Reduction of Mandibular Incisors Proclination during Leveling and Aligning Phase in Non-extraction Orthodontic Treatment

Pornpat Theerasopon

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Oral Health Sciences

Prince of Songkla University

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Major Program	Oral Health Sciences

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I hereby certify that this work has not been accepted in substance for any degree, and is not being currently submitted in candidature for any degree.

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ชื่อวิทยานิพนธ์ การลดยื่นของฟันตัดล่างในขั้นตอนการปรับระดับและเรียงฟันในการรักษาทางทันตกรรมจัดฟันโดยไม่ถอนฟัน

ผู้เขียน นายพรพัฒน์ ธีรโสภณ

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บทคัดย่อ

การปรับระดับฟันในฟันล่างที่มีโค้งของสปีลึกด้วยลวดนิกเกิลไทเทเนียม จะมีแรงกดลงทางปลายรากฟันกระทำต่อฟันตัดล่าง ซึ่งแรงดังกล่าวมีตำแหน่งของแรงอยู่หน้าต่อจุดศูนย์กลางฟัน ส่งผลให้ฟันตัดล่างเคลื่อนที่แบบล้มเอียงไปทางด้านริมฝีปาก **<u>วัตถุประสงค์</u>** เพื่อเปรียบเทียบผลจากแรงกดในลวดนิกเกิลไทเทเนียมที่มีรูปร่างของหน้าตัดลวดแตกต่างกัน โดยการวิเคราะห์ทางไฟไนต์เอลิเมนต์ และเพื่อศึกษาว่าการแยกขั้นตอนการเรียงฟันและปรับระดับฟัน จะช่วยให้ผลการรักษาทางทันตกรรมจัดฟันในระยะแรกดีขึ้น และฟันตัดล่างเอียงไปทางด้านริมฝีปากลดลงเมื่อเปรียบเทียบกับกลุ่มที่รักษาด้วยวิธีปกติหรือไม่ **<u>วัสดุและวิธีการ</u>** สร้างแบบจำลองทางไฟไนต์เอลิเมนต์ของขากรรไกรล่างซึ่งประกอบด้วยฟันล่างทุกซี่ เนื้อเยื่อปริทันต์ และกระดูกเบ้าฟันโดยใช้ภาพรังสีส่วนตัดอาศัยคอมพิวเตอร์ชนิดโคนบีมของผู้ป่วย รวมทั้งสร้างแบร็กเก็ตท่อด้านแก้ม และลวดทางทันตกรรมจัดฟัน วิเคราะห์ผลทางไฟไนต์เอลิเมนต์หลังให้แรงกดในระยะไม่เกิน 0.2 มิลลิเมตรจากลวดนิกเกิลไทเทเนียม 3 ขนาด ได้แก่ 0.016 นิ้ว, 0.016 x 0.016 นิ้ว และ 0.016 x 0.022 นิ้ว เปรียบเทียบความเครียดที่ตำแหน่งรากฟัน อวัยวะปริทันต์ และระยะการเคลื่อนที่ของฟัน และศึกษาเปรียบเทียบการแยกขั้นตอนการเรียงฟันด้วยลวดกลมนิกเกิลไทเทเนียมที่มีโค้งของสปีและปรับระดับฟันด้วยลวดเหลี่ยมในกลุ่มทดลอง กับ การเรียงฟันและปรับระดับฟันด้วยวิธีปกติในกลุ่มควบคุมจนถึงลวดเหลี่ยม ในผู้ป่วยที่มีโครงสร้างกระดูกขากรรไกรแบบที่ 1 จำนวน 30 รายที่มีฟันหน้าซ้อนเก 3-5 มิลลิเมตร และมีโค้งของสปี 3-4 มิลลิเมตร เปรียบเทียบตำแหน่ง และการเอียงตัวของฟันโดยการวิเคราะห์ภาพรังสีกะโหลกศีรษะด้านข้าง และเปรียบเทียบปริมาณโค้งของสปีที่เปลี่ยนแปลงด้วยการวิเคราะห์แบบจำลองฟันล่าง **<u>ผลการศึกษา</u>** ผลจากแรงกดในลวดนิกเกิลไทเทเนียมพบความเครียดสูงสุดในตำแหน่งคอฟันทั้งในด้านริมฝีปาก และด้านลิ้น โดยความเครียดของด้านริมฝีปากมีค่ามากกว่าด้านลิ้น และอยู่ในตำแหน่งที่สูงกว่าในทุกโมเดล เมื่อเปรียบเทียบทั้ง 3 โมเดล พบลวดกลมมีความเครียดสูงสุด ซึ่ง

มากกว่าลวดเหลี่ยม 0.016 x 0.016 นิ้ว และ 0.016 x 0.022 นิ้ว และพบการเคลื่อนที่ฟันไปทางด้านริมฝีปากมากที่สุดเกิดขึ้นในลวดกลมเช่นกัน การศึกษาทางคลินิกไม่พบความแตกต่างทางสถิติของตำแหน่งฟันไปแนวหน้า-หลัง (*P*>0.05) แต่พบกลุ่มควบคุมมีฟันตัดเอียงไปทางด้านริมฝีปากเพิ่มขึ้นมากกว่าในกลุ่มทดลอง (*P*<0.0001) ปริมาณฟันซ้อนเกลดลงในทั้งสองกลุ่ม แต่ปริมาณโค้งของสปีในกลุ่มทดลองลดลง 2.88 มิลลิเมตร ส่วนในกลุ่มควบคุมลดลง 1.69 มิลลิเมตร (*P*<0.0001) ในกลุ่มทดลองใช้เวลาในการรักษามากกว่ากลุ่มควบคุม 8.50 สัปดาห์ (*P*<0.0001) **สรุป:** แรงกดฟันตัดล่างในลวดกลมทำให้เกิดความเครียดที่รากฟันและอวัยวะปริทันต์ทางด้านริมฝีปาก รวมถึงระยะเคลื่อนที่ไปทางด้านริมฝีปากมากกว่าในลวดเหลี่ยม และการปรับระดับฟันด้วยลวดเหลี่ยมในกลุ่มทดลองพบมีการเอียงตัวของฟันตัดล่างลดลง

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ABSTRACT

Tooth leveling in mandibular teeth with deep curve of Spee by nickel titanium archwires found intrusive forces at mandibular incisors. These forces which applied labial to center of resistance of teeth caused labial tipping of mandibular incisors occurred. **Objectives** To compare the results of intrusive forces from different shapes nickel titanium archwires cross-sections by finite element analysis and to determine whether separating the alignment and leveling phases can improve the outcome of the early stages of treatment and lead to less proclination of the mandibular incisors compares to conventional technique. **Materials and Methods** Construction of finite element model of mandible with all teeth, periodontal tissues and alveolar bone from cone beam computed tomography of selected patient, and construction of brackets, buccal tubes and orthodontic archwires. Finite element analysis was done by applying intrusive forces limited for 0.2 mm from 3 different shapes nickel titanium archwires of 0.016-inch, 0.016 x 0.016-inch and 0.016 x 0.022-inch archwires. Comparison of stress at root surfaces, periodontal tissues and tooth displacement. And comparison between separating of alignment by round nickel titanium archwires with accentuated curve of Spee and leveling by rectangular archwire in experimental group to the conventional alignment and leveling progressively to rectangular archwires in control group. This study was done in 30 skeletal Class I patients with 3-5 mm of anterior crowding and 3-4 mm of curve of Spee depth. Determined changes of mandibular incisor position and inclination with lateral cephalometric analysis and compared curve of Spee depth changes by mandibular teeth model analysis. **Results** After applied intrusive forces from nickel titanium archwires found the highest stress at the cervical areas in both labial and lingual surfaces but much higher stress and higher vertical level were found on labial surfaces in all models.

