขากรรไกรบนทั้งด้านซ้ายและขวา 3 มิลลิเมตร ใช้จุดกึ่งกลางรากฟันในบริเวณส่วนหน้าที่สวยงามของขากรรไกรบนเป็นจุดอ้างอิงในการวัดความกว้างส่วนโค้งแนวฟันบริเวณฟันเขี้ยว ความกว้างส่วนโค้งแนวฟันบริเวณฟันกรามน้อยซี่ที่หนึ่ง ความลึกส่วนโค้งแนวฟันบริเวณฟันเขี้ยว และความลึกส่วนโค้งแนวฟันบริเวณฟันกรามน้อยซี่ที่หนึ่ง รวมถึงการกำหนดพิกัด X และ Y จากนั้นจำแนกประเภทความโค้งของกระดูกเบ้าฟันบริเวณขากรรไกรบนส่วนหน้าบริเวณที่สวยงามโดยอ้างอิงจากขนาดในแนวขวางและสัดส่วนความกว้างต่อความลึกของส่วนโค้งแนวฟันเขี้ยวแล้วสร้างกราฟเส้นโค้งที่เหมาะสมกับพิกัด X และ Y เฉลี่ยในแต่ละประเภทความโค้งขากรรไกรด้วยสมการโพลีโนเมียลระดับที่สี่ วัดความหนากระดูกเบ้าฟันในแต่ละรูปแบบความโค้งของขากรรไกรเพื่อตรวจสอบความแตกต่างระหว่างกลุ่ม

ผลการศึกษา: สามารถจำแนกรูปแบบความโค้งขากรรไกรบนส่วนหน้าได้เป็น โค้งยาวแคบ โค้งสั้นกลาง โค้งยาวกลาง และโค้งยาวกว้าง ความหนาของกระดูกเบ้าฟันมีความแตกต่างกันระหว่างกลุ่มรูปแบบความโค้งขากรรไกรอย่างมีนัยสำคัญ โดยกลุ่มยาวกว้างมีความหนามากที่สุด ตามมาด้วยกลุ่มยาวกลาง ส่วนกลุ่มที่มีความหนาน้อยที่สุดคือกลุ่มยาวแคบและกลุ่มสั้นกลาง

สรุปผลการศึกษา: ความโค้งของกระดูกเบ้าฟันบริเวณขากรรไกรบนส่วนหน้าที่สวยงามสามารถจำแนกได้เป็น 4 ประเภท คือ โค้งยาวแคบ โค้งสั้นกลาง โค้งยาวกลาง และโค้งยาวกว้าง โดยที่ความกว้างของกระดูกเบ้าฟันในแต่ละรูปแบบความโค้งนั้นแตกต่างกัน

สาขาวิชา	ทันตกรรมบูรณะเพื่อความสวยงาม	ลายมือชื่อนิสิต	....
	และทันตกรรมรากเทียม	ลายมือชื่อ อ.ที่ปรึกษาหลัก	....

ปีการศึกษา 2558

5475833632 : MAJOR ESTHETIC RESTORATIVE AND IMPLANT DENTISTRY
KEYWORDS: ANTERIOR ARCH FORM / ANTERIOR MAXILLARY ARCH FORM / ANTERIOR MAXILLARY ALVEOLAR ARCH FORM / ALVEOLAR BONE / ALVEOLAR BONE THICKNESS / BONE THICKNESS / BUCCOLINGUAL BONE THICLNESS / BUCCOLINGUAL ALVEOLAR BONE THICKNESS / CONE BEAM CT / CONE BEAM COMPUTED TOMOGRAPHY / CBCT

ATCHAREE BULYALERT: ARCH FORM AND ALVEOLAR BONE THICKNESS IN MAXILLARY ANTERIOR ESTHETIC REGION: A CONE BEAM COMPUTED TOMOGRAPHY ASSESSMENT. ADVISOR: ASSOC. PROF. ATIPHAN PIMKHAOKHAM, Ph.D., 89 pp.

Objectives: This study investigated alveolar arch forms and the differences of buccolingual alveolar bone thickness among arch forms in anterior esthetic region using cone beam computed tomography (CBCT) images.

Material and methods: Axial views of 113 CBCT images were assessed at the level of 3 mm below cementoenamel junction (CEJ) of left and right canines. Root center points of all teeth in anterior esthetic region were set as the reference points in order to measured Intercanine width, interpremolar width, intercanine depth, interpremolar depth and intercanine width/depth ratios and digitized X and Y coordinates. Arch forms were then classified following transverse dimensions and intercanine width/depth ratio. Best fitting curves were created from mean coordinates of each arch form using fourth degree polynomial equation. Buccolingual alveolar bone thickness of anterior maxillary teeth was measured at 3 mm below CEJ and middle of root length levels. The differences of mean thickness between arch forms were analyzed.

Results: This study demonstrated that anterior maxillary arches were classified as long narrow arch, short medium arch, long medium arch and long wide arch. The significant differences of buccolingual alveolar bone thickness among arch form groups were found at both levels (p-values < 0.001). Long wide arch presented the thickest buccolingual alveolar bone followed by long medium arch while both long narrow and short medium arches showed the narrowest.

Conclusions: In anterior esthetic region, alveolar arches were classified as long narrow arch, short medium arch, long medium arch and long wide arch. The buccolingual alveolar bone thickness exhibited significant differences between arch forms.

Field of Study:	Esthetic Restorative and Implant Dentistry	Student's Signature	....
		Advisor's Signature	....
Academic Year:	2015		

ACKNOWLEDGEMENTS

Firstly, I would like to express my sincere gratitude to my advisor, Associate Professor Atiphan Pimkhaokham, Ph.D., for his supports, his patience, motivation, and immense knowledge of this thesis. His guidance helped me in all the processes of the experiment as well as the writing of this thesis.

Besides my advisor, I would like to thank the rest of my thesis committee: Associate Professor Chalermpol Leevailoj, and Assistant Professor Lertrit Sarinnaphakorn, Ph.D., for their insightful comments and encouragement, also for the excellent questions which inspired me to widen my research from various perspectives.

My sincere thanks also go to Vannaporn Chuenchompoonut, Ph.D., Department of Radiology, Faculty of dentistry, Chulalongkorn University, for the provision of expertise, and technical support, Assistant professor Nataphan Kitisin, Ph.D., and Sirisup Laohakiat Department of Mathematics and Computer Science, Faculty of Science, Chulalongkorn University, who provided me a professional guidance in geometry as well as curve fitting methods, and Nat Kulvanich, Ph.D., Department of Statistics, Faculty of Commerce and Accountancy, Chulalongkorn University, for the suggestions in statistical analysis. This study could not be finished without their precious supports.

Last but not the least, I would like to thank my family for supporting me spiritually throughout the difficulty of this thesis and my life in general.

CONTENTS

Page

Lists of tables

List of figures

CHAPTER 1

INTRODUCTION

Rationale and Significance of the Problem

Periimplant bone foundation is an important factor affecting the success of dental implant treatment. However after tooth extraction, alveolar bone will change in volume.[1] In this situation, implant placement simultaneously with guided bone regeneration might be necessary, somehow it might affect patient's quality of life.[2] In order to prevent further bone resorption after implantation especially in anterior maxilla which requires carefully attention to provide esthetic outcomes, many parameters should be taken in account to limit stress on dental implant.[3]

Sagat et al. in 2010 reported that the favorable implant numbers and positions in relation to the stress concentration were dissimilar in different full alveolar arch forms.[4] Partial alveolar arch form especially in the premaxilla area also influenced implant numbers and positions due to the stress distribution around dental implant.[3] In the past, many studies identified full dental arch forms using plaster models and 3D visual models [5-11] as well as maxillary anterior dental arch forms that were classified by analysing plaster models.[12] In order to evaluate the dental arches, the position of cusp tips, facial axis points which referred to the midpoints of the facial axis of clinical crowns, or the most facial points of the teeth were usually set as the reference points.[5-12] The mathematical functions were applied in order to describe dental arch forms. The previous study reported that beta function, parabola equation and polynomial equation provided best fitting curves.[5-9, 11-13] The study of Preti et al. in 1986 and Ferrario et al. in 1994 used parabola equation and elliptic equation respectively for creating best fitting curve of anterior arch.[11, 12] Ferrario et al. found the strong correlation between mixed model, which was the combination of elliptic curve in anterior arch and parabola curve in posterior arch, and fourth degree polynomial equation.

Conversely, the studies of alveolar arch form exhibited a very few numbers. In 2008, Ronay et al. displayed the assessment of the alveolar arch form at the level of WALA which referred to the keratinized tissue band superior to mucogingival junction of mandible.[14] Still, this method might present the inaccurate arch forms due to the interference of movable tissue. Recently, cone beam computed tomography (CBCT) was introduced. This method is non-invasiveness and helpful because three dimensional radiographic images including the buccolingual, mesiodistal and apicocoronal dimensions can be identified. The application use of CBCT in evaluation of bone surrounding the tooth and implant was demonstrated previously.[15-22] Moreover, there were studies that evaluated human arch form at alveolar bone level using CBCT images.[10, 13] The midpoints of the roots at coronal third level of right and left mandibular canines were set as the reference points. These points were selected due to the corresponding with the vertical level of WALA.

Nevertheless, alveolar arch forms have never been classified using the CBCT images up to now, they were usually classified into simple geometric forms using clinical experience.

Buccolingual bone width is another important factor related to implant success, since it is included in the three dimensional bone that has to be defined before implant placement.[23, 24] After an implant was placed following recommendation that implant platform should be located at 3-4 mm below gingival margin of the future restoration,[25, 26] the remaining labial bone requires at least 2 mm thickness in order to provide implant stability, decrease marginal bone loss, prevent gingival recession and promote esthetic outcome.[23] Thus, in the situation of insufficient bone, the bone reconstruction should be performed to improve the functional and esthetic results.[27, 28] Nevertheless, buccolingual thickness of the augmented bone may later slightly decrease due to bone remodelling.[28, 29] The understanding of alveolar arch form and buccolingual alveolar bone thickness in anterior esthetic zone may be very helpful not only to define the treatment plan and prognosis, but also to determine implant numbers and implant positions in order to increase the survival rate and success rate. Furthermore, it may help to predict the amount of bone augmentation. So far, there is no article associated to the alveolar arch form in anterior esthetic zone.

Research Questions

1. Can arch forms of the alveolar bone in anterior esthetic region be classified at the implant platform level?
2. Is there any difference of buccolingual alveolar bone thickness among arch form in anterior esthetic zone?

Objectives of the Study

This study aimed to evaluate arch forms in anterior esthetic region at the level of implant platform and to investigate the differences of buccolingual alveolar bone thickness between arch forms using CBCT images.

Statement of Hypothesis

- Null hypothesis

1. The arch forms in anterior esthetic region cannot be classified at the level of implant platform.
2. There is no difference of buccolingual alveolar bone thickness among the classified arch forms.

- Alternative hypothesis

1. The arch forms in anterior esthetic region can be classified at the level of implant platform.
2. There are differences of buccolingual alveolar bone thickness among the classified arch forms.

Conceptual Framework

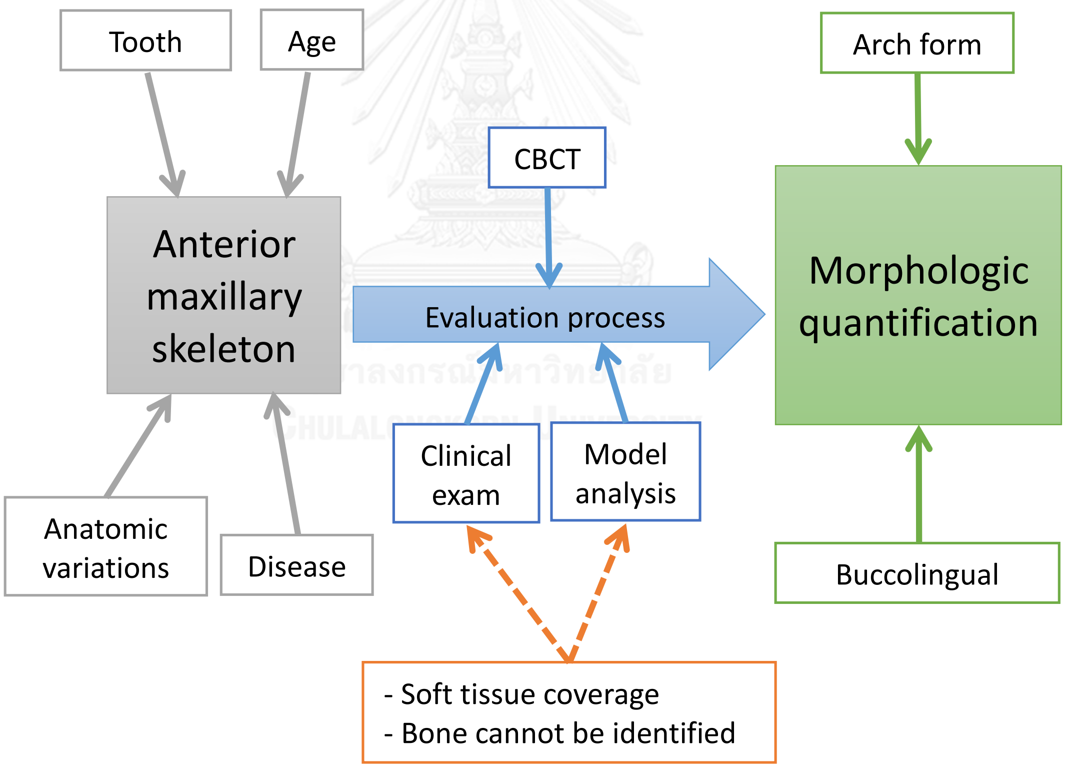

Figure 1. Conceptual framework of the study

Basis Assumptions

1. All the CBCT images were measured with one program by one operator and evaluated by one examiner.
2. Intra-examiner calibration and Inter-examiner calibration with the expertise were performed.