Comparison among 3 models found the highest stress in round archwire model than square and rectangular archwire models. The highest labial displacement also found in round archwire model. The clinical study found no significant difference of antero-posterior mandibular incisor position (*P*>0.05). But control group found more proclination of mandibular incisors than experimental group (*P*<0.0001). Crowding was resolved in both group but curve of Spee reduction in experimental group was 2.88 mm which higher than control group of 1.69 mm (*P*<0.0001). Experimental group found longer treatment time than control group of 8.50 weeks (*P*<0.0001). **Conclusion** Intrusive forces from round archwire produced higher stress on the root surfaces and periodontal tissues at labial side, including more labial displacement. Tooth leveling with rectangular archwire in experimental group found less proclination of mandibular incisors.

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Pornpat Theerasopon

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LISTS OF ABBREVIATIONS AND SYMBOLS

U.S.	=	the United States of America
%	=	percent
mm	=	millimeters
et al	=	and others
^{o}	=	degree
IMPA	=	incisor-mandibular plane angle
NT	=	nickel titanium
”	=	inch (es)
II	=	Irregularity index
TSASD	=	tooth size-arch size discrepancy
cN	=	centi newton
N	=	number of sample
>	=	more than
<	=	less than
PDL	=	periodontal tissues
MPa	=	mega pascal
COS	=	curve of Spee

CHAPTER 1

INTRODUCTION

Background and rationale

Orthodontic treatment for crowding correction by non-extraction approach is resulted in all dimensional expansion of all teeth consists of lateral expansion of posterior teeth and proclination of anterior teeth which can gain more spaces for tooth alignment and leveling within the alveolar ridge. These situations happen since the first archwire use in the early stage for corrective orthodontic treatment which is known as leveling and aligning phase. Therefore, factors which contribute to tooth expansion in all dimensions are mainly the amount of tooth crowding and the depth of the curve of Spee.

Comparison among each area, labial surface of mandibular anterior region was pointed as the area that should be the most concerned especially in patients who have narrow alveolar bone support which is the high risk for alveolar bone dehiscence. Tooth leveling and aligning affected in labial tipping of incisors due to the mechanic use which prone to produce high stress at labial alveolar crest which may lead to alveolar dehiscence and gingival recession. Furthermore, proclined lower incisors still affects the dental appearance and also worsen the soft tissue profile.

This study aimed to introduce the new technique for tooth leveling and aligning by attempting to separate the aligning phase from leveling phase for controlling the mechanical effect of treatment in leveling phase that would cause proclination of lower incisors. The teeth were firstly aligned while keeping the original curve of Spee by using shallow reverse curve of Spee nickel titanium archwire in upside down positioned until well-aligned of teeth was achieved, then leveling the teeth by reducing the curve of Spee in rectangular beta-titanium archwire which began with passive the presented curve of Spee and gradually flatten the curve until straight archwire was obtained. Therefore, less change in mandibular incisor inclination was the objectives of this study.

Review of Literatures

1. Dental crowding

Dental crowding was cited as the most frequent problem which made patients seek for orthodontic therapy.[1-3] From the Third National Health and Nutrition Examination Survey in 1988–1994 or NHANES III which was the first U.S. survey of dental characteristics among American population showed that untreated individuals had mandibular incisors crowding increased with age especially during early adulthood before twenties.[4] The survey found more than a half of untreated U.S. population between 15 and 50 years of age had mild to moderate incisor irregularity and only 17% of this had well-aligned teeth.

Concordantly with several survey studies which reported that more than a half of people who were seeking for orthodontic treatment focused on dental appearance[5] and marked tooth irregularity was the main problem range from 52 to 72 percent.[6-9] Slightly more than a half from a cross-sectional survey of 312 patients who had orthodontic treatment rated dental crowding as a reason that made them seek for the treatment.[7] Approximately the same percent of participants who were on the waiting list for orthodontic treatment and completed the questionnaire rated their dental appearance as bad and felt that dental appearance can be improved their esthetic concern.[8] In the same way, the survey study in Kuala Lumpur with 250 individuals aged 10-35 year-old said that 72% of them had tooth irregularity.[6] These were supported by the study of the affected factors to dental esthetic by 60 laypersons with 45 frontal and right lateral view of intraoral photographs in maximum intercuspation claimed that crowding was the best predicted variable that effected dental attractiveness.[9]

2. Facial profile influences extraction or non-extraction orthodontic treatment plan

Although the most frequency of clinician decision on extraction reasons was tooth irregularity over 73%[10], but from several literatures concluded that the facial profile also be another factor which contributes to the decision for extraction or not.[10-12]

The effect of extraction on facial esthetics had much concern while recent orthodontic mechanics were available making class I crowding can be treated in either extraction or non-extraction.[13] These reasons caused the number of tooth extraction for orthodontic treatment decreased.[13-16] Most of literatures[17-29] which studied facial profile changed following premolars extraction and anterior teeth retraction in Caucasian, African and Asian concluded that there was a positive correlation between incisors retraction subsequent to tooth extraction and lip retrusion significantly. Jamilian *et al*[24] found the significant positive correlation (r=0.72). However, the ratio of lip retrusion among different studies were varied. The study of Young and Smith[28] agreed with Luppanapornlarp and Johnston Jr[29] that lip retruded about 2-3 mm after premolars extraction cases. Some studies reported the ratio between lingual movement of lower incisors and lower lip change horizontally range from 1 to 3 mm[24, 27] of incisors retraction on 1 mm of lip retrusion. While Erdinc *et al*[27] revealed that degree of flatten lip after incisors retraction was individual. They stated the average ratio of 3:1 but noted that there was no such correlation in thick lips and high correlation in thin lips. Thus, he concluded that lip thickness is the one factor for this relationship.

Comparing studies[12, 19, 22, 23, 25, 30, 31] on the effect of extraction versus non-extraction on facial profile showed premolars extraction group had greater retruded in facial profile more than non-extraction group. Not only premolar extraction influenced on lip retrusion but lower incisor extraction did too. Færøvig and Zachrisson[12] studied the effect of lower incisor extraction in class III non-growing patients treated with fixed orthodontic appliance and found that with mean irregularity index of 1.1 mm, lower incisor was retracted 1.2 mm (L1/APog) affected lower lip retruded (LL/E-plane) in the same amount. Thus, lips are influenced by the teeth and lip retrusion is usually the consequence of orthodontic treatment with extraction which is quite irreversible and literature[32] proved the antero-posteior lip position usually retrude with age, thereby patients who present without obviously lip prominence is harmless to treat by non-extraction treatment.

3. Non-extraction orthodontic treatment

All literatures [13-15] that reviewed the frequency of extraction from the past until present concluded that there was an increasing rate of non-extraction orthodontic treatment and decreasing in extraction simultaneously. Proffit[13] published the 40 years review of the extraction frequency at the orthodontic clinic, University of North Carolina from 1953 to 1993 resulted that overall extraction percentage was 30% in 1953, then increased to the peak at 76% in 15 years later and declined to 28% in 1993. He stated that the increasing tendency may due to the introduction of Begg technique in 1960s which promoted extraction treatment and declined after the peak period because many studies showed that extraction did not guarantee the stability.[33] Another study of 1,484 records from 1980 to 2011 at the orthodontic clinic of Universidade Estadual do Rio de Janeiro in Brazil found that 54.2% of all cases in this study treated with non-extraction and the extraction frequency decreased from 61.6% in 1980 to 40.8% in 2011 while non-extraction treatment increased in opposite direction. If focused on Angle's classification, the class I malocclusion found to be the lowest percentages of extraction treatment for only 43% insignificantly while no sex different among all types of patients.[15] Another study in Brazil at the orthodontic department, Bauru Dental School, University of São Paulo recorded 3,413 patients from 1973-2007 found similar change which was the dramatic increasing frequency of non-extraction from 14.29% in 1973-1977 to 54.55% in 2003-2007.[14] The results showed that at present time, more than a half of patients have been treated with non-extraction approach. The authors gave the explanation for this paradigm shift from extraction to non-extraction mainly due to the variety of technique available for correcting malocclusion and also the concern of facial profile after extraction.[13] Furthermore, the stability concern still be one of the reason. Previously, posterior segment expansion in non-extraction treatment was believed in the cause of relapse tendency[34] which might cause orthodontists preferred extraction. But Little[16] studied the relapse and reported that orthodontic treatment with extraction did not guarantee the stability resulted from his study of 31 cases with mean of irregularity index 7.41 mm treated with 4 premolar extraction to minimal irregularity (mean 1.66 mm) found that after 10 years retention the mean irregularity index increased approximately 5 mm and plus a 1 mm more for 20 years retention. He concluded that there were only 10 percent remained clinically acceptable alignment of mandibular teeth after 20 years retention followed orthodontically four premolar extracted treatment. The cause of such relapse may due to the remodeling of periodontal tissues.[35]

The confirmation of rising in non-extraction treatment found in a survey study[36] of 992 members of the American Association of Orthodontists revealed that the increasing years of clinician experiences made them push the non-extraction envelope wider and the slightly more lip and tooth protrusion seem to be an acceptable treatment purpose.

There were the evidences that non-extraction can preserve fullness of lips compared to extraction procedure. Bishara *et al*[25] compared lip position between extraction and non-extraction in class II division 1 patients by using lateral cephalograph with soft tissue pronasale (Pr) and soft tissue pogonion (Pog') as references to evaluate lower lip position. They found that lower lip retruded 3.9±2.0 mm in extraction group compared to protrusion of 0.8±2.0 mm in non-extraction group in male subjects with statistically significant difference while retrusion of 3.0±1.6 mm in extraction group and protrusion of 0.2±1.7 mm in non-extraction group were found in female subjects with statistically significant difference.

4. Tooth dimension changes from non-extraction orthodontic treatment

The major change of tooth position begins since the first phase of comprehensive orthodontic treatment, named leveling and aligning phase. This step has two main objectives which are to level the vertical uneven of teeth and to arrange teeth with malposition into alignment.

Weinberg and Sadowsky[37] proposed that 52% of crowding correction was accounted for an increase in arch perimeter concurrent with Fleming[38] who concluded his study that greater correction of crowding resulted in more proclination and also arch expansion for increasing the arch perimeter.

There were many studies that attempted to calculate the inclination change of lower incisors or amount of buccal segments expansion in related to the degree of crowding correction and flattening of the curve of Spee. McLaughlin[39] suggested that every 1 mm of crowding alleviation, incisors will be proclined 1.25^{O} and Sadowsky[40] claimed that solving each millimeter of dental crowding should resulted in mandibular incisors advanced by 0.5 mm (L1-APog). Conversely, the study of relationship between dental crowding and proclination of lower incisors in 2016[41] found tip of mandibular incisor moved forward (L1-APog) only 0.19 mm from every millimeter of crowding alleviation (R^2 = 0.1797) and lower incisor proclination 0.52^{O} (IMPA) for each millimeter of correction (R^2 = 0.0939). Nevertherless, the R^2 of these were low means that the result cannot be used as the good predictive tools. The result of such predictable linear relationships among different studies were vary because of the limitation in the retrospective study design effected the variety types of included subjects and different methodologies. For example, Yitschaky *et al*[41] studied in non-extraction patients with different bracket types and also pooled of patients with both crowding and spacing in lower arch, the tooth size-arch length discrepancy were range from -10.9 to 9.1 with average of 1.2±3.2 before treatment. In several literatures[41, 42] studied in growing patients which still have change in arch length. These factors might effect in the variation of the result.

Pandis *et al*[42] constructed the prospective study in 50 non-extraction patients with irregularity index greater than 2.5 to evaluate the relationship between the leveling of the curve of Spee and proclination of mandibular incisors. The regression analysis found IMPA was a significant predictor for curve of Spee leveling and the increase of lower incisor inclination for 4^{O} can be expected when each 1 mm is levelled.

The mathematical model of mandibular arch showed that combination of canine and molar expansion could increase the arch perimeter slightly less than incisor expansion alone.[43] In order to expand 1 mm of canine and molar width, the arch perimeter will increase 0.93 mm while 1 mm of incisor expansion effects 1.04 mm of increased arch perimeter. Although the slightly greater increment of arch perimeter gaining while increase the amount of expansion, if 5 mm of increased arch perimeter are needed, the canine-molar would be expanded nearly 5 mm while incisor expansion alone would be expand only a little more than 4 mm, but the different of periodontal tissue around incisor teeth especially lower incisor area and the posterior teeth should mentioned.

Tooth movement is limited by the physical environment around the teeth and position of mandibular incisors were known as the key to achieve good facial esthetic and treatment stability.[44-48] Thus, labial movement of mandibular incisors was advised only when its position are behind the expected position. But orthodontic treatment is commonly found anterior position of teeth[49] especially in crowding cases which treated by non-extraction of teeth[50] because the spaces for correction of crowded teeth gain from buccally position of posterior teeth along with labial tipping of anterior teeth. Anterior position of incisors causes the force concentration to the labial alveolar crest that seem to be the high force exerts to the small area of bone crest or high force per square millimeter which may affect the health of alveolar bone and periodontal tissue and can lead to labial bone dehiscence.[51]

Lower incisors flaring has been markedly observed since the initial phase of orthodontic treatment when leveling and aligning the teeth.[52] Coincidently with the laboratory study[53] of different arch form shapes of superelastic NiTi wire supported that the increase in lower incisor inclination occurred during leveling and aligning phase and the statistically significant change was found marked proclination in the initial archwires use which were 0.014-inch NiTi wire, regardless in any arch form shapes. This situation occurs due to crowded teeth was presented and high flexibility archwires are universally use in the initial phase. The increase in archwire length is required to ligate on all teeth, then the memory effect of the wire produces the buccal and labial movement of teeth.

The increased in mandibular teeth inclination from the treatment change and post-retention period in each clinical studies are shown in table 1.