Study Limitations

1. Since there was no study about the arch form classification and the difference of buccolingual alveolar bone thickness among arch forms in anterior esthetic region, the future studies are necessary to approve the reliability of the results.
2. This study evaluated the alveolar arch form and the buccolingual alveolar bone thickness at the implant related levels using the CBCT images of patients with full dentitions in order to reduce the dissimilar rates of bone resorption in the real edentulous patients.

Keywords

Alveolar arch form, Anterior maxillary arch form, Anterior maxillary alveolar arch form, Alveolar bone, Alveolar bone thickness, Bone thickness, Buccolingual bone thickness, Buccolingual alveolar bone thickness, Cone beam CT, CBCT

The Expected Benefits

The results of arch form classification at the implant platform level in anterior esthetic region and the difference of buccolingual alveolar bone thickness among arch forms might help the clinicians to design the initial treatment plan, to determine implant numbers and positions, as well as to predict the amount of bone augmentation.

CHAPTER 2

REVIEW OF LITERATURES

Alveolar bone

Alveolar bone and alveolar socket are created to support teeth and gingiva. In adult human, 65% of alveolar bone is inorganic crystal which mainly composes of calcium and phosphate, while 35% is organic matrix that contains 89% of type I collagen.[21] The alveolar bone can be roughly divided into three layers. The outer most is the compact bone layer called an external plate of cortical bone. The inner most is the socket wall or the alveolar bone proper or bundle bone, which is the layer of thin dense bone adjacent to the periodontal ligament space. The principle fibers of periodontal ligament which are called Sharpey's fibers terminate in this layer.[30] Between the two dense bone layers, there is the spongy bone called cancellous trabeculae.[31]

The alveolar socket is able to remodel in order to resist the force, repair the wound, and balance the level of calcium and phosphate in the body. The remodeling process relates to the activity of osteoblast in bone apposition and osteoclast in bone resorption.[31] After tooth extraction, bone volume changes in both horizontal and vertical dimensions due to the loss function of bundle bone.[32] In 2005 the histological study using dog model of Araújo and Lindhe reported that the alveolar bone altered after tooth extraction. At one week after tooth extraction, the soft tissue covering the extraction site showed a slightly sign of inflammation, lingual bone was wider than buccal bone, and bundle bone was still found along the inner surface of socket with a very few numbers of osteoclasts. The crestal portion of bone walls exhibits the large amount of bundle bone especially the buccal plate. After two weeks passed, mucosa was full of fibroblasts. At this stage, the bundle bone decreased and the osteoclasts were found at the outer surfaces of alveolar ridge resulted in the resorption of crestal bone. The buccal crest was slightly more apical compared to the lingual crest. Woven bone formed in the apical and lateral of the socket and was lined with a bulk of osteoblasts. Four weeks of healing process, the bundle bone was completely disappeared and the woven bone was replaced by lamellar bone at the crestal part of buccal bone. The osteoclasts were still lined at the outer surfaces of alveolar bone while the inner socket was filled with the primitive bone marrow. Buccal crest located approximately 1 mm apical to lingual crest. At eight weeks, the buccal bone was obviously thinner than lingual bone. The crestal bone of buccal plate was about 2 mm lower than lingual plate. Large amount of osteoclasts were observed on the crestal and apical area of the outer surface of buccal bone. In the socket, there were bone marrow, woven bone, and lamellar bone. The authors concluded that there are two overlapped phases of bone resorption. The first phase occurred after tooth extraction due to the loss of bundle bone. The second phase is the resorption at the outer surfaces of alveolar bone.[1]

The resorption causes the residual ridges of both maxilla and mandible to shift lingually. Since the basal bone of mandible is wider than maxilla, the complete edentulous patients seem to have a protruding chin.[33]

Arch form

Arch forms are divided into 2 large categories, dental arch form and basal arch form. Dental arch form is identified at clinical crown levels using incisal edge and cusp tips, facial axis points, or the most facial parts of the teeth as the reference points.[5-12] Dental arches can be classified as reported by the previous studies.[8, 9, 12] They are influenced by transverse dimensions, anteroposterior dimensions, width/depth ratio, tooth size, and tooth inclination.[8-10] In the past, dental arch form was identified based on simple geometric or clinical experience. Recently, the correlation between dental arch form and mathematical function was reported.[5-9, 11]

In 1994, Ferrario et al. compared fourth degree polynomial equation with mixed model. Digital photographs of the dental models which were obtained from 50 males and 45 females were taken. Midpoints of the incisal edge as well as buccal and lingual cusp tips of premolars and molars were set as the reference points. Cusp coordinates were recorded and their center of gravity was used as the origin of X and Y axes. Maxillary and mandibular arches were fit with fourth degree polynomial equation and mixed models which composed of anterior and posterior curves. The anterior curve of mixed models was an ellipse using elliptic equation while posterior curve was parabola. The means correlation of cusp coordinates and fourth degree polynomial equation were reported over 0.97. For the mixed models, anterior curves exhibited well fit with the elliptic curves with the correlation ranging from 0.873 – 0.933. The posterior curves displayed the results of correlation more than 0.92. Mean plots of fourth degree polynomial equation and mixed models were not significant difference. Thus, human dental arches could be fit with both of mathematical functions.[11]

According to the study of Braun et al. in 1998, the beta function formula was tested about the ability to distinguish 80 plaster models of class I normal occlusion, class II and class III malocclusion patients. The data of cross-arch distance or transverse dimension which is the distance between distobuccal cusp tips of left and right second molar of both maxillary and mandibular arches and the perpendicular distance which is the shortest distance between any point on cross-arch line and the center point of two central incisors were recorded and then calculated using beta function formula. The results showed that the beta function could represent the human dental arch accurately. The mean correlation coefficient of curve fit was 0.98 with standard deviation of 0.02. Class I normal occlusion models would be a standard size of jaws, thus class III malocclusion models and class II malocclusion models had to be compared with class I models. Class III maxillary and mandibular models showed significantly wider cross-arch distance and shorter arch depth, while class II mandibular models exhibited narrower cross-arch distance but the arch depth was also shorter.

In maxillary arch, the arch depths of all three categories are not significant difference, but in arch width of cross-arch distance, class III models demonstrate wider distance, while class II models were statistically comparable to class I models, even though the results tended to be narrower. However, the authors concluded that beta function has been proved to be a good method to describe arch form.[5]

In 2001, Noroozi et al. used sixth degree polynomial equation to evaluated dental arch form and described as ovoid, taper, square. Four parameters were considered when twenty three sets of dental models had been analyzed which are distance between the distobuccal cusp tips of the second molars or intersecondmolar width (Wm), distance between canine cusp tips or intercanine width (Wc), the shortest distance between the contact of central incisors and intersecondmolar width line or secondmolardepth (Dm), and the shortest distance between the contact of central incisors and intercanine width line or caninedepth (Dc). The results demonstrated the correlation between arch form and the sixth degree polynomial curve. The curves could be described as ovoid, taper, and square. The authors found that if the ratio of intercanine distance and intersecondpremolar distance decreased (Dc:Dm) or the ratio of intercanine width and intersecondpremolar increase (Wc:Wm), the arch would become square shape. The ratio of dental arch can be calculated by this formula $(Wc/Wm) \times (Dc/Dm)^{-1}$. If the ratio was within the mean range ± 1SD, the arch form would be described as ovoid. If the ratio was more than +1SD, the arch form would be described as square and the arch form would be described as tapered when the SD of ratio was less than -1SD.[7]

The combination of arch form classification and mathematical curve fitting were reported in the recent article of Lee et al. 2011 found the new method to classify arch form, the cluster analysis. In the study, the models had been analyzed on both dental level which is the level of cusp tip and basal level which is referred to the apical third of alveolus. 306 casts were taken photos and transferred the data of 14 reference points from the central incisors to the second molars to Cartesian coordinates with custom-made software. With this software the arch forms could be identified and classified into three types, based on the average silhouette width which was the method for revealing the dissimilarity within group and between groups. The narrow arches, middle arches, and wide arches were discovered.[8] Bayome et al. in the same years analyzed dental arch forms using 3D visual models. Facial axis points were set as the references. Transverse dimensions and anterior curve were used to classified arch form by k-means cluster analysis. The results exhibited five groups of arch form. However, after fit the arch form with the mathematical function, fourth degree polynomial equation, some pair of curves showed the superimposition. Hence, the authors combined the superimposed curves in to the same group. From this study, arch form could be classified into narrow, moderate and wide groups.[9] Not only full arch form, the maxillary anterior arch was also identified in the study of Preti et al. in 1986. 1000 plaster castes were measured to find the correspondence between interfrenulum distance and parabola curve. The most facial point of anterior teeth were used as the references. Center of incisive papilla was the origin of X and Y coordinates. The strong correlation of 0.999 was found. The anterior dental arches could be reported as Large, medium and small depended on the c value in the equation of parabola, $y = ax^2 + bx + c$.

The alveolar arches were described in simple geometric terms using clinical experience, such as ellipse, ovoid, tapered or square. In the recent article of Suk et al. 2013, the mathematical formulas were used to identify for more precise alveolar arch form. 32 CBCT images of normal occlusion patients and 33 CBCT images of Class III malocclusion patients were analyzed in the axial view for the evaluation of dental arch and alveolar arch. Arch dimensions which composed of transverse dimensions, anteroposterior dimensions and width/depth ratios were measured at the level of coronal third of mandibular canines which related to the level of WALA ridge, root center points were set as references. The root center points were digitized for the coordinates then the mean coordinates of Class I normal occlusion and Class III malocclusion were calculated. The best fitting curves for Class I and Class III groups were generated using fourth degree polynomial equation.[13] Interestingly, most of the studies in orthodontic field defined alveolar arch as basal arch even though the arch was measured at the level of WALA ridge which was the keratinized band above mucogingival junction.[10, 13, 14]

Implant positions and implant numbers

Proper implant position and implant number increases survival and success rate in implant therapy by reducing stress of the occlusal force and providing stable soft tissue profile.[3, 4, 23, 24]

In order to establish proper implant position, implant site has to be examined in 3 dimensional views, mesiodistal view, buccolingual view, and apicocoronal view. In mesiodistal view, the esthetic appearance mainly depends on the volume of interdental papilla that is limited by the underlying crestal bone. As a result of bone saucerization, periimplant bone has been horizontally destroyed for 1.3-1.4 mm within 3 years after implant crown insertion.[34] Hence, the distance between an implant and a natural tooth should be more than 1.5 mm and the satisfactory distance for two adjacent implants should be at least 3 mm for crestal bone preservation.[23, 24, 34] Buccolingual view demonstrates the facial contour of gingiva that is supported by buccal bone. The buccal bone thickness should not be less than 2 mm to prevent gingival recession which is affected from bone remodeling as well as saucerization.[23] If the proper thickness cannot be achieved, ridge augmentation would be performed. Available bone height is presented in apicocoronal view. In anterior esthetic region, the preferable location of bone level implant shoulder is 3-4 mm below the facial gingival margin of future restoration.[25, 26] However, at least 2 mm distance above vital structures, which is the floor of maxillary sinus in the area of first premolars, should be remained for safety.[35] Bone angulation is another factor that is necessary to locate an implant position. The angulation is the relation of occlusal plane and natural tooth root which should ideally be perpendicular in order to transfer occlusal force along root axis. However, in anterior esthetic region, only first premolar can provide on-axis loading force, since anterior teeth are loaded at 12 degrees diverged from root axis.[3] The study of Romeo et al in 2002 reported that under the standard anatomic condition, the single tooth implant restorations would be a predictable treatment, if the available bone was sufficient.[36]

Implant numbers are dictated by bone quality, occlusal force and arch form especially in the patients with long edentulous area since it relates to the stress distribution. Various arch forms provide different available length of cantilevers. Even though, the cantilevers should be eliminated in order to decrease an excessive force, however for some limitations such as to avoid the vital structures, the cantilevers are selected to be the choice for treatment.[3, 4]

In complete maxillary edentulous arch, six to eight implants are commonly used. When focusing on the premaxilla segment, implant positions and numbers are influenced by arch form beneficial to control the stress from cantilevers length. Assume that, four implants were already placed in the posterior segment, square arch form requires only two implants placed at right and left canine positions, since the anterior cantilever length is less than 8 mm. Thus six implants may be enough for this type of arch. Ovoid arch form needs three implants at the area of right canine, left canine and one of the incisors because the anterior cantilever length is ranged from 8 to 12 mm which is longer than that of square arch. Seven implants may be the proper implant numbers for the ovoid arch. Taper arch form has the longest cantilever. The length is more than 12 mm. Four implants are needed at the area of right canine, left canine and two of the incisors for preventing additional force. Hence, eight implants may be appropriate for taper arch.[3] Sagat et al. in 2010 evaluated the influence of alveolar arch form and stress distribution around implants supported the full arch prostheses. In the study, alveolar arch forms were divided into five categories, shortest ellipsoid shape and medium width, longest ellipsoid shape and narrow, U-shaped long and narrow, U-shaped short and wide, and U-shaped medium length and medium width. The numbers of implant per arch were assessed; six or eight implants were placed into the different positions. The results exhibited that the stress distribution was not significant difference whether using six or eight implants per arch, but it was difference when the implants were placed into different alveolar arch forms. In every type of arch forms, placing eight implants in the positions of lateral incisors, canines, the first and the second premolars provided the most favorable result. After implant numbers were reduced to six, longest ellipsoid shape and narrow, shortest ellipsoid shape and medium width, U-shaped short and wide, and U-shaped medium length and medium width demonstrated the good results when the implants were placed into lateral incisors, the first and the second premolars areas, while the U-shaped long and narrow showed the favorable result when implants were placed into central incisors, canines and the second premolars areas. The study also reported that the stress value in the posterior portion was higher than the anterior portion, hence the posterior cantilever increased the stress concentration. However, arch forms provided more influence upon stress distribution around implant than the length of cantilever.[4]

Implant restorations in the patients with partial edentulous arch in premaxillary region depend on the alveolar arch forms. Since the recommendation of interimplant distance should be at least 3 mm, square and ovoid arches cannot support more than four implants. Taper arch may exhibited wider interimplant distance, but usually no more than four implants can be replaced the sixth anterior teeth. The patients who have edentulous arch in the area of central and lateral incisors, two or three implant can be placed depended on arch form. Taper arch may not suitable for two implants placement since the longer anterior cantilever increases more periimplant stress.[3]

In complete mandibular edentulous arch the cantilevers cannot be extended further than 2.5 times of A-P distance. The distance varies in the different arch form, ovoid arch has 6-8 mm of A-P distance, square arch has 2-5 mm, and tapered arch has an A-P distance larger than 8 mm.