Table 1 Crowding and mandibular incisor inclination changes at pre-, post-treatment and post-retention

Study	N	Crowding	Pre-treatment IMPA	Post-treatment IMPA	Post-retention IMPA (Retention period)
Paquette *et al*, 1992[26]	30	II 5.1 mm	91.3^{O}	99.7^{O}	96.2^{O} (14.49 years)
Luppanapornlarp and Johnston, 1993[29]	29	II 2.9 mm	94.9^{O}	100.0^{O}	96.0^{O} (15.3 years)
Bishara *et al*, 1997[25]	46	TSALD 1.55	97.0^{O}	103.1^{O}	101.2^{O} (2.1 years)
Erdinc *et al*, 2007[27]	49	II 2.38 mm	94.92±7.24^{O}	100.56±7.73^{O}	97.78±7.43^{O} (4.7 years)
Pandis *et al*, 2007[54]	54	II 5.43 mm	94.70±6.98^{O}	101.50±8.10^{O}	-

In vertical dimension, leveling the curve of Spee resulted in incisor intrusion and extrusion of premolars and molars. Shannon and Nanda[55] evaluated the treatment change of lower teeth with average of 4.42±3.33 mm of crowding correction and 1.60±1.94 mm of curve of Spee leveling found lower central incisor intrusion 0.20±2.28 mm and extrusion of first premolar, second premolar, first molar and second molar in 1.44, 2.66, 2.33 and 1.65 respectively. Thus, the main change when leveling teeth was the extrusion of posterior teeth with minimal intrusion of incisors.

5. Factors affected lower incisor proclination

Curve of Spee

The curve of Spee is the naturally occurring phenomenon, firstly proposed by Spee[56] who studied path of mandibular movement in dry skulls and he defined it as the concave curvature of the occlusal surfaces of all teeth from mandibular second molar to incisal edges of mandibular incisors and the anterior path of condyle along with the articular eminence as the same surface of a cylinder perpendicular to the midsaggital plane. The center of this cylinder located in the midorbital plane with a radius of 6.5 to 7 centimetres.

However, clinically in orthodontics, curve of Spee was defined as the depth of occlusal curvature of mandibular teeth in tangent to the flat plane from buccal cusp tip of the posterior molar to the incisal edge of mandibular incisors in saggital plane. Marshall *et al*[57] studied the development of curve of Spee by recording the study models of the selected subjects from Iowa Facial Growth Study in deciduous dentition at age 4 years to permanent dentition at 26 years old. The result of this study found that there was nearly flat curve of Spee in deciduous dentition about a quarter of millimeter. At the mean age of 6.91 years of age, the depth of curve of Spee increased significantly to 1.32 mm corresponding with the eruption of the first permanent mandibular molars and lower incisors. Then, the curve of Spee was maintained with slightly decreased until the eruption of mandibular permanent second molars at the mean age of 12.38 years, the mean depth of this curve was further increased to 2.17 mm and slightly decreased again to 2.02 mm at adult. The study found no significant difference among the right and left sides or the sex difference. After the age 26 years, there were very few change of the depth of curve of Spee less than 0.05 mm and would be clinically insignificant of the changing amount.

From Andrews's study of 120 nonorthodontic patients with normal occlusion and proposed as six keys to normal occlusion, the sixth key stated that normal occlusal plane ranged from slight to flat curve of Spee so he believed that the flat curve of Spee should be treatment goal. In generally, the theory[58] said that 1 mm of additional arch circumference is required to level each millimetre of the curve of Spee. But recent literatures found less than 1 mm of arch perimeter needed for 1 mm of leveling the curve of Spee.[59-61]

A mathematical model[60] for analysing arch length requirement for leveling the curve of Spee calculated the arch circumference of zero curve of Spee compared with the presented curve in various degrees and found a non-linear relationship between these two variables but less than one to one for every millimeters of flattening the curve of Spee. Different mandibular arch form models showed different arch circumference need for flattening the curve of Spee but definitely less than one for each depth of curve of Spee less than nine millimeters.

Similar measurement of arch circumference differential between planar projection from distobuccal cusp tip of mandibular second molar to the center of incisal tips and various degree of curve of Spee by using linear regression and proposed the equation from these data was $Y=0.2462X-0.1723$ where Y is the different in arch circumference and X is the sum of right and left maximum depths of the curves of Spee in millimeters.[61] For example, if the total depth is 9 mm, the arch circumference differential will be 2.04 mm.

The results from those literatures[60, 61] could be implied that flattening the curve of Spee may not the major factors which resulted in lower incisor proclination. These findings were coincidence with Woods[59] who stated that lower incisors can be moved vertically independent with buccal segments and does not required additional arch length but the proclination of mandibular incisors caused by the mechanic use.

From the retrospective study[37] of 30 class I non-extraction found the flattening of curve of Spee during treatment was correlated only with mandibular incisors proclination but could not find any significance difference with neither arch length, arch depth, intercanine width, interpremolar width, intermolar width or the movement of lower first molar.

The study of Marshall *et al*[57] measured the depth of the curve of Spee by using the digital caliper vertically mounted on a surveyor. Dental casts were adjusted to the plane of tripod landmarks in the same level which are distobuccal cusp tips of right and left most posterior mandibular molars and the most central point on the more erupted central incisors.

Amount of crowding

Weinberg and Sadowsky[37] found the correlation between dental crowding resolution and the increase in arch perimeter (r = 0.68), arch depth, interpremolar width and intermolar width. Furthermore, the increase in arch perimeter had significant correlated with arch depth, interpremolar width, intermolar width, and also correlated with anterior movement and proclination of lower incisors. The multiple linear regression analysis showed that 52% of crowding alleviation was accounted for an increase in arch length. The conclusion is that resolving of crowding caused generalized expansion of posterior segments buccally and the advancement of anterior teeth. For 2.3 mm of crowding resolution in this study found an increase in 0.9 mm of intercanine width, 1.6 mm of interfirst premolar width, 1.8 mm of intersecond premolar width, 1.2 mm of intermolar width and lower incisor moved anteriorly 2.3 mm and 6.1^{O} of proclination were found without significant horizontal movement of lower molars. The anterior tipping and proclination of lower incisors were also found in the retrospective study of Yared *et al*[62] in 2006. This study constructed from the record of 34 patients who completed non-extraction orthodontic treated for 7-47 months found anterior movement of lower central incisor tip 2.69 mm range from 0.50-8.00 mm and proclination change found an increase of 5.85^{O} of IMPA from 1.00-16.00 degrees.

6. Tipping force at mandibular incisors

The major change of tooth position begins since the first phase of

Tipping force is one type of tooth movement that is the easiest to occur. Tipping movement is produced by applying a single force that does not pass the center of resistance of the tooth. The result is that crown and root which locate in different side from center of resistance point will move in the opposite direction.[63] The study of force application at lower central incisor tooth in finite element model show tipping displacement of tooth either from labio-lingual force or linguo-labial force direction. Intrusive force from labial application also causes tipping movement.[64] These refer to the force which commonly occur in leveling and aligning teeth which produces linguo-labial force and intrusive force which always tip the lower incisor tooth. Yan *et al*[65] constructed the mandibular teeth model and apply an intrusive force of 10 cN at 4 mm apical to incisal edge on labial surface of central incisor which represent an orthodontic intrusive force. They found the highest stress at labial cervical portion of tooth. And for the periodontal tissues, high von Mises stress were found at labial alveolar crest and at the apical root.

Another finite element method study[66] showed that when occlusal force exerted to proclined central mandibular incisors more than 90 degrees would cause the displacement of incisal edge to labial and root apex to lingual much higher than 90 degrees inclination concurrent with the von Mises stress at periodontal tissues found higher at cervical area and root apex in tipped mandibular central incisors.

7. Anatomical consideration of anterior mandibular area

Teeth are surrounded and supported by periodontal tissues consist of periodontal ligament, alveolar bone and covered by gingival tissue. Swasty *et al*[67] evaluated the cortical bone thickness in 13 cross sections of mandible from right second molar to left second molar, including the midline. The study aimed to compare the cortical bone thickness between high, normal and low mandibular angles and found that in all groups showed the thinnest cortical thickness at upper parts of midline section both buccal and lingual without sex difference. However, hyperdivergent group found slightly much thinner of cortical bone thickness compared to the other two groups. Concurrent with the study of Farnsworth *et al*[68], Han and Jung[69] and Kim *et al*[70] who found the thinnest of cortical bone thickness at alveolar crest of mandibular anterior region compared to other areas.

8. Periodontal tissue consideration in mandibular anterior region

The position of mandibular incisors has much attention along with the greater use of orthodontic fixed appliances over 30 years especially the antero-posterior position which accepted as a clinical importance in treatment planning and was being the most area of restriction due to its anatomical structure[71-73] which lead to the concept of an alveolar envelope.[74] This envelope uses the cortex of an alveolar process as anatomical boundary for tooth movement. The importance to determine the desired lower incisor position are lower facial aesthetic, stability of treatment and periodontal health.

The mandibular incisors area found to be the most frequently area of bone dehiscence and also gingival recession.[50, 73, 75-77] The study of 108 adult human skulls found 7.5 percent of all teeth experienced bone dehiscence or fenestration especially in anterior teeth and anterior mandibular region found greater number of dehiscence two times than maxilla. The prevalence of bony defects found in anterior mandibular teeth area were 14.3 percent without any relationship among different skull ages. Concurrence with the retrospective study[78] which used cone beam computed tomography to evaluate the distance from cemento-enamel junction to alveolar bone crest for represented bone dehiscence in both maxillary and mandibular from central incisors to first molar in both buccal and lingual surfaces compared 2 time points between before and after non-extraction orthodontic treatment resulted that the greatest frequency of increasing the distance found in buccal surfaces of mandibular central incisors for 75% of cases and the mean distance from CEJ to alveolar bone crest of 60 mandibular central incisors increased about 0.5 mm at buccal surfaces which higher than other areas. The case-control study[77] also found the most susceptible area for gingival recession in mandibular incisor area and orthodontic treated individuals had more recession than untreated subjects.

The alveolar bone dehiscence is defined by the distance from CEJ to the alveolar bone crest. If this distance is greater than 2 mm can be classified as alveolar bone dehiscence[79] because the distance that below 2 mm revealed zero loss of attachment level.[80] The retrospective study used cone beam computed tomography to evaluate the distance from cemento-enamel junction to alveolar bone crest for represented alveolar bone loss of 30 Angle class I malocclusion patients with mild to moderate crowding treated with non-extraction orthodontic treatment found that from all of 1,440 root surfaces the bone dehiscence marked in 11% before treatment to 19% after treatment. The greatest frequency of increasing found at buccal surface of central incisors which had more dehiscent surfaces from 13% before treatment to 37% after treatment and all mandibular anterior teeth had the mean distance increased significantly both buccal and lingual surfaces except lingual surface of lower canine. The mean distance increased of labial surface of mandibular central incisors was from 1.72±0.98 mm to 2.28±1.56 mm (p-value <0.0001).[78]

The dry mandible from autopsy of 19 years-old woman who was treating orthodontic treatment for 19 months was investigated the alveolar bone dehiscence and could be concluded that pronounced saggital mandibular incisor movement can lead to progressive cortical alveolar bone loss especially in cases of narrow and high mandibular symphysis.[81]

The study from University of Gothenburg in 2017[82] found positive correlation between a reduced marginal bone level of buccal surface of mandibular incisors area and the forward position of mandibular incisors tip (L1-APog and L1-NB) and also correlated with high irregularity index. Conversely, the negative correlation could be found between a reduced marginal bone level and retroclination of lower incisors (L1/ML and L1/NB). Thus, upright mandibular incisors or slightly retroclination may be the benefit for healthy buccal marginal bone of mandibular incisors area. Supported by the retrospective study of Ngan *et al*[83] found that labial gingival recession was improved after retroclination of mandibular incisors even if moderate gingivitis with average to poor oral hygiene. Concurrent with Tweed studies [84-87] that position of mandibular incisors should be right angle to the mandibular plane or contracted lingually to position over their basal bone and harmony with the surrounding structures supported with the study of the association between lower incisors inclination and gingival movement found that 60 percent of the gingival margin migrated coronally found in retroclination group.[88] Furthermore, there was a trend of increased in keratinized gingiva in lower incisors moved lingual group[89] which is one of the important factor for periodontal attachment loss. Furthermore, behavioural factor for oral hygiene control could be considered in both growing and non-growing patients. Due to the brushing trauma and plaque deposit should consider to be a key factor in gingival recession.[90]

The summarized of studies the relationship between forward position of mandibular incisors and periodontal changes are shown in table 2 (monkey studies) and table 3 (clinical studies).

Table 2 Periodontal tissues changes from forward positioned mandibular incisors in monkey studies

Study	N	Experiment (control)	Treatment time	Retention time	Labial movement	Gingival recession (control)	Bone loss (control)
Batenhorst *et al*, 1974[91]	2	31, 32 / 41, 42 (31, 32 / 41, 42)	54-64 days	240 days	6 mm	-3.15 mm (-0.35 mm)	-7.38 mm (-2.50 mm)
Wingard and Bowers, 1976[92]	4	31, 41 (32, 42)	36-95 days	120 days	3.35 mm	-	-1.7 mm (no change)
Steiner *et al*, 1981[93]	5	11, 21, 31, 41 (13, 23, 33, 43)	13 weeks	3 weeks	3.05±0.8 mm	-1.01±0.4 mm (-0.20±0.3 mm)	-5.48±3.1 mm (-1.52±1.0 mm)
Engelking and Zachrisson, 1982[94] (further study from Steiner *et al*, 1981[93])	5	11, 21, 31, 41	13 weeks	8 months	3.05±0.8 mm	-2-3 mm	-

Table 3 Periodontal tissues changes from forward positioned mandibular incisors in clinical studies

Study	N	Treatment time	Retention time	Labial movement (control)	Teeth	Gingival recession (control)
Årtun and Kongstad,1987[95]	40	-	-	>10^{O} (<2^{O})	31, 32, 41, 42	-0.76±0.62 mm* (-0.31±0.35 mm)
Djeu *et al*, 2002[96]	67	33.2 months	-	5.03±6.37^{O} (1.04±6.62^{O})	31	-0.04±0.17 mm† (-0.01±0.11 mm)
					41	-0.10±0.32 mm† (-0.07±0.28 mm)
Allais and Melsen, 2003[47]	300	-	-	3.4±2.6 mm	31, 32, 41, 42	0.36 mm [0.22 mm)
Melsen and Allais, 2005[50]	150	-	-	3.4 mm	31, 32, 41, 42	-0.34±0.69 mm* (-0.20±0.68 mm)
Yared *et al*, 2006[62]	34	-	7-47 months	5.85±3.92^{O}	31, 41	0 to -2.48 mm†

Table 3 (Continued)

Study	**N**	**Treatment time**	**Retention time**	**Labial movement (control)**	**Teeth**	**Gingival recession (control)**
Garlock *et al*, 2016[97]	57	22.7±7.3 months	-	2.40±6.90^{O}	41	-1.12±2.26 mm*

† Statistically insignificant

*Statistically significant (P<0.05)

The proclination of mandibular incisors was considered as a possible factor for labial gingival recession[62, 89, 98, 99] but other studies found no relationship between labial displacement of lower incisors and apical migration of gingival tissue.[50, 95, 96, 100, 101] Due to most of literatures that studied gingival recession from proclination of incisors assessed the gingival level immediately or within the few months after the treatment that why it remained unchanged.