Moreover, each arch is divided into five segments. The first is central and lateral incisors segment. The second and third segments are left and right canines. The fourth and fifth segments are respectively left and right premolars and molars.

The recommendation for proper implant numbers and positions is at least one implant for fixed partial denture should be placed in each segment of an arch to provide the resistance of the lateral force.[3]

CBCT Evaluation

Although periapical and panoramic radiography can be used in many kinds of dental treatment including implants, only two dimensions of mesiodistal width and inciso-apical height are displayed. In the implant treatment planning, the information of buccolingual width is also necessary. Ridge mapping by penetrating a sharp point instrument through buccal and lingual soft tissues under local anesthesia is one of the methods for measuring buccolingual underlying bone.[37] However, most of the patients are not cooperate with the methods due to invasiveness. Besides, some factors, such as the locations of vital structure and small bone defects, cannot be detected by this technique.[38]. Recently, cone-beam computed tomography (CBCT) system was introduced. This technique provides a reliable three dimensional radiographic images that are beneficial for diagnosis and treatment planning.[39]

CBCT is the recent type of computed tomography (CT) that is developed for dental treatment to create three-dimensional images. With this technology, the structures of future implant site especially the underlining bone and important vital structures are able to be visualized in various views using specific software.

Therefore, many studies relied on CBCT in order to assess the amount of bone, the thickness of alveolar bone, or the thickness of facial plate in the area of interest. [15-20] The references of the CBCT evaluated studies were mostly located in hard tissue, such as CEJ and bone crest, since CBCT provided poor quality of soft tissue. Lee et al. in 2010 examined the thickness of anterior facial bone plate at 3 mm below CEJ, 4.5 mm below CEJ, mid root, and root apex. 3 mm below the CEJ referred to the proper location of the implant shoulder after placement which is influential in the esthetic result because the bone in this area supports the appearance of marginal gingiva. Information of the bone thickness in other positions is beneficial for the prevention of alveolar plate perforation during placement procedure.[18] Braut et al. in 2011 measured the facial bone thickness of the teeth in anterior esthetic zone at the level of 4 mm below CEJ, since it indicated to the crestal bone area, and at the level of midroot.[15] There were some studies used bone crest as the reference for identifying facial bone thickness.[16, 20, 22]

Axial image of CBCT is able to describe the form of alveolar arch which is necessary to determine the number and the distribution of implants.[13] Even though measuring the plaster models is the convenient method to identify dental or alveolar arch form, but the movable soft tissue may affect the accuracy of the results.[5, 7, 8] Suk et al. evaluated the alveolar arch using CBCT images at the level of WALA. The reference points were the root center points of the teeth from right to left mandibular second molars.

CHAPTER 3

MATERIALS AND METHODS

Research Design

This study evaluated the alveolar arch form in anterior maxillary region, consists of anterior and premolar teeth,[20, 40] at the implant related levels, in order to find out whether they could be classified into different categories or not and also evaluated the difference between the arch form and the buccolingual alveolar bone thickness.

Diagram of Study Design

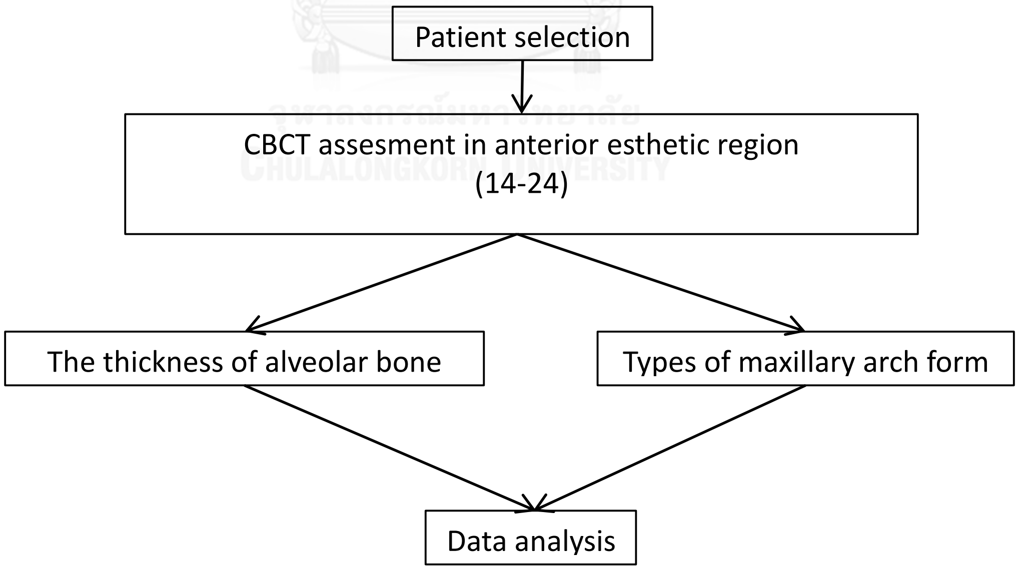

Figure 2. Diagram of study design

Ethical Consideration

This study had been approved by the ethical committee of the Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand.

Image selection

CBCT images that were taken from the patients at faculty of dentistry, Chulalongkorn University, between January 2010 and December 2013 will be used as the samples of this study.

Sample collection

113 CBCT images met the inclusion criteria (Table 1). All the images were taken using a scanner (iCAT™; Imaging Sciences International, Hatfield, PA, USA) with a 170 x 130-mm field of view that resulted in 0.25 mm voxel size. Raw digital imaging and communications in medicine (DICOM) files of the CBCT images were imported into a CBCT viewing software (Kodak Dental Imaging Software 3D Module 2.4.10; Carestream Health, Inc., NY, USA**).** The measurement was done by one examiner.

Table 1. Inclusion criteria for image selection

Inclusion criteria	Exclusion criteria
CBCT image without defects or artifacts	Periodontal disease and bone loss
Images presented teeth from right to left maxillary 2^{nd} molars	The presence of root canal treatments in anterior esthetic zone
Patient's ages were at least 21 years old	The presence of root resorption
All patients were Thai	History of orthodontic treatment
Normal occlusion	The presence of tooth restorations
Normal overjet and overbite	
Mild or lack of crowding and spacing	

Image setting and measurement

All CBCT images were set as follows: Transverse plane was parallel to occlusal plane, anteroposterior plane was parallel to median palatine suture and vertical plane was perpendicular to other planes.

- Arch form measurement

The CBCT images were measured in axial view at the level of 3 mm below CEJ of right and left canines. The variables in Table 2 were evaluated in order to identify the alveolar arch.

Table 2 Definitions of arch form variables

Variables	Definitions
Intercanine width	The distance between the root center points of the right and left maxillary canines
Interpremolar width	The distance between the root center points of the right and left maxillary first premolars
Intercanine depth	The shortest distance from line between the root center points of the right and left maxillary canines to the midpoint between the root center points of the central incisors
Interpremolar depth	The shortest distance from line between the root center points of the right and left maxillary first premolars to the midpoint between the root center points of the central incisors
Intercanine width/depth ratio	Ratio between intercanine width and depth

The measurements of variables were performed according to Figure 3. Root center points of maxillary central incisors (a and a'), canines (b and b') and first premolars (c and c') were used as the reference points. Three horizontal reference lines were created. The first reference line connected root center points of maxillary right and left central incisors (aa' line). The second reference line was drawn from the root center point of right canine to the root center point of left canine and was called intercanine width (bb’ line). The third reference line was made between the root center points of right and left maxillary first premolars, it was called interpremolar width (cc’ line). There were 2 vertical distance, intercanine depth and interpremolar depth. The intercanine depth was the shortest distance linked the intercanine width to the midpoint of the first reference line ($a_m b_m$ line). The interpremolar depth was the shortest distance linked the intrpremolar width to the midpoint of the first reference line ($a_m c_m$ line). Intercanine width/depth ratio was calculated.

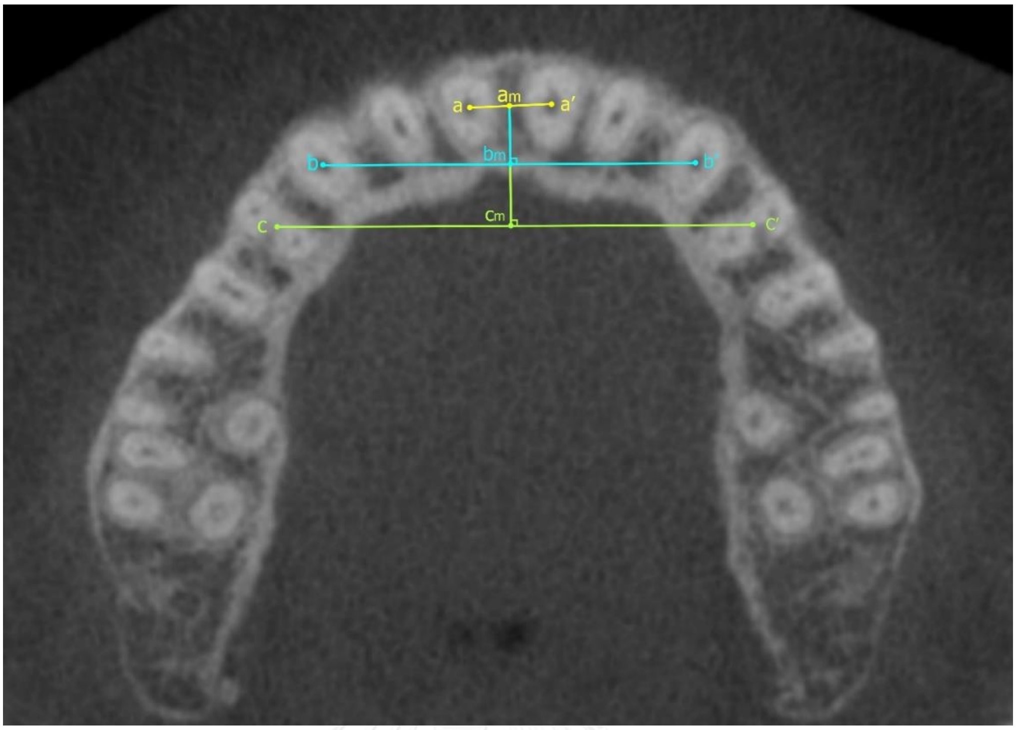

Figure 3. An example of maxillary alveolar arch, a and a' were the root center points of central incisors. aa' line was the line that linked a and a' points. b and b' were the root center points of canines. The line that linked between b and b' points (bb' line) was called intercanine width. c and c' were the root center points of first premolars. The line between c and c' points (cc' line) was called interpremolar width. a_m *was the midpoint of aa' line.* b_m *point was the end point of the perpendicular line originated from am point to bb' line.* $a_m b_m$ *line was intercanine depth.* c_m *point was the end point of the perpendicular line originated from am point to cc' line.* $a_m c_m$ *line was interpremolar depth.*

Intercanine width/depth ratio, intercanine width, and interpremolar width were used as parameters for arch form classification since the intercanine width/depth ratio represented curve of anterior arch, while intercanine width and interpremolar width referred to anterior and posterior arch dimensions respectively. K-means cluster analysis was performed to classified subjects into several groups. The appropriate numbers of arch form group were provided using average silhouette width which was the method for identifying the dissimilarity in the same group and between groups. The proper groups of classification exhibited the widest average silhouette width.

In order to identify the type of alveolar arch, fourth degree polynomial function was used according to the previous studies that reported human dental and alveolar arches could be fit with the fourth degree polynomial equation.[9, 11, 13] The fourth degree polynomial equation created the smooth curves which were approximately fit the exact data of X and Y coordinates. Thus, the X and Y coordinates of each CBCT image were set using Kodak Dental Imaging Software 3D Module 2.4 (CodeWeavers, Inc., Saint Paul, MN, USA) (Figure 4). Y-axis was created parallel to the median palatine suture with the maximum length of 40 mm. X-axis was the line perpendicular to Y-axis at the level of root center point of the most posterior second molar, maximum length was 80 mm, midpoint of X-axis was located on the median palatine suture. The junctional point of X-axis and Y-axis was set as the origin of X and Y coordinates.