Two studies[47, 49] found significant gingival recession in treated cases with lower incisor proclination compared to untreated controls. Pearson did not reported the extent of neither amount of labial movement nor amount of recession while Allais and Melsen[47] proclined lower incisors for 3.4±2.6 mm and found significant recession on tooth number 32 and 41 with 0.4±0.86 mm of gingival recession.

The study of Pearson[49] which selected 45 subjects who exhibited recession of mandibular labial gingiva at least 0.5 mm after orthodontic treatment from more than 600 cases and concluded that the significance of gingival recession could be found only a small percentage in orthodontic treated patients. There was no correlation between the degree of gingival recession and any types of incisors movement which concurrence with the retrospective studies[96, 101] which divided the treatment result into proclination and non-proclination groups by measurement of lower central incisors from lateral cephalographs and the result could not found that the change of lower incisors led to the recession of labial gingiva.

Melsen and Allais[50] studied the gingival recession of non-extraction orthodontic treatment records and found no significant increase of gingival recession of mandibular incisors after treatment but the data was found the increase percentage of teeth with gingival recession in each lower incisor teeth. For four lower incisor teeth, there were the increasing number of teeth with gingival recession from 12% before treatment to 21% after treatment and found new recession developed in 10% of incisor teeth. This study identified pretreatment recession, thin gingival biotype and inflammation of gingival tissue as possible predictors for posttreatment gingival recession.

Allais and Melsen[47] found an increase arch length 3.4 mm in 150 non-extraction orthodontic treatment cases which had an impact on gingival level of lower incisor areas. Thirty-five percent of treated individual had gingival recession at least one lower incisors compared to 26% of non-treated individuals with significant statistically difference.

The study of 5-year retention by divided patients into 3 groups after complete treatment which were retrocline, stable and procline group. At the end of observation, the procline group found 16.3% of subjects presented gingival recession while stable group and retrocline group showed only 8.8 and 4.5 percent, respectively but without statistically significant difference.[102] Yared *et al*[62] in 2006 also found the proclination of lower central incisors and concluded that the final inclination of lower incisors was more important than amount of proclination in the factor for gingival recession because they found 92.86% of patients who developed recession had final inclination equal or greater than 96 degrees. Another factor that was an important factor for gingival recession was the thickness of free gingival margin, they found that 93% of patients who developed gingival recession had less than 0.5 mm of free gingival thickness which coincided with the study of Melsen and Allais[50] who demonstrated that thin gingival biotype was an important factor for gingival recession.

However, there were controversies between the loss of buccal gingival attachment and lower incisor proclination among human studies. Some studies found proclination effected loss of buccal gingival attachment [62, 95, 99] while others count not be found these association.[47, 50, 100, 103]

In animal studies, most of them either in monkey models [91, 93, 94, 98] or beagle dog models [104, 105] supported that tipping mandibular incisor teeth resulted in facial alveolar bone loss. There was only one study could not find these significance.[92] These six articles except the study of Karring *et al*[105] which had similar subjects as Thilander and colleagues[104] were included in a systematic review[106] and were rated their evidence value as low due to lack in diagnostic reliable tests. The measuring method in all animal studies made directly on teeth without error were reported. Two studies[91, 93] could find the significance in loss of gingival margin after proclination of lower incisor teeth significantly. Steiner *et al*[93] displaced incisor teeth facially 3.05±0.8 mm and gingival recession was found 1.01±0.4 mm after 3 weeks retention while Batenhorst *et al*[91] protracted lower incisors for 6 mm and retained for 8 months. They found significant recession of 1.9 mm. Only one study[92] could not found these recession after lower incisors moved anteriorly for 2.1-5 mm (mean = 3.35 mm) and remained at displaced position for 4 months.

Interesting observation which can be explained why other study found the minimal changes of gingival recession or no gingival recession occurrence after labial tipped lower incisors could be explained from Engelking and Zachrisson [94] study that used the monkey models from Steiner and colleagues study[93] which tipped both upper and lower central incisors facially and found apical migration of gingival margin at lower incisors about 1 mm with statistically significance compared to control teeth and upper incisors. After 3 weeks for retention period in the first study[93] and waiting time prior to beginning of the consequent study[94] which were totally eight months revealed that recession of labial gingiva continued to develop in several experimental teeth to 2-3 mm of gingival recession. Thus, the totally effect of orthodontic treatment on periodontium may not be discerned at the time of appliances removal. Subsequently, retained position of teeth after tipping forward could cause the progression of gingival damage.

Wennström *et al*[98], Karring *et al*[105] and Thilander *et al*[104] concluded that alveolar bone recession was inevitably accompanied by the loss of connective tissue attachment and marginal gingiva which was the result from forward position of lower anterior teeth.

Karring *et al*[105] explained the mechanism that bone dehiscence occurred when teeth moved facially out of its alveolar housing resulted in degradation of both organic and inorganic components, including osteogenic cells. Although soft tissue which covered the dehiscent bone may contained osteogenic cells but it was incapable such an area outside the boundary of jaw bone to form the new bone coverage. Concurrence with Steiner and colleagues[93] who stated that when teeth moved out of bone boundary, it would be out of its gingival coverage and caused margin of labial gingiva became thinned.

Some patients may experience alveolar bone dehiscence prior to orthodontic treatment that why evaluation of bone loss is essential. High risk patients who are prone to loss their cortical bone level or gingival recession consist of person who has compromised periodontal health, old age, traumatic injury, poor oral hygiene or patient with thin alveolar bone which usually found at mandibular incisor region.[76] And narrow symphysis was correlated with hyperdivergent patient.[76]

Several studies especially in human studies could not found the relationship between the proclination of lower incisors and alveolar bone dehiscence. These may due to there were retrospective studies[50, 62, 96, 103] and did not included subjects only with crowding treated by non-extraction orthodontic treatment.[47] Some article studied in adolescent patients and could not found relationship between mandibular incisors advancement and gingival recession.[103]

9. The previous studies which tried to reduce lower incisor proclination

Self-ligating system was introduced as low friction which would cause more tooth movement such as increased posterior teeth expansion efficiency. Three prospective clinical trials[38, 54, 107] compared self-ligating brackets and conventional brackets on mandibular arch changes resulted that there were no difference of mandibular incisor inclination change between two bracket systems but self-ligating groups found a significant increase only in the intermolar width about 1-2 mm. From mathematical model that evaluated quantitative arch length change after expansion showed molar expansion of 1-2 mm will cause only 0.27-0.58 mm in increased arch perimeter which was a small amount and also clinically insignificant. [43] Furthermore, Pandis *et al*[107] found that neither the amount of crowding nor Angle classification were not significant predictors for post-treatment intermolar width.