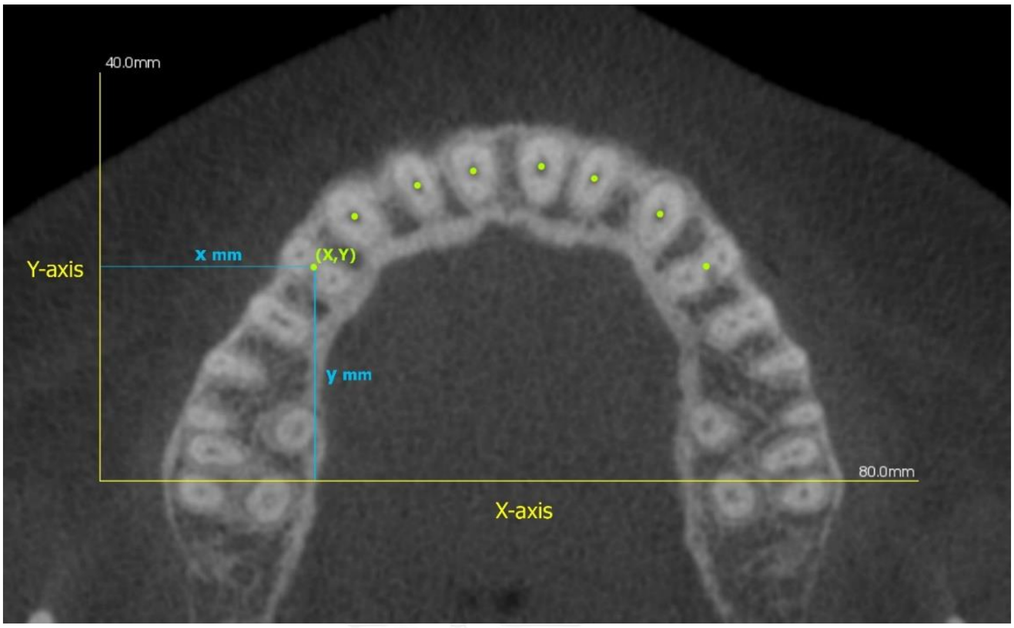

Figure 4. Y-axis was created parallel to median palatine suture while X-axis was perpendicular to Y-axis and pass through the most posterior second molar. This example both left and right second molars were in the same level. Green dots referred to root center points of the teeth in anterior esthetic zone. X and Y coordinates were digitized from the distances between root center point of each tooth to Y-axis and X-axis respectively.

All X and Y coordinates of the teeth in anterior esthetic zone (right to left 1st premolars) were digitally located at the root center point of each tooth. The mean coordinates of each group were exported to the mathematical software (MATLAB R2013a; Mathworks, Inc., Natick, MA, USA) in order to plot and create the best fitting curve using the fourth degree polynomial equation, as follow:

$$f(x) = ax^4 + bx^3 + cx^2 + dx + e$$

- The thickness of buccolingual alveolar bone measurement

The buccolingual thickness of alveolar bone was measured in order to investigate the correlation with the type of arch form in anterior esthetic zone. The CBCT images of all the teeth in anterior esthetic zone were sliced parallel to root axis and perpendicular to labial or buccal contour of alveolar bone (Figure 5).

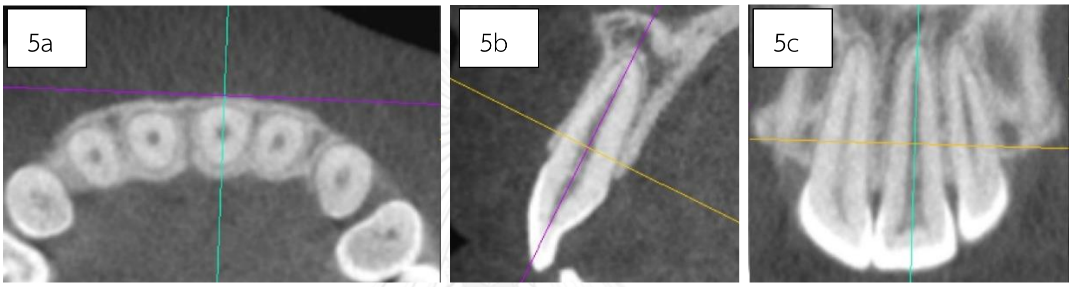

Figure 5 (5a) The CBCT image in the axial plane that was sliced perpendicular to labial or buccal contour of alveolar bone of left central incisor. (5b) The CBCT image in the coronal plane that was sliced parallel to the root axis of left central incisor. (5c) The CBCT image in the sagittal plane that was sliced parallel to the root axis of left central incisor.

The buccolingual bone thickness measurement was performed in cross sectional view perpendicular to the long axis of the tooth at 3 mm below CEJ and midroot (Figure 6). The average alveolar bone thickness of along the curve of arch form in anterior esthetic zone were calculated at both levels.

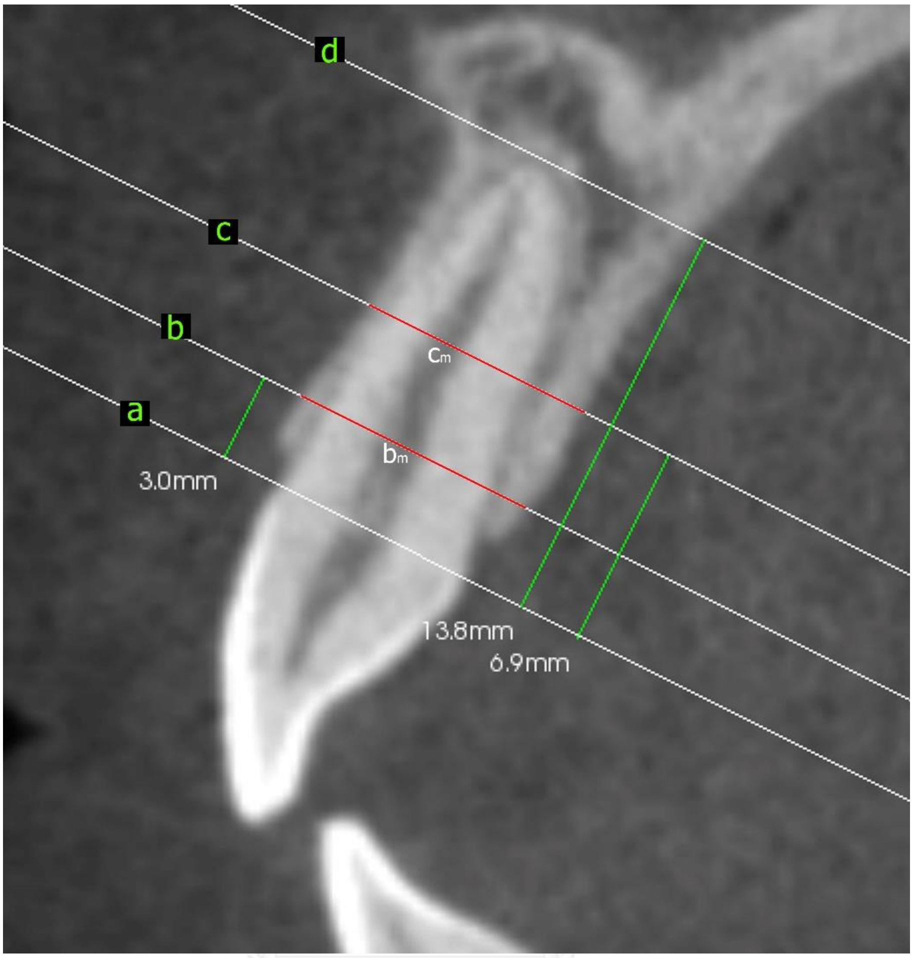

Figure 6. a level was the CEJ level of left central incisor, b level was the level of 3 mm below CEJ, c level was the level of mid root and d level was the level of root apex. Alveolar buccolingual thickness was measured perpendicular to the long axis at the level of 3 mm below CEJ (b) and midroot (c). b_m was the buccolingual alveolar bone thickness at the level of 3 mm below CEJ. c_m was the buccolingual alveolar bone thickness at the level of midroot.

The differences between thickness and each type of arch form were evaluated. The measurement of buccolingual alveolar bone thickness was modified from the study of Braut in 2011 which identified facial bone thickness of the teeth in anterior maxillary zone.[15]

Reliability tests

To assure that the examiner reported the reliable results, inter-examiner calibration with the expertise was performed by measuring all the variables of ten randomly selected subjects until the results of the expertise and the examiner showed no significant differences. After that, intra-examiner calibration was achieved by measuring all the variables of ten randomly selected subjects for two times, the second measurement was carried out 2 weeks apart from the first time.

Data Analysis

Inter-examiner calibration and intra-examiner calibration were evaluated by intraclass correlation coefficient (ICC), using two way mixed model with 95% confident interval. The maxillary anterior alveolar arch forms were classified using K-means cluster analysis and silhouette width. One way ANOVA and LSD post hoc test were achieved to find out the variables which influenced the arch form and the differences of buccolingual alveolar bone thickness between arch forms. *p*-values < 0.05 were adjudged as statistically differences. The statistical software (SPSS 20.0, SPSS, Chicago, IL, USA) was used for statistical data analysis of intra-examiner calibration, inter-examiner calibration, one way ANOVA and LSD post hoc test. K-means cluster was performed by using R software (R 3.2.0, http://www.r-project.org).

CHAPTER 4

RESULTS

The samples consisted 113 subjects (43 males and 70 females), their ages ranged from 20 to 39 years, the average age was 30.43 years. The inter-examiner and intra-examiner calibrations were subsequently 0.996 and 0.992 in correlations. The subjects were classified from three to ten clusters by using K-means cluster analysis and found that four clusters showed the highest value of Silhouette width that meant the four clusters provided the most similarity within the same cluster and the most dissimilarity between clusters (Table 3).

Table 3. K-means cluster analysis and the comparison of average silhouette width. The clusters referred to the groups of classification and the widest average silhouette width represented the appropriate number of arch form groups.

Clusters	Average silhouette width
3	0.3
4	0.34
5	0.28
6	0.27
7	0.28
8	0.28
9	0.27
10	0.28

Mean coordinates of the subjects in each group were fit with fourth degree polynomial equation’s curves (Figure 7). The arch forms related to width and height of the curves were group 1; long narrow arch, group 2; short medium arch, group 3; long medium arch, and group 4; long wide arch.

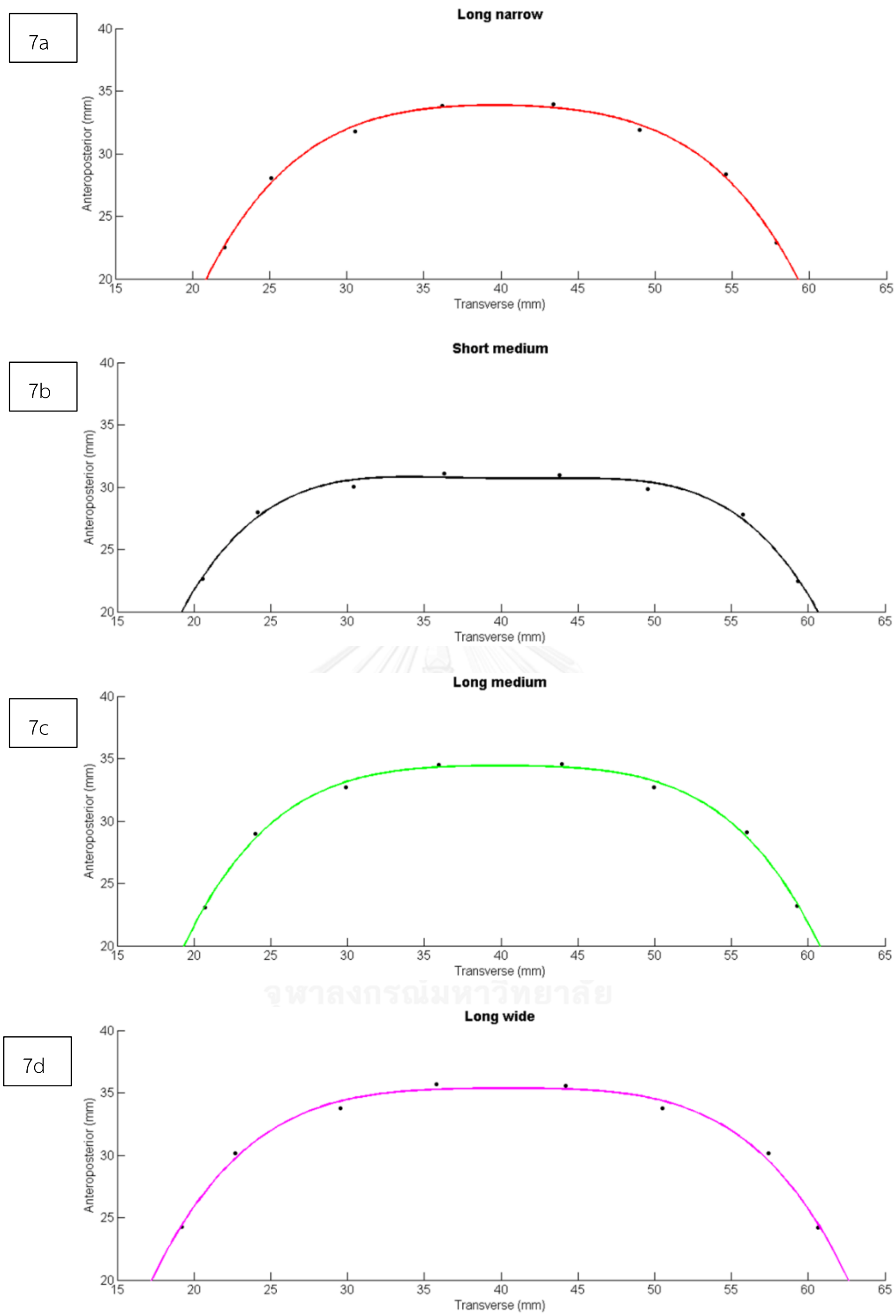

Figure 7. The best fitting curve of each cluster. (7a) Long narrow arch form, (7b) Short medium arch form, (7c) Long medium arch form, (7d) Long wide arch form.

The comparison of arch shapes between four arch groups was demonstrated in Figure 8. Numbers of subject, the mean values of all the variables and the cut off numbers which were the lower bounds and the upper bounds in each group were presented in Table 4. All four groups showed strongly significant difference between groups (*p*-values < 0.001). According to LSD post hoc test, intercanine width and interpremolar width of long narrow arch group (29.66 ± 1.32 mm and 36.01 ± 1.39 mm) were the narrowest transverse dimensions among all arch form groups followed by the intercanine and interpremolar widths of short medium arch group (31.81 ± 1.56 mm and 38.96 ± 1.41 mm) as well as those of long medium arch group (32.36 ± 1.02 mm and 38.75 ± 0.84 mm), the two medium groups showed no significant difference between each other, while long wide arch group exhibited the widest distance of transverse dimensions (35.01 ± 1.26 mm and 41.74 ± 1.41 mm). Intercanine depth and interpremolar depth displayed no statistically different between long narrow group (5.57 ± 0.90 mm and 11.16 ± 1.38 mm), long medium group (5.43 ± 1.07 mm and 11.30 ± 1.49 mm) and long wide group (5.28 ± 0.96 mm and 11.35 ± 1.42 mm), these three long groups provided significant longer anteroposterior dimensions than short medium arch group (3.05 ± 0.52 mm and 8.45 ± 1.10 mm). Intercanine width/depth ratio presented that short medium arch group demonstrated the largest curve (10.70 ± 1.70), followed by long wide arch group (6.83 ± 1.14), long medium arch group (6.14 ± 1.07) and the smallest curve was shown in long narrow arch group (5.45 ± 0.85).

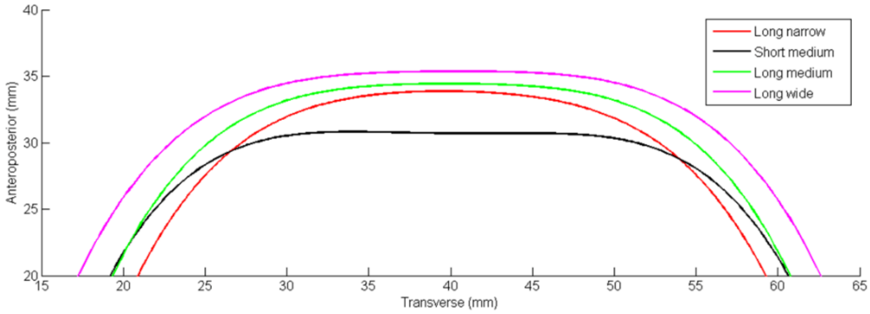

Figure 8. The comparison of best fitting curves between clusters.

Table 4. Numbers of subject, means, standard deviations, lower bounds and upper bounds of arch dimensions in four groups of arch form.

Groups of arch form	Subjects	Arch dimensions	mean(mm)	sd	Lower bound(mm)	Upper bound(mm)
Long narrow	32	Intercanine width*	29.66	1.32	29.18	30.13
		Interpremolar width*	36.01	1.39	35.51	36.51
		Intercanine depth	5.57	0.90	5.25	5.89
		Interpremolar depth	11.16	1.38	10.66	11.65
		Intercanine width/depth*	5.45	0.85	5.15	5.76
Short medium	18	Intercanine width	31.83	1.56	31.05	32.60
		Interpremolar width	38.96	1.41	38.26	39.67
		Intercanine depth*	3.05	0.52	2.79	3.31
		Interpremolar depth*	8.45	1.10	7.90	9.00
		Intercanine width/depth*	10.70	1.70	9.85	11.54
Long medium	36	Intercanine width	32.26	1.02	31.91	32.60
		Interpremolar width	38.75	0.84	38.46	39.03
		Intercanine depth	5.43	1.07	5.07	5.79
		Interpremolar depth	11.30	1.49	10.79	11.80
		Intercanine width/depth*	6.14	1.07	5.78	6.30
Long wide	27	Intercanine width*	35.01	1.26	34.51	35.51
		Interpremolar width*	41.74	1.41	41.18	42.30
		Intercanine depth	5.28	0.96	4.90	5.66
		Interpremolar depth	11.35	1.42	10.79	11.91
		Intercanine width/depth*	6.83	1.14	6.38	7.28

LSD Post hoc test; * p-value ≤ 0.05.

Table 5 exhibited the length of arch dimensions, the standard deviations, the lower bounds and the upper bounds of each type of arch form. The average buccolingual bone thickness along arch curve showed significant difference between groups of arch forms at both 3 mm below CEJ and midroot levels with *p*-values < 0.001. At the level of 3 mm below CEJ, long wide arch group has the widest thickness (9.26 ± 0.61 mm) followed by long medium arch group (8.86 ± 0.53 mm) while long narrow arch group (8.20 ± 0.49 mm) and short medium arch group (8.35 ± 0.72 mm) were the narrowest. The similar results presented at the level of midroot, long wide arch group exhibited the widest buccolingual bone thickness (9.88 ± 0.95 mm), followed by long medium arch group (9.33 ± 0.87 mm), the narrowest buccolingual bone thickness were shown in long narrow arch group (8.51 ± 0.57 mm) and short medium arch group (8.50 ± 1.01 mm).

Table 5. *Numbers of subfect, means, standard deviations, lower bounds and upper bounds of bucolingual alveolar bone thickness at the 3 mm below CEJ and midroot levels in four groups of arch form.*

Groups of arch form	Subjects	Variables	mean(mm)	sd	Lower bound(mm)	Upper bound(mm)
Long narrow	32	3mm below CEJ	8.20	0.49	8.00	8.39
		Midroot	8.51	0.57	8.29	8.74
Short medium	18	3mm below CEJ	8.35	0.72	7.98	8.72
		Midroot	8.50	1.01	7.98	9.02
Long medium	36	3mm below CEJ*	8.86	0.53	8.67	9.05
		Midroot*	9.33	0.87	9.02	9.64
Long wide	27	3mm below CEJ*	9.26	0.61	8.96	9.55
		Midroot*	9.88	0.95	9.42	10.34

LSD Post hoc test; * p-value ≤ 0.05.

CHAPTER 5

DISCUSSIONS AND CONCLUSIONS

Discussions

Previously, many studies investigated human full arch form at dental level[5, 7-9, 11, 41], only few studies paid attention to the alveolar arches which related to implant dentistry.[10, 13, 14] Most of the studies used plaster or 3D virtual models to evaluate arch form, while a few study demonstrated the use of CBCT imaging.[10, 13] However none of them gave precedence to alveolar arch form in maxillary anterior esthetic zone, thus this study is the first study reported the classification of alveolar arch form and the identification of buccolingual thickness of alveolar bone in anterior esthetic zone using CBCT imaging.

In 2013, Bayome et al. and Suk et al. evaluated full alveolar arch from using the axial view of CBCT images. The root center points at the level of coronal third of right and left mandibular canines were used as the references.[10, 13] Since the root center points took more advantageous than WALA points because they were located in hard tissue that was immovable, hence they were chosen to be the reference points in this study. There were studies reported that implant platform should be located 3-4 mm below free gingival margin of the facial aspect to provide the esthetic outcomes.[25, 26] This study evaluated the arch forms at the level resembled to recommended implant platform level, consequently the level of 3 mm apical to CEJ of left and right canines was used as the reference because the gingival margins were possible to locate at CEJ [42] and CBCT images did not present a good quality of soft tissue such as gingival margins. Moreover, the zenith points, the most apical point of gingival margin, of canines were mostly equal to that of central incisors.[43, 44] Even though the zenith points of lateral incisors and premolars were approximately 1 mm coronal to that of central incisors and canines[45], yet they were still in the range of appropriate implant positions. Recent studies demonstrated that arch form classification was based on transverse dimensions and arch width/depth ratio.[8, 9, 41] Therefore our study used intercanine width, interpremolar width, which subsequently represented the transverse dimensions of anterior and posterior parts of the anterior esthetic arch, and intercanine width/depth ratio, which was described as anterior arch curve, as the parameters for anterior arch form classification. In this study, the subjects were classified into four groups and the strongly significant differences between groups were reported. The results demonstrated that arch form of maxillary anterior esthetic region can be classified at the level of implant platform corresponded to the studies of dental arch form classification which report the heterogeneous of the dental arches.[8, 9, 12] Hence, the first null hypothesis was rejected.

Even though alveolar arch forms in anterior esthetic region could be classified similar to dental arch forms, still the influence of arch dimensions were difference.

In our study, intercanine width and interpremolar width that represented transverse dimensions of anterior alveolar arch played an important role upon the arch form. These results corresponded to the previous studies which evaluated full maxillary arch form at dental level that reported the effect of anterior transverse dimension on anterior dental arch form.[8, 9] The anteroposterior dimensions as well as anterior arch curve which referred to arch depth and intercanine width/depth ratio respectively also influenced the anterior alveolar arch form in our study. However, the previous study showed that dental anterior arch depth as well as intercanine width/depth ratio did not affected full maxillary dental arch form.[9] These results revealed a dissimilarity compared to our study. The results could be explained by the study of Bayome in 2013 that displayed a strong correlation of anterior transverse dimensions between dental and alveolar arches. Nevertheless, there was no significant correlation of anterior anteroposterior dimension and anterior arch curve between them.[10] Hence, anterior alveolar arch form may be different from anterior dental arch form because of the dissimilarity in anteroposterior dimension and arch curve.

Previous reports applied various mathematical function in order to identify human dental arches.[5-8, 11] Fourth degree polynomial equation was extensively applied to create best fitting curve of dental and alveolar arches in many articles.[9, 11, 13] However, the mathematical functions that represented arch form in anterior esthetic zone were parabola and mixed model.[11, 12] The mixed model separated anterior arch and posterior arch. Midpoints of incisal edge of anterior teeth and canine cusp tips were fit with semi-ellipse curve while buccal cusp tips of posterior teeth were fit with parabola curve. In 1994, the study of Ferrario compared fourth degree polynomial equation with mixed model and revealed that both of the equations were able to use for mathematical description of dental arches [11]. Since there was no study about curve fitting of arch form in anterior esthetic zone at bone level, pilot study was achieved to validate the best fitting curves of parabola, ellipse and fourth degree polynomial equations. The correlation coefficient of curve fitting was 0.943 in parabola curve, 0.971 in ellipse curve and 0.995 in fourth degree polynomial curve. Although all curves correlated to alveolar arch form in anterior esthetic zone, still fourth degree polynomial curve exhibited the highest value. We also tried to fit the data with higher degree polynomial equations as reported in the previous study[7], but the equations exhibited non-smooth curves. Therefore, fourth degree polynomial equation was selected for curve fitting in our study. Four different arch curves were displayed after fit the average X and Y coordinates of each categories (figure 7) with fourth degree polynomial equation, the curves represented shape of the maxillary anterior arch at implant platform level. Names of the arches depended on arch width and arch depth. Hence, arch form can be classified as long narrow arch, short medium arch, long medium arch and long wide arch.

Since buccolingual alveolar bone thickness is one of important factors for not only the selection of implant diameter and number, but also the decision of bone contour augmentation. Moreover, each type of arch form might effect to the buccolingual alveolar bone thickness, thus the present study focused on the differences of buccolingual alveolar bone thickness between arch forms in anterior esthetic region. The results showed that at both levels of implant platform and the middle of the root, long wide arch group presented the widest buccolingual bone thickness followed by long medium arch group while the narrowest buccolingual bone thickness were long narrow arch group and short medium arch group. The results rejected the second null hypothesis. These findings implied briefly idea for clinical treatment planning that small arches, both in anteroposterior dimension which was short medium arch and transverse dimension which was long narrow arch, provided narrow alveolar bone thickness. In order to place implants in these types of arch form, clinicians should carefully consider implant placement with bone contour augmentation or reduce implants diameter or bone contour augmentation when horizontal bone loss occurs.

Within the limits of this study, there were four types of arch form with different thickness of buccolingual alveolar bone. These information may help the clinicians to thoroughly determine the proper implant diameters and to predict the necessity of bone augmentation for each type of arch form. However, there is still lack of the information regarding alveolar bone axis, the relationship between alveolar bone axis and maxillary skeletal types, the changes of alveolar arch forms after the different periods of anterior teeth extraction and the suitable implant numbers and implant position for reducing stress around dental implants which is one of the possible factors of further bone resorption after implant placement. Hence, the future studies are necessary to promote the esthetically sustainable result of implant treatment in anterior esthetic region. The clinical implication of our study in the future is to develop the AA curves into 1:1 scaled templates for CBCT software, the clinicians will put the template over axial CBCT image of anterior alveolar arch of each patient at the implant platform level then determine the appropriate implant numbers, implant positions as well as the anterior border of bone augmentation.

Conclusions

Arch forms in anterior esthetic zone at the level of implant platform were classified into four groups as long narrow arch, short medium arch, long medium arch and long wide arch. The buccolingual alveolar bone thickness showed significant difference among anterior arch forms.

REFERENCES

1. Araujo MG, Lindhe J. Dimensional ridge alterations following tooth extraction. An experimental study in the dog. J Clin Periodontol 2005;32(2):212-8.
2. Kamankatgan S, Pimkhaokham A, Krisdapong S. Patient-based outcomes following surgical implant placements. Clin Oral Implants Res 2015.
3. Misch CE. CONTEMPORARY IMPLANT DENTISTRY. Missouri: Mosby; 2008.
4. Sagat G, Yalcin S, Gultekin BA, Mijiritsky E. Influence of arch shape and implant position on stress distribution around implants supporting fixed full-arch prosthesis in edentulous maxilla. Implant Dent 2010;19(6):498-508.
5. Braun S, Hnat WP, Fender DE, Legan HL. The form of the human dental arch. Angle Orthod 1998;68(1):29-36.
6. Currier JH. A computerized geometric analysis of human dental arch form. Am J Orthod 1969;56(2):164-79.
7. Noroozi H, Nik TH, Saeeda R. The dental arch form revisited. Angle Orthod 2001;71(5):386-9.
8. Lee SJ, Lee S, Lim J, Park HJ, Wheeler TT. Method to classify dental arch forms. Am J Orthod Dentofacial Orthop 2011;140(1):87-96.
9. Bayome M, Han SH, Choi JH, et al. New clinical classification of dental arch form using facial axis points derived from three-dimensional models. Aust Orthod J 2011;27(2):117-24.

10. Bayome M, Park JH, Han SH, et al. Evaluation of dental and basal arch forms using cone-beam CT and 3D virtual models of normal occlusion. Aust Orthod J 2013;29(1):43-51.

11. Ferrario VF, Sforza C, Miani A, Jr., Tartaglia G. Mathematical definition of the shape of dental arches in human permanent healthy dentitions. Eur J Orthod 1994;16(4):287-94.

12. Preti G, Pera P, Bassi F. Prediction of the shape and size of the maxillary anterior arch in edentulous patients. J Oral Rehabil 1986;13(2):115-25.