Fleming *et al*[108] studied the efficiency of mandibular arch alignment in the alignment phase by measured the contact points movement in all 3 planes compared between self-ligating brackets and conventional brackets and concluded that the bracket type was not correlated on alignment efficiency both in labial and buccal segments, and also no difference in duration of treatment. The major factor that found to be significance was the pretreatment irregularity which could explain 60% of the variance in posttreatment irregularity.

A prospective randomized clinical trial on axial inclination of lower incisors from the effect of rectangular continuous archwire with the hypothesis that rectangular archwire would counteract the flared labial crown moment during leveling and aligning phase. The intervention group started at 0.016 x 0.022 nickel-titanium archwire and ended with 0.016 x 0.022 stainless steel while the control group received round archwire throughout the experiment. The mean pretreatment curve of Spee was approximately 4 mm. The result found no significant different in the change of lower incisor proclination between two groups and there were a significant reduction in the depth of curve of Spee in both groups by uncontrolled labial tipping. Due to the effect of intrusive force from leveling the curve of Spee which was located labial to the center of resistance of mandibular incisors. This study was not supported that rectangular archwire had ability to control mandibular incisor proclination. [109]

The study of intrusion effect on periodontal tissue of mandibular incisors used segmented 0.016 x 0.016 in-Blue Elgiloy utility arch for lower incisor intrusion for 2.62 mm also found the effect of proclination 4.27^{O}

10. Measurement methods

Cephalometric analysis for mandibular incisor inclination

Most of literatures projected position of lower incisors relied on several cephalometric points, lines and planes which had various limitations including subject variation, error in determination and also change resulted from growth. The intention is to use these methods as a guide for establishing an objective of treatment and comparing both treatment change and also posttreatment change during retention period. The popular reference lines which use to determine the position of lower incisors consist of A-Pog line, NB plane and mandibular plane.[72] Housley *et al*[110] discussed that B-point is the area of bone resorption and can be altered by orthodontic tooth movement whereas, Pog is the area of bone deposition and can be affected by mandibular rotation. Thus, B-point and Pog may not be stable points and can be altered by orthodontic treatment.

The concept of Tweed's diagnostic triangle was well-known among orthodontists.[84, 111] The mandibular incisor-mandibular plane angle (IMPA) could be adjusted by treatment mechanics for perceiving ideal Frankfort plane-mandibular incisor angle (FMIA) of 65^{O}-70^{O}.[84] Thus, Tweed proposed that IMPA should be right angle to the mandibular plane. Steiner[112] proposed the Chevron diagram which considered the mandibular incisor position in relation to NB line with the mean angular of 25^{O} and linearly +4 mm. However, these value can be altered by the ANB angle, if it is not 2^{O}, and desired as acceptable compromises value. Down[46] and Ricketts[44] considered lower incisors position in relation to A-Pog as the reference line. Ricketts considered esthetic lip relationship and stability of treated cases. He suggested the angulation of lower incisor as 22^{O} and +1 mm to A-Pog as the clinical objective. William and Hosila[113] also supported to use A-Pog as a reference line to place the mandibular incisor tip on this plane or slightly anterior to it for achieving both facial esthetic of soft tissue profile and treatment stability. Schulhof *et al*[72] concluded that A-Pog is better than other references in the objective of placing the maxillary incisors by using A-Pog as a guide which others could not.

Gingival recession and bone dehiscence

Gingival recession can be measured from clinical crown height on plaster models by using sharpened pointed Boley gauge or digital caliper from midpoint of incisal edge to the deepest point on labial gingival margin of lower central incisors.[47, 49, 50, 96, 100-102] The pilot study of 30 subjects resulted the statistically significant differences of crown heights which performed on plaster models and clinical examination. However, the correlation between two assessments were 0.986 which was a high correlation.[102] Previous researchers constructed the retrospective studies and tried to evaluate the development of gingival recession by using intraoral photographs[47, 103] but they found that there were unreadable teeth more than from the plater models. And the pilot study[102] assessed for validity of measuring gingival recession between clinically and on plaster models found a very good concordance[114] with kappa was >0.800. In detail, Clinical examination found 147 recessions in 20-30 subjects, whereas on plaster model 137 recessed areas were found.

Most of recent literatures[76, 78, 82, 115-117] that studied alveolar bone surrounding the teeth used cone-beam computed tomography as the measurement tool because it is the most accurate device[118, 119] for indirect measuring either alveolar bone height or bone thickness. However, the accuracy of CBCT in the measurement ability of marginal bone level has been questioned. Molen[116] stated that CBCT is influenced by several factors and he suggested the use of small voxel sizes, small fields of view and using the highest gray-scale bit depth for the beneficial of the visualization for thin bones which can be reduced the risk of partial volume averaging and less noise from scatter radiation.

The evaluation of alveolar bone crest level with various voxel dimensions consisted of 0.2, 0.3 and 0.4 voxel sizes compared to direct measurement method found the smallest voxel size could increase intraexaminer precision. The 0.2 and 0.3 mm of voxel size could both demonstrate the accuracy for measuring bone level especially the mandibular incisor area. This study found the significant difference between CBCT for 0.4 mm of voxel size and direct method. Thus, evaluating alveolar bone level at lower incisor area, less than 0.4 mm-voxel size was recommended.[118]

Rather than voxel size, the spatial resolution is one factor to be considered for accuracy of CBCT.[115] Spatial resolution is the minimal distance needed to distinguish between two objects in close proximity usually calculate by using high contrast line pairs.[120, 121] Although spatial resolution is mainly depends on the voxel size, but some factors make it cannot achieve a resolution equal to the voxel size. These factors can be metal artifact, halo effect, partial volume averaging which is one-average grey value displayed in one voxel when two different densities are presented in the same voxel or noise in the images which is an energy from other sources rather than the X-ray tube such as light or scatter radiation. Result from the study of spatial resolution in several settings showed that smaller voxel size, smaller field of view and longer scan time would result in a smaller spatial resolution. The scan time effects this factor because increasing time leads to increasing exposure which can get more information captured and leads to clear image with less of noise.[120]

The study[115] of accuracy and reliability of CBCT for detecting alveolar bone dehiscence found high specificity (0.95) but low sensitivity (0.42) and negative predictive values were high (0.93) but lower positive predictive value (0.51). These finding meant when dehiscent defect was found on CBCT, only a half was true dehiscence. Conversely, when the defects could not be seen on CBCT meant that most of them were absent of dehiscence. In detail, CBCT could distinguish the different density of materials such as between enamel and cementum (CEJ) better than the similar densities such as cementum and alveolar bone. Moreover, the defects were gradual and tapering in margin that limited the detection. The voxel size of CBCT device indicated the marginal bone error. In this study used 0.38 mm in voxel size and found an actual margin of error 0.40 mm. Furthermore, the physical spatial resolution of the image was approximately 0.6 mm indicated that the bone thickness less than 0.6 mm might be seen on the CBCT as no bone which made the positive predictive value was about a half. Although the detection with CBCT cannot perform with high accuracy or reliability, but it was the best device for measuring these defects instead of direct inspection.