13. Suk KE, Park JH, Bayome M, et al. Comparison between dental and basal arch forms in normal occlusion and Class III malocclusions utilizing cone-beam computed tomography. Korean J Orthod 2013;43(1):15-22.

14. Ronay V, Miner RM, Will LA, Arai K. Mandibular arch form: the relationship between dental and basal anatomy. Am J Orthod Dentofacial Orthop 2008;134(3):430-8.

15. Braut V, Bornstein MM, Belser UC, Buser D. Thickness of the anterior maxillary facial bone wall-a retrospective radiographic study using cone beam computed tomography. Int J Periodontics Restorative Dent 2011;31(2):125-31.

16. Ghassemian M, Nowzari H, Lajolo C, et al. The thickness of facial alveolar bone overlying healthy maxillary anterior teeth. J Periodontol 2012;83(2):187-97.

17. Jin SH, Park JB, Kim N, et al. The thickness of alveolar bone at the maxillary canine and premolar teeth in normal occlusion. J Periodontal Implant Sci 2012;42(5):173-8.

18. Lee SL, Kim HJ, Son MK, Chung CH. Anthropometric analysis of maxillary anterior buccal bone of Korean adults using cone-beam CT. J Adv Prosthodont 2010;2(3):92-6.

19. Naitoh M, Hayashi H, Tsukamoto N, Ariji E. Labial bone assessment surrounding dental implant using cone-beam computed tomography: an in vitro study. Clin Oral Implants Res 2012;23(8):970-4.

20. Vera C, De Kok IJ, Reinhold D, et al. Evaluation of buccal alveolar bone dimension of maxillary anterior and premolar teeth: a cone beam computed tomography investigation. Int J Oral Maxillofac Implants 2012;27(6):1514-9.

21. Brand RW. Anatomy of Orofacial Structures. 6th ed. United States: Mosby; 1998.

22. Januario AL, Duarte WR, Barriviera M, et al. Dimension of the facial bone wall in the anterior maxilla: a cone-beam computed tomography study. Clin Oral Implants Res 2011;22(10):1168-71.

23. Grunder U, Gracis S, Capelli M. Influence of the 3-D bone-to-implant relationship on esthetics. Int J Periodontics Restorative Dent 2005;25(2):113-9.

24. Ishikawa T, Salama M, Funato A, et al. Three-dimensional bone and soft tissue requirements for optimizing esthetic results in compromised cases with multiple implants. Int J Periodontics Restorative Dent 2010;30(5):503-11.

25. Palacci P, Nowzari H. Soft tissue enhancement around dental implants. Periodontol 2000 2008;47:113-32.

26. Saadoun AP. The key to peri-implant esthetics: hard- and soft-tissue management. Dent Implantol Update 1997;8(6):41-6.

27. Darby I, Chen ST, Buser D. Ridge preservation techniques for implant therapy. Int J Oral Maxillofac Implants 2009;24 Suppl:260-71.

28. von Arx T, Buser D. Horizontal ridge augmentation using autogenous block grafts and the guided bone regeneration technique with collagen membranes: a clinical study with 42 patients. Clin Oral Implants Res 2006;17(4):359-66.

29. Urban IA, Nagursky H, Lozada JL, Nagy K. Horizontal ridge augmentation with a collagen membrane and a combination of particulated autogenous bone and anorganic bovine bone-derived mineral: a prospective case series in 25 patients. Int J Periodontics Restorative Dent 2013;33(3):299-307.

30. Saffar JL, Lasfargues JJ, Cherruau M. Alveolar bone and the alveolar process: the socket that is never stable. Periodontol 2000 1997;13:76-90.

31. Carranza FA, Newman, M.G. Glickman's clinical periodontology. 10 ed. Philadelphia: Saunders; 2006.

32. Wang RE, Lang NP. Ridge preservation after tooth extraction. Clin Oral Implants Res 2012;23 Suppl 6:147-56.

33. Tallgren A, Lang BR, Miller RL. Longitudinal study of soft-tissue profile changes in patients receiving immediate complete dentures. Int J Prosthodont 1991;4(1):9-16.

34. Tarnow DP, Cho SC, Wallace SS. The effect of inter-implant distance on the height of inter-implant bone crest. J Periodontol 2000;71(4):546-9.

35. Dym H, Ogle, O.E., Wettan, H.L. Atlas of Minor Oral Surgery. Philadelphia: Saunders; 2001.

36. Romeo E, Chiapasco M, Ghisolfi M, Vogel G. Long-term clinical effectiveness of oral implants in the treatment of partial edentulism. Seven-year life table analysis of a prospective study with ITI dental implants system used for single-tooth restorations. Clin Oral Implants Res 2002;13(2):133-43.

37. Chen LC, Lundgren T, Hallstrom H, Cherel F. Comparison of different methods of assessing alveolar ridge dimensions prior to dental implant placement. J Periodontol 2008;79(3):401-5.

38. Angelopoulos C, Thomas SL, Hechler S, Parissis N, Hlavacek M. Comparison between digital panoramic radiography and cone-beam computed tomography for the identification of the mandibular canal as part of presurgical dental implant assessment. J Oral Maxillofac Surg 2008;66(10):2130-5.

39. Buser D, Martin W, Belser UC. Optimizing esthetics for implant restorations in the anterior maxilla: anatomic and surgical considerations. Int J Oral Maxillofac Implants 2004;19 Suppl:43-61.

40. Bornstein MM, Halbritter S, Harnisch H, Weber HP, Buser D. A retrospective analysis of patients referred for implant placement to a specialty clinic: indications, surgical procedures, and early failures. Int J Oral Maxillofac Implants 2008;23(6):1109-16.

41. Park KH, Bayome M, Park JH, et al. New classification of lingual arch form in normal occlusion using three dimensional virtual models. Korean J Orthod 2015;45(2):74-81.

42. Nield-Gehrig JS. Fundamentals of Periodontal Instrumentation and Advanced Root Instrumentation. 6th ed. Philadelphia: Lippincott Williams & Wilkins; 2008.

43. Allen EP. COMMENTARY. Gingival zenith positions and levels of the maxillary anterior dentition. J Esthet Restor Dent 2009;21(2):121.

44. Chu SJ, Tan JH, Stappert CF, Tarnow DP. Gingival zenith positions and levels of the maxillary anterior dentition. J Esthet Restor Dent 2009;21(2):113-20.

45. Duran I, Yilmaz B, Tatar N, Ural C, Guler AU. Determining the localization of premolar zenith positions according to the gingival line. Niger J Clin Pract 2015;18(2):273-5.

APPENDIX

Appendix A. Sample size calculation

$$n = (z^2 * \sigma^2) / e^2$$

n = Sample size

σ = Standard deviation

Z = Value from standard normal distribution corresponding to desired confidence level

e = Desire decision

This study determined these value form the previous study.

σ = 1.54

Z = 1.96 at 95 % confidence interval

e = 0.30

According to the result of pilot study, mean and standard deviation was applied to calculate the sample size using STATA software (version 10). The number of sample size estimation was 109.

Appendix B. Alveolar anterior arch dimensions and the classification

Case	Intercanine width (mm)	Intercanine depth (mm)	Intercanine W/D ratio	Interpremolar width (mm)	Interpremolar depth (mm)	group
1	33.6	3.2	10.5	39.7	8.1	2
2	30.9	6.3	4.9	35.9	12.3	1
3	33.0	3.9	8.5	39.0	10.6	2
4	32.9	6.8	4.8	39.0	12.7	3
5	33.4	5.2	6.4	39.6	11.1	3
6	35.0	5.4	6.5	43.0	12.6	4
7	34.3	5.1	6.7	40.5	11.1	4
8	30.2	4.7	6.4	38.4	10.0	3
9	33.9	4.5	7.5	40.1	9.4	4
10	30.5	6.1	5.0	36.8	12.9	1
11	32.7	5.9	5.5	38.9	12.3	3
12	29.4	5.8	5.1	36.1	10.9	1
13	32.9	5.9	5.6	39.0	11.7	3
14	31.5	6.7	4.7	38.6	12.4	3
15	28.3	4.0	7.1	35.2	8.5	1
16	29.6	6.5	4.6	34.0	11.8	1
17	31.6	5.8	5.4	38.9	11.0	3
18	30.9	5.7	5.4	36.0	10.8	1
19	32.4	5.2	6.2	38.6	11.4	3
20	29.6	5.0	5.9	36.6	8.7	1
21	32.7	2.6	12.6	39.4	7.6	2
22	35.2	7.0	5.0	41.6	14.4	4
23	29.7	5.6	5.3	36.3	12.0	1
24	30.0	5.9	5.1	35.9	11.8	1
25	30.8	6.5	4.7	36.4	12.7	1
26	31.0	5.1	6.1	38.6	10.9	3
27	30.8	4.4	7.0	36.8	9.7	1

Case	Intercanine width (mm)	Intercanine depth (mm)	Intercanine W/D ratio	Interpremolar width (mm)	Interpremolar depth (mm)	group
28	30.9	5.9	5.2	38.2	12.0	3
29	27.9	4.0	7.0	35.7	9.0	1
30	29.6	5.7	5.2	38.0	12.1	1
31	28.7	4.8	6.0	38.2	10.1	1
32	31.0	5.0	6.2	38.1	10.8	3
33	32.8	4.8	6.8	39.9	11.3	3
34	29.4	6.0	4.9	35.6	12.5	1
35	37.0	6.3	5.9	44.6	13.4	4
36	30.9	5.5	5.6	38.1	11.7	3
37	33.6	6.5	5.2	39.3	13.6	3
38	30.8	6.8	4.5	37.5	11.8	1
39	30.9	5.9	5.2	37.6	10.9	1
40	33.5	5.9	5.7	39.4	11.6	3
41	32.6	7.4	4.4	38.0	14.0	3
42	33.5	4.3	7.8	41.0	9.6	4
43	34.1	5.6	6.1	37.7	11.9	3
44	33.2	6.8	4.9	39.5	13.0	3
45	29.1	5.0	5.8	33.8	10.3	1
46	33.1	6.2	5.3	38.9	12.7	3
47	33.0	8.8	3.8	39.0	15.7	3
48	29.5	6.3	4.7	34.2	11.7	1
49	28.3	4.5	6.3	36.9	9.9	1
50	31.5	6.0	5.3	39.5	12.0	3
51	29.8	7.2	4.1	34.6	12.9	1
52	33.0	5.6	5.9	39.8	11.1	3
53	26.6	5.7	4.7	34.7	12.0	1
54	28.8	4.9	5.9	36.2	11.4	1
55	29.9	6.0	5.0	35.9	12.2	1
56	30.0	2.9	10.3	37.5	9.2	2

Case	Intercanine width (mm)	Intercanine depth (mm)	Intercanine W/D ratio	Interpremolar width (mm)	Interpremolar depth (mm)	group
57	32.2	5.6	5.8	39.3	11.1	3
58	36.8	6.1	6.0	43.6	12.4	4
59	32.4	4.5	7.2	39.8	9.8	3
60	34.1	5.1	6.8	42.2	9.4	4
61	33.8	5.3	6.4	41.0	11.2	4
62	34.2	5.1	6.7	42.2	10.7	4
63	31.0	2.2	13.9	38.6	7.4	2
64	33.8	3.8	9.0	40.5	10.2	2
65	31.4	3.9	8.0	39.1	9.5	3
66	29.0	2.7	10.6	35.4	8.1	2
67	32.3	4.9	6.6	38.8	10.9	3
68	32.3	2.2	14.4	40.2	8.3	2
69	35.1	6.1	5.7	40.5	12.6	4
70	33.0	6.4	5.2	40.4	12.4	4
71	35.0	5.0	6.9	41.4	10.9	4
72	31.5	4.2	7.4	39.6	8.4	3
73	28.7	2.4	11.9	37.5	9.1	2
74	32.4	3.2	10.1	39.6	8.8	2
75	34.6	4.3	8.0	39.9	10.4	4
76	31.4	4.4	7.1	39.0	9.9	3
77	35.8	4.4	8.1	41.0	10.3	4
78	31.0	4.8	6.5	38.5	9.8	3
79	31.8	4.0	8.0	38.9	9.6	3
80	32.2	6.6	4.9	36.0	13.0	1
81	25.6	3.5	7.4	31.9	8.0	1
82	33.5	4.0	8.5	41.5	9.0	4
83	31.5	2.9	11.0	40.6	7.7	2
84	35.3	5.8	6.1	42.4	11.4	4
85	31.7	3.5	9.0	38.3	7.6	2

Case	Intercanine width (mm)	Intercanine depth (mm)	Intercanine W/D ratio	Interpremolar width (mm)	Interpremolar depth (mm)	group
86	36.9	5.4	6.9	43.6	11.6	4
87	34.4	3.4	10.0	40.7	9.3	2
88	30.1	5.4	5.6	34.4	11.4	1
89	31.1	3.0	10.4	39.8	7.7	2
90	31.1	4.0	7.8	39.3	9.5	3
91	32.4	4.1	7.9	38.5	9.1	3
92	30.5	4.6	6.6	37.5	9.8	1
93	31.4	4.5	7.0	36.4	10.6	3
94	37.5	5.2	7.2	44.0	11.1	4
95	31.4	3.8	8.4	38.7	10.0	2
96	34.0	4.2	8.2	40.6	9.9	4
97	33.9	4.2	8.2	43.3	10.5	4
98	35.7	5.9	6.1	42.9	13.3	4
99	37.0	5.7	6.5	39.4	11.7	4
100	35.9	3.8	9.5	42.9	10.7	4
101	30.9	2.6	12.1	37.4	6.3	2
102	32.6	3.4	9.7	38.3	8.1	2
103	30.3	6.6	4.6	35.7	12.8	1
104	33.7	4.7	7.2	39.9	10.7	4
105	32.8	3.2	10.3	40.3	8.1	2
106	31.0	5.3	5.9	37.3	10.7	1
107	34.2	5.3	6.5	38.7	12.5	3
108	29.5	5.7	5.2	37.9	10.7	1
109	33.6	5.7	5.9	37.9	10.7	3
110	34.6	7.8	4.5	42.3	14.0	4
111	36.1	5.6	6.4	41.1	11.8	4
112	32.6	4.2	7.7	36.0	10.1	3
113	30.0	6.0	5.0	36.7	11.8	1

Appendix C. Buccolingual alveolar bone thickness

Group	Case	tooth number	3 mm below CEJ (mm)	mid root (mm)
2	1	14	9.4	10.4
		13	9.3	7.8
		12	7.0	5.5
		11	7.6	7.2
		21	7.3	6.6
		22	5.9	6.2
		23	8.5	8.3
		24	9.6	8.6
1	2	14	9.0	9.8
		13	8.3	7.2
		12	7.9	8.9
		11	7.9	7.7
		21	7.6	6.5
		22	7.2	7.1
		23	8.5	7.8
		24	9.2	8.6
2	3	14	12.4	13.5
		13	11.8	12.4
		12	9.9	8.9
		11	9.4	9.8
		21	9.4	8.9
		22	8.9	8.6
		23	10.0	11.4
		24	11.0	11.0
3	4	14	11.0	10.5
		13	10.2	10.1
		12	7.4	7.3
		11	8.3	8.4
		21	8.1	8.1
		22	7.9	7.6
		23	9.8	9.4
		24	10.7	10.2
3	5	14	10.3	11.8
		13	9.9	12.3
		12	8.2	10.0
		11	8.7	9.5
		21	8.2	8.9
		22	7.4	8.7
		23	9.5	12.2
		24	11.5	12.6

Group	Case	tooth number	3 mm below CEJ (mm)	mid root (mm)
4	6	14	10.3	10.3
		13	9.9	11.2
		12	7.8	7.9
		11	8.2	8.6
		21	7.9	8.4
		22	7.5	6.5
		23	9.9	10.0
		24	9.9	10.2
4	7	14	9.9	10.7
		13	9.8	10.1
		12	7.6	8.3
		11	8.3	9,2
		21	8.4	9.0
		22	7.5	7.7
		23	9.2	9.6
		24	9.9	10.2
3	8	14	10.9	10.0
		13	9.5	8.1
		12	8.7	7.6
		11	8.6	7.4
		21	8.7	7.7
		22	8.2	7.6
		23	9.4	7.3
		24	10.5	10.0
4	9	14	12.3	13.2
		13	11.6	12.6
		12	9.1	10.3
		11	9.5	10.6
		21	10.5	11.6
		22	8.7	9.9
		23	10.5	13.4
		24	11.2	12.7
1	10	14	10.3	10.5
		13	9.7	10.6
		12	7.9	7.6
		11	8.7	9.5
		21	8.4	9.0
		22	7.5	7.7
		23	9.3	10.1
		24	9.7	10.9

Group	Case	tooth number	3 mm below CEJ (mm)	mid root (mm)
3	11	14	10.2	10.2
		13	9.7	8.6
		12	7.0	6.5
		11	8.2	8.4
		21	7.9	9.4
		22	7.5	6.9
		23	10.3	8.9
		24	10.4	10.4
1	12	14	10.2	9.1
		13	8.1	8.0
		12	6.5	8.0
		11	7.2	7.7
		21	7.6	8.9
		22	7.3	7.9
		23	7.8	8.3
		24	9.6	9.9
3	13	14	10.4	11.3
		13	8.9	10.7
		12	8.1	8.6
		11	9.1	9.5
		21	8.9	10.0
		22	6.9	7.5
		23	9.4	10.5
		24	10.1	10.9
3	14	14	9.2	9.2
		13	9.3	8.5
		12	7.0	6.8
		11	7.5	7.5
		21	7.5	8.1
		22	6.5	6.9
		23	8.2	7.9
		24	9.4	9.7
1	15	14	8.0	8.8
		13	7.6	8.9
		12	4.7	5.4
		11	7.0	7.9
		21	6.8	8.2
		22	5.0	5.9
		23	7.2	8.1
		24	7.4	9.0

Group	Case	tooth number	3 mm below CEJ (mm)	mid root (mm)
1	16	14	9.1	9.0
		13	7.7	7.5
		12	7.5	7.6
		11	8.1	8.6
		21	8.2	8.7
		22	7.7	7.7
		23	7.9	7.2
		24	9.0	8.9
3	17	14	9.9	10.9
		13	9.0	10.4
		12	7.3	7.2
		11	7.8	7.9
		21	8.1	7.7
		22	6.7	6.6
		23	9.3	9.5
		24	10.2	10.5
1	18	14	9.5	9.7
		13	8.0	8.6
		12	6.9	6.8
		11	8.0	8.7
		21	8.2	9.2
		22	7.1	7.0
		23	8.4	8.6
		24	9.7	10.4
3	19	14	9.1	9.2
		13	8.8	8.3
		12	7.2	7.2
		11	7.2	7.7
		21	7.4	7.0
		22	8.1	7.0
		23	8.4	9.1
		24	9.7	9.2
1	20	14	9.5	10.0
		13	9.2	8.4
		12	6.7	6.8
		11	7.3	7.4
		21	6.6	7.6
		22	6.6	6.5
		23	8.5	8.9
		24	9.2	10.0

Group	Case	tooth number	3 mm below CEJ (mm)	mid root (mm)
2	21	14	10.7	11.5
		13	9.6	10.6
		12	7.5	8.6
		11	8.1	9.0
		21	8.5	9.3
		22	7.5	7.5
		23	9.6	11.6
		24	9.5	10.6
4	22	14	11.6	11.4
		13	11.2	10.2
		12	9.1	10.0
		11	8.7	11.3
		21	8.7	11.3
		22	9.6	10.5
		23	10.4	11.6
		24	10.3	10.5
1	23	14	9.0	9.3
		13	9.2	8.7
		12	7.4	6.9
		11	8.0	8.3
		21	7.1	8.2
		22	7.2	6.9
		23	8.7	9.2
		24	9.3	9.6
1	24	14	9.0	10.1
		13	8.4	10.6
		12	7.4	8.2
		11	8.1	9.1
		21	7.9	7.7
		22	7.0	7.9
		23	8.7	9.2
		24	8.9	9.8
1	25	14	10.5	11.1
		13	10.2	10.6
		12	7.8	8.5
		11	9.3	10.4
		21	9.2	10.5
		22	7.8	8.2
		23	10.0	11.0
		24	9.9	10.6

Group	Case	tooth number	3 mm below CEJ (mm)	mid root (mm)
3	26	14	8.6	8.9
		13	7.5	8.1
		12	7.0	8.5
		11	8.6	10.3
		21	8.2	10.4
		22	7.5	8.7
		23	8.0	8.7
		24	9.7	9.4
1	27	14	7.1	7.2
		13	8.9	8.3
		12	6.2	6.7
		11	6.7	7.0
		21	7.1	6.5
		22	6.4	6.4
		23	8.2	8.5
		24	9.0	9.2
3	28	14	11.0	11.6
		13	9.7	10.5
		12	7.9	8.1
		11	8.2	10.6
		21	9.1	11.2
		22	7.3	9.6
		23	10.2	11.4
		24	10.2	12.0
1	29	14	7.9	8.7
		13	8.2	8.7
		12	6.7	6.4
		11	7.4	7.1
		21	7.8	7.1
		22	6.7	6.5
		23	7.9	7.8
		24	7.8	7.5
1	30	14	9.6	10.0
		13	7.8	9.0
		12	7.2	7.5
		11	8.1	9.2
		21	8.6	9.0
		22	7.7	8.0
		23	9.4	9.4
		24	8.8	10.0

Group	Case	tooth number	3 mm below CEJ (mm)	mid root (mm)
1	31	14	9.7	10.2
		13	10.1	9.1
		12	7.2	8.3
		11	8.4	9.7
		21	8.1	8.9
		22	8.3	8.5
		23	9.2	9.3
		24	9.6	10.1
3	32	14	9.8	10.3
		13	9.0	9.7
		12	7.5	7.6
		11	8.0	7.2
		21	8.0	8.2
		22	6.2	7.9
		23	9.0	8.6
		24	9.7	9.8
3	33	14	10.3	10.5
		13	9.8	11.1
		12	9.2	9.4
		11	9.9	9.9
		21	10.4	11.1
		22	8.8	9.8
		23	9.9	12.3
		24	10.5	11.1
1	34	14	10.4	10.4
		13	7.6	8.2
		12	7.2	7.2
		11	7.4	7.4
		21	7.6	8.4
		22	7.0	7.8
		23	8.2	8.1
		24	10.4	10.6
4	35	14	8.0	9.2
		13	9.7	11.7
		12	7.6	8.3
		11	8.2	9.5
		21	8.4	10.6
		22	7.6	9.4
		23	9.1	10.5
		24	8.5	9.0

Group	Case	tooth number	3 mm below CEJ (mm)	mid root (mm)
3	36	14	9.4	11.2
		13	9.1	12.8
		12	7.3	7.9
		11	8.0	9.4
		21	7.7	8.7
		22	7.6	8.5
		23	9.0	9.9
		24	9.4	10.0
3	37	14	10.2	10.1
		13	9.3	9.5
		12	8.4	7.4
		11	8.3	8.5
		21	8.5	8.8
		22	8.3	8.7
		23	8.7	9.1
		24	9.7	10.3
1	38	14	9.9	10.2
		13	7.9	9.3
		12	7.7	7.9
		11	8.3	10.0
		21	8.8	10.0
		22	7.2	8.2
		23	8.1	8.7
		24	10.1	10.3
1	39	14	10.9	12.8
		13	10.9	12.0
		12	6.4	10.1
		11	8.0	9.8
		21	7.8	9.4
		22	7.0	10.0
		23	11.5	12.4
		24	10.9	11.6
3	40	14	10.6	10.7
		13	9.7	10.5
		12	8.8	8.1
		11	8.4	8.8
		21	8.6	8.8
		22	8.5	8.3
		23	9.4	10.0
		24	10.4	10.4

Group	Case	tooth number	3 mm below CEJ (mm)	mid root (mm)
3	41	14	9.6	9.5
		13	8.6	10.3
		12	7.4	7.3
		11	7.7	7.3
		21	7.8	7.3
		22	7.2	7.0
		23	9.1	10.4
		24	9.8	9.2
4	42	14	10.4	11.3
		13	8.7	10.2
		12	7.3	8.1
		11	6.9	8.3
		21	7.0	8.5
		22	7.4	8.1
		23	9.1	10.5
		24	9.2	10.8
3	43	14	10.0	10.1
		13	10.0	15.6
		12	8.4	9.6
		11	9.2	9.8
		21	8.4	9.3
		22	7.8	8.8
		23	9.4	10.0
		24	8.9	9.7
3	44	14	9.2	10.2
		13	9.5	9.8
		12	8.0	8.0
		11	8.6	8.0
		21	8.3	8.3
		22	7.9	8.4
		23	9.8	10.2
		24	10.3	10.0
1	45	14	10.0	9.2
		13	9.7	9.2
		12	8.3	8.3
		11	8.7	7.5
		21	8.3	8.0
		22	7.7	7.2
		23	9.8	9.7
		24	10.2	9.5

Group	Case	tooth number	3 mm below CEJ (mm)	mid root (mm)
3	46	14	11.2	11.2
		13	9.0	11.4
		12	7.8	8.2
		11	8.9	10.1
		21	8.6	9.5
		22	8.1	8.3
		23	9.8	11.4
		24	10.2	10.8
3	47	14	11.6	11.8
		13	10.4	11.2
		12	8.6	10.1
		11	9.6	11.6
		21	9.8	12.2
		22	9.1	11.5
		23	10.7	10.9
		24	11.2	12.2
1	48	14	9.3	8.9
		13	7.8	7.4
		12	7.5	7.5
		11	7.8	8.4
		21	7.9	8.7
		22	7.6	7.6
		23	8.1	7.4
		24	9.2	9.2
1	49	14	8.6	10.9
		13	8.0	7.2
		12	7.2	7.5
		11	7.2	7.4
		21	7.0	7.2
		22	7.7	8.5
		23	8.3	9.7
		24	9.0	10.2
3	50	14	8.7	9.8
		13	8.7	10.2
		12	7.5	7.4
		11	8.1	8.3
		21	7.9	8.8
		22	7.5	7.4
		23	9.1	9.4
		24	9.6	9.1

Group	Case	tooth number	3 mm below CEJ (mm)	mid root (mm)
1	51	14	10.1	9.7
		13	8.5	8.8
		12	7.4	7.1
		11	8.1	8.0
		21	8.1	8.0
		22	7.3	7.1
		23	9.7	10.5
		24	10.1	10.3
3	52	14	11.5	12.3
		13	10.6	10.8
		12	7.7	7.2
		11	8.1	7.6
		21	8.8	7.7
		22	8.5	7.2
		23	10.1	9.4
		24	12.1	10.6
1	53	14	10.0	8.8
		13	8.4	7.7
		12	6.9	7.7
		11	8.4	7.7
		21	8.4	7.7
		22	7.3	7.3
		23	8.2	8.0
		24	9.2	8.9
1	54	14	9.1	9.1
		13	8.6	8.8
		12	7.2	6.6
		11	6.7	7.5
		21	7.7	8.4
		22	7.0	7.4
		23	8.7	8.8
		24	10.0	10.6
1	55	14	8.5	9.7
		13	8.7	8.3
		12	7.0	6.9
		11	6.8	7.5
		21	6.9	8.0
		22	6.9	7.2
		23	7.9	8.7
		24	8.9	9.9

Group	Case	tooth number	3 mm below CEJ (mm)	mid root (mm)
2	56	14	10.0	9.8
		13	9.3	8.9
		12	6.7	6.3
		11	8.0	7.5
		21	7.8	7.7
		22	6.8	6.6
		23	8.9	7.8
		24	9.4	9.0
3	57	14	9.0	9.4
		13	8.2	8.3
		12	7.0	6.8
		11	7.3	7.6
		21	6.9	7.7
		22	6.2	5.9
		23	7.4	8.0
		24	8.6	8.5
4	58	14	10.9	11.4
		13	10.2	10.4
		12	7.5	8.8
		11	8.2	8.4
		21	8.0	8.5
		22	8.0	9.0
		23	10.4	9.9
		24	10.1	9.9
3	59	14	10.9	11.2
		13	9.1	9.8
		12	7.4	7.4
		11	8.0	8.5
		21	7.7	8.0
		22	7.2	7.2
		23	9.4	10.1
		24	9.9	9.4
4	60	14	9.6	12.0
		13	8.8	10.1
		12	7.4	8.2
		11	9.0	10.1
		21	8.6	9.8
		22	8.1	8.3
		23	10.6	11.7
		24	10.4	11.2

Group	Case	tooth number	3 mm below CEJ (mm)	mid root (mm)
4	61	14	9.3	10.2
		13	8.5	9.1
		12	7.4	6.9
		11	7.7	8.0
		21	7.5	7.7
		22	7.5	7.4
		23	9.0	9.0
		24	9.3	9.6
4	62	14	10.4	11.0
		13	9.0	9.9
		12	7.7	7.8
		11	7.5	8.2
		21	8.3	9.0
		22	7.6	7.2
		23	9.8	9.9
		24	9.0	9.0
2	63	14	9.3	9.9
		13	7.8	8.8
		12	5.8	5.9
		11	6.6	6.6
		21	7.0	7.0
		22	6.9	6.4
		23	9.9	10.4
		24	9.3	9.6
2	64	14	11.7	12.0
		13	10.1	11.0
		12	8.2	8.0
		11	8.8	9.1
		21	9.0	9.0
		22	8.0	7.7
		23	10.1	10.1
		24	10.7	12.2
3	65	14	9.3	9.8
		13	9.1	9.0
		12	7.4	8.3
		11	8.6	9.9
		21	8.6	10.4
		22	7.8	8.5
		23	9.6	9.9
		24	10.6	10.4

Group	Case	tooth number	3 mm below CEJ (mm)	mid root (mm)
2	66	14	8.8	10.4
		13	8.8	8.6
		12	7.7	6.9
		11	8.2	7.8
		21	8.2	7.2
		22	8.2	7.0
		23	8.8	8.9
		24	8.6	9.0
3	67	14	10.4	11.4
		13	9.8	11.2
		12	9.0	10.6
		11	8.6	9.3
		21	8.3	10.6
		22	8.2	8.8
		23	9.6	10.9
		24	9.4	11.2
2	68	14	11.0	11.7
		13	9.8	12.5
		12	7.7	7.7
		11	7.8	8.5
		21	7.5	8.2
		22	7.5	6.7
		23	10.7	12.0
		24	11.0	10.6
4	69	14	10.4	11.8
		13	11.5	13.1
		12	9.0	9.9
		11	10.1	10.6
		21	10.2	12.2
		22	8.6	9.9
		23	11.4	12.5
		24	10.6	11.7
4	70	14	8.8	9.0
		13	8.8	9.1
		12	6.2	6.4
		11	6.4	6.9
		21	6.9	6.2
		22	6.1	6.1
		23	8.2	9.8
		24	9.8	9.5

Group	Case	tooth number	3 mm below CEJ (mm)	mid root (mm)
4	71	14	9.9	9.8
		13	8.6	8.5
		12	6.5	6.4
		11	7.2	7.1
		21	7.4	7.6
		22	6.5	6.4
		23	8.2	8.1
		24	9.8	9.5
3	72	14	9.0	10.0
		13	8.2	7.8
		12	6.3	7.3
		11	7.8	8.1
		21	7.8	7.2
		22	6.0	6.8
		23	8.3	7.8
		24	9.0	10.0
2	73	14	9.3	9.4
		13	8.6	8.6
		12	7.0	6.8
		11	7.7	7.8
		21	7.8	7.8
		22	6.9	7.1
		23	8.8	8.8
		24	9.8	8.0
2	74	14	8.5	9.4
		13	6.2	6.2
		12	6.3	6.3
		11	6.9	6.5
		21	6.6	6.7
		22	5.5	5.5
		23	6.4	6.3
		24	8.2	8.3
4	75	14	10.6	10.1
		13	9.2	11.8
		12	7.4	8.0
		11	7.8	7.8
		21	7.6	7.4
		22	7.0	7.7
		23	9.4	11.5
		24	10.0	10.8

Group	Case	tooth number	3 mm below CEJ (mm)	mid root (mm)
3	76	14	10.1	9.8
		13	9.2	8.6
		12	7.8	8.2
		11	8.1	8.6
		21	8.5	9.0
		22	7.7	7.7
		23	9.4	9.6
		24	10.6	10.6
4	77	14	10.6	11.1
		13	11.2	12.6
		12	7.7	9.8
		11	7.8	9.4
		21	7.7	8.4
		22	8.1	8.7
		23	10.8	12.1
		24	10.2	10.6
3	78	14	8.0	8.3
		13	8.2	7.5
		12	6.6	6.5
		11	7.2	7.4
		21	7.0	7.3
		22	6.5	6.5
		23	8.4	8.3
		24	8.6	8.7
3	79	14	9.3	10.2
		13	7.9	7.8
		12	6.9	6.4
		11	6.9	6.8
		21	6.6	7.0
		22	7.0	7.0
		23	7.8	8.1
		24	8.6	9.4
1	80	14	11.0	9.9
		13	10.0	10.2
		12	8.2	8.0
		11	8.3	7.8
		21	8.2	8.4
		22	8.2	7.7
		23	9.9	10.1
		24	10.5	10.4

Group	Case	tooth number	3 mm below CEJ (mm)	mid root (mm)
1	81	14	8.7	9.1
		13	8.5	8.5
		12	6.6	7.0
		11	6.6	7.4
		21	6.9	6.8
		22	7.3	7.3
		23	8.2	7.9
		24	8.9	8.6
4	82	14	9.6	8.7
		13	9.0	9.4
		12	7.4	7.3
		11	8.1	7.7
		21	7.8	7.8
		22	7.0	7.1
		23	9.8	9.4
		24	9.1	8.4
2	83	14	9.4	8.5
		13	8.6	7.9
		12	5.9	5.4
		11	6.6	6.6
		21	6.5	6.2
		22	6.1	5.7
		23	8.6	8.2
		24	9.4	9.5
4	84	14	8.4	9.4
		13	9.4	9.9
		12	7.8	8.0
		11	7.7	8.1
		21	7.7	8.0
		22	7.6	7.6
		23	9.4	10.1
		24	8.5	8.9
2	85	14	10.9	11.5
		13	10.6	10.4
		12	7.5	7.3
		11	7.3	8.0
		21	7.3	7.3
		22	6.2	6.3
		23	11.0	10.5
		24	10.0	10.2

Group	Case	tooth number	3 mm below CEJ (mm)	mid root (mm)
4	86	14	10.1	11.4
		13	10.1	9.8
		12	7.4	8.3
		11	10.0	10.2
		21	9.0	8.9
		22	7.5	7.7
		23	8.8	9.3
		24	10.0	11.2
2	87	11	10.5	12.1
		13	10.8	13.0
		12	7.4	7.9
		11	8.5	9.5
		21	8.8	9.7
		22	7.4	7.8
		23	10.4	12.4
		24	10.5	12.2
1	88	11	10.3	10.0
		13	9.9	10.4
		12	7.2	7.3
		11	7.7	8.1
		21	7.9	7.8
		22	7.7	7.7
		23	9.2	9.8
		24	10.2	10.0
2	89	11	9.4	10.0
		13	9.7	9.5
		12	7.7	7.3
		11	8.1	8.1
		21	8.2	8.2
		22	7.8	7.3
		23	9.3	8.0
		24	9.8	8.2
3	90	11	9.6	10.5
		13	9.5	10.8
		12	7.8	8.4
		11	8.0	9.0
		21	8.2	9.2
		22	7.4	8.4
		23	9.7	10.6
		24	9.2	9.6

Group	Case	tooth number	3 mm below CEJ (mm)	mid root (mm)
3	91	11	9.9	9.7
		13	9.5	10.2
		12	7.5	7.5
		11	8.7	10.2
		21	7.8	8.6
		22	7.4	8.1
		23	9.4	10.7
		24	9.5	10.6
1	92	11	10.6	11.3
		13	10.2	10.3
		12	7.0	7.8
		11	8.2	8.9
		21	8.2	8.1
		22	7.0	7.4
		23	10.2	10.4
		24	9.7	10.4
3	93	11	10.2	10.9
		13	9.6	11.0
		12	6.5	6.0
		11	7.5	8.2
		21	7.1	7.9
		22	6.7	6.3
		23	10.2	11.9
		24	10.4	11.6
4	94	11	9.2	10.0
		13	10.1	10.9
		12	7.4	8.3
		11	9.0	8.8
		21	8.5	8.7
		22	7.4	8.0
		23	9.8	10.3
		24	9.0	9.7
2	95	11	9.6	9.6
		13	9.9	9.2
		12	6.6	6.6
		11	7.6	7.0
		21	8.2	8.4
		22	6.7	6.8
		23	9.7	9.8
		24	9.8	9.9

Group	Case	tooth number	3 mm below CEJ (mm)	mid root (mm)
4	96	11	10.3	11.0
		13	9.1	10.1
		12	6.6	6.8
		11	6.9	8.2
		21	6.6	8.4
		22	6.5	6.6
		23	9.6	11.7
		24	9.3	10.6
4	97	11	10.3	10.8
		13	10.1	9.8
		12	7.8	7.8
		11	8.5	8.2
		21	8.3	8.2
		22	7.4	7.4
		23	9.5	9.5
		24	9.8	10.5
4	98	11	9.5	11.3
		13	10.7	13.0
		12	8.4	9.9
		11	9.7	10.4
		21	9.2	9.8
		22	8.1	9.2
		23	10.6	12.2
		24	10.8	11.1
4	99	11	10.0	11.3
		13	11.2	11.7
		12	7.7	7.0
		11	8.3	8.0
		21	8.7	8.9
		22	9.9	8.9
		23	11.9	13.0
		24	11.3	11.5
4	100	11	11.4	11.8
		13	10.6	10.6
		12	8.0	8.3
		11	9.0	9.6
		21	9.1	9.5
		22	8.3	9.6
		23	10.6	12.0
		24	11.4	11.4

Group	Case	tooth number	3 mm below CEJ (mm)	mid root (mm)
2	101	11	9.8	11.3
		13	9.6	10.5
		12	6.9	6.5
		11	7.4	7.8
		21	7.4	8.2
		22	6.7	6.6
		23	9.3	10.3
		24	10.2	10.7
2	102	11	9.2	9.9
		13	7.8	9.0
		12	6.5	6.6
		11	7.3	7.7
		21	7.3	7.4
		22	6.5	6.0
		23	7.6	8.5
		24	7.3	7.8
1	103	11	9.8	10.0
		13	9.9	9.5
		12	7.8	7.6
		11	9.4	9.5
		21	8.8	8.9
		22	7.9	7.1
		23	10.5	10.4
		24	10.2	10.2
4	104	11	11.1	11.7
		13	10.2	11.0
		12	7.8	8.1
		11	7.9	8.1
		21	7.8	8.5
		22	7.5	8.2
		23	10.3	10.8
		24	11.0	12.0
2	105	11	10.5	10.6
		13	8.5	8.2
		12	5.8	5.5
		11	6.9	6.6
		21	7.2	6.6
		22	6.0	6.2
		23	8.6	9.0
		24	10.0	10.2

Group	Case	tooth number	3 mm below CEJ (mm)	mid root (mm)
1	106	11	10.2	10.6
		13	8.9	9.9
		12	7.1	7.5
		11	7.9	8.5
		21	7.5	7.8
		22	6.9	7.8
		23	9.9	11.0
		24	10.6	10.1
3	107	11	8.9	8.3
		13	9.0	9.9
		12	7.6	8.3
		11	8.4	8.6
		21	8.8	10.0
		22	8.2	8.2
		23	10.0	9.8
		24	9.0	8.9
1	108	11	8.7	9.0
		13	8.4	9.3
		12	7.4	7.7
		11	8.0	7.4
		21	7.6	7.6
		22	7.1	7.4
		23	9.0	8.2
		24	7.9	8.7
3	109	11	8.3	8.4
		13	8.4	8.5
		12	5.9	7.0
		11	6.6	7.5
		21	7.2	7.9
		22	5.8	5.8
		23	8.2	7.4
		24	8.2	8.2
4	110	11	9.0	6.9
		13	8.5	8.7
		12	6.8	6.9
		11	7.8	7.5
		21	7.4	8.2
		22	6.7	6.7
		23	7.7	8.2
		24	9.4	9.3

Group	Case	tooth number	3 mm below CEJ (mm)	mid root (mm)
4	111	11	11.2	11.5
		13	10.5	11.1
		12	7.6	7.5
		11	9.6	9.7
		21	9.2	9.9
		22	7.7	7.8
		23	11.4	12.2
		24	11.3	11.5
3	112	11	10.4	10.7
		13	10.7	10.8
		12	8.0	7.7
		11	8.2	7.8
		21	8.3	7.9
		22	7.6	7.7
		23	10.2	10.6
		24	9.8	9.5
1	113	11	9.5	10.8
		13	8.6	8.8
		12	7.6	6.7
		11	8.3	8.7
		21	8.5	9.1
		22	7.3	7.9
		23	8.8	9.4
		24	10.8	11.0

VITA

Name Atcharee Bulyalert

Date of birth July 19 1983

Place of birth Chiangmai, Thailand

Address 5 Somdejchaopraya 17, Somdejchaopraya Rd., Klongsan, BKK, 10600, Thailand

Instution attended

- 2013-2013 Preceptorship Rrogram in Advanced Implantology from University of California, Los Angeles School of Dentistry, California, USA