The evaluation of alveolar bone defects is essential and beneficial to plan for the actual treatment and close follow up during or after treatment. For evaluation of bony dehiscence, the referent planes have to be constructed. Most of the studies used length axis of the root in coronal and saggital view as vertical dental axis from the incisal edge to the root apex and draws a straight lines to be the reference.[78]

11. Intrusive force for lower anterior teeth

Owing to the quantity of root surface areas of mandibular incisors are minimum compare to other teeth. Furthermore, the conical shaped root makes it at high risk for root damage from orthodontic force. Thus, light force concept for incisor intrusion is indicated for minimized the side effects.[122] Levander *et al*[123] found the pause of active treatment for 2-3 months by using passive arch wire could reduce the amount of root resorption.

Schwarz[124] proposed the optimal force for tooth movement based on capillary blood pressure about 20-26 grams per cm^2. There are many studies recommended the optimal intrusive force for four mandibular incisors. Burstone[125] recommended 40 grams of intrusive force for correcting deep overbite. Same as Weiland *et al*[126] who recommended 40-50 grams of intrusive force for four lower incisors while McNamara[127] recommended 25 grams per lower incisor tooth. The light force produced effectiveness incisor intrusion with minimal root resorption of 0.4 mm compared to control without clinically significant difference.[128]

Conceptual framework

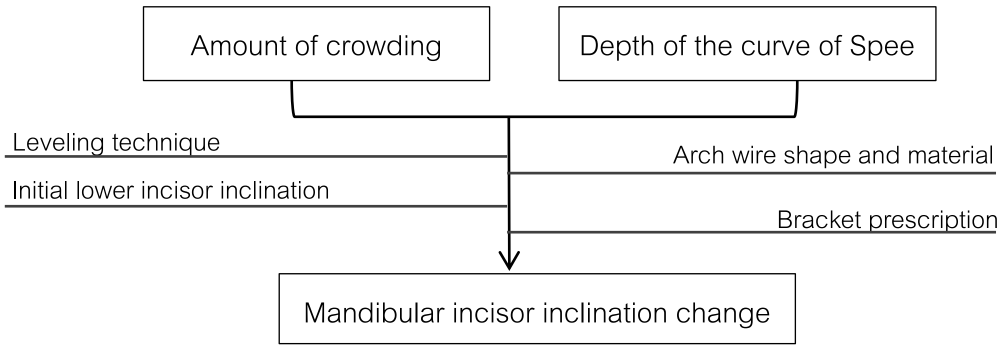

Figure 1 Conceptual framework

Objectives

Part 1

Objectives

1. To compare the maximum von Mises stress at labial and lingual of root and periodontal tissue of lower incisors after initial leveling by 0.016-inch, 0.016 x 0.016-inch and 0.016 x 0.022-inch nickel titanium archwires.
2. To compare the sites of maximum von Mises stress at labial and lingual root surface of lower incisors after initial leveling by 0.016-inch, 0.016 x 0.016-inch and 0.016 x 0.022-inch nickel titanium archwires.
3. To compare the amount of lower incisor displacement in labio-lingual direction after initial leveling by 0.016-inch, 0.016 x 0.016-inch and 0.016 x 0.022-inch nickel titanium archwires.

Hypothesis

1. The maximum von Mises stress at labial and lingual of root and periodontal tissue of lower incisors after initial leveling by 0.016-inch, 0.016 x 0.016-inch and 0.016 x 0.022-inch nickel titanium archwires were difference.
2. The sites of maximum von Mises stress at labial and lingual root surface of lower incisors after initial leveling by 0.016-inch, 0.016 x 0.016-inch and 0.016 x 0.022-inch nickel titanium archwires were difference.
3. After initial leveling by 0.016-inch, 0.016 x 0.016-inch and 0.016 x 0.022-inch nickel titanium archwires, lower incisor displaced in the different amount.

Part 2

Objectives

1. To compare the changes of lower incisor inclination between experimental group and control group after tooth aligning and leveling.
2. To compare the reduction of curve of Spee between experimental group and control group after tooth aligning and leveling.

Hypothesis

1. Experimental group had less changes in the lower incisor inclination than control group after tooth aligning and leveling.
2. Curve of Spee reduction between experimental group and control group after tooth aligning and leveling were no difference.

Significance of the study

This study compared between the new proposed technique which levels the curve of Spee with rectangular archwires and the routine treatment which teeth are levelled with round nickel titanium archwires and rectangular stainless steel archwires which would provide the knowledge about lower incisor inclination change and amount of vertical lower incisor positioned change for flat the curve after leveling with each technique. These knowledges would be benefit to choose appropriate technique for particular patients.

CHAPTER 2

MATERIALS AND METHODS

Part 1

Determination of von Mises stress from different 0.016-inch-height nickel titanium archwires after initial leveling by using finite element model

The objective of this section was to describe the stress distribution on surrounding alveolar bones and periodontal tissue after initial leveling of anterior teeth within its periodontal ligament spaces from different shapes of 0.016-inch height nickel titanium archwires consisted of 0.016-inch, 0.016 x 0.016-inch and 0.016 x 0.022-inch archwires.

This finite element study was approved by the Ethics committee on human research of the Faculty of Dentistry, Prince of Songkla University (No. EC6101-05-P-HR)

Sample

A cone beam computed tomograph from selected patient at Dental hospital, Faculty of Dentistry, Prince of Songkla University who qualified for inclusion and exclusion criteria as followed.

Inclusion criteria were:

- Age 18-30 years old
- Skeletal Class I
- All mandibular teeth were presented except third molar
- No crowding in mandibular anterior teeth
- No tooth size-arch length discrepancies in mandibular posterior teeth
- Curve of Spee depth within 3-4 millimeters
- Non-extraction orthodontic treatment was planned by expert opinion

Exclusion criteria were:

- Patients who were previously treated by orthodontic treatment
- Patients with underlying diseases or periodontal diseases
- Spacing in mandibular teeth
- Transposition of teeth
- Missing teeth or excessive tooth surface loss

Development of the finite element model

The finite element model was generated by using data from selected cone beam computed tomography of mandibular teeth of patient at pre-treatment to generate 3D solid model by using SolidWorks version 2015 software (DS SolidWorks Corp., Waltham, MA, USA). The model was transferred and constructed buccal tubes of mandibular first molars, brackets of mandibular central incisors to mandibular second premolars with 0.018x0.025-inch of slots and archwires as computer aided design (CAD) model with PowerSHAPE2013 software (PowerShape, Delcam Co. Ltd., Birmingham, UK). Meshing of the CAD model as finite elements and analysis were done by using ANSYS software version 14.5 (ANSYS Inc., Canonsburg, PA, USA). All softwares in this part of the finite element study were used under the program licenses of Khon Kaen University, Thailand with collaboration.

The final finite element model consisted of lower jaw with all mandibular teeth except mandibular third molars. All roots were covered with the periodontal tissues as the interface between root surfaces and alveolar bone sockets. Teeth were well-aligned but presented with 4 mm of curve of Spee depth (Figure 2).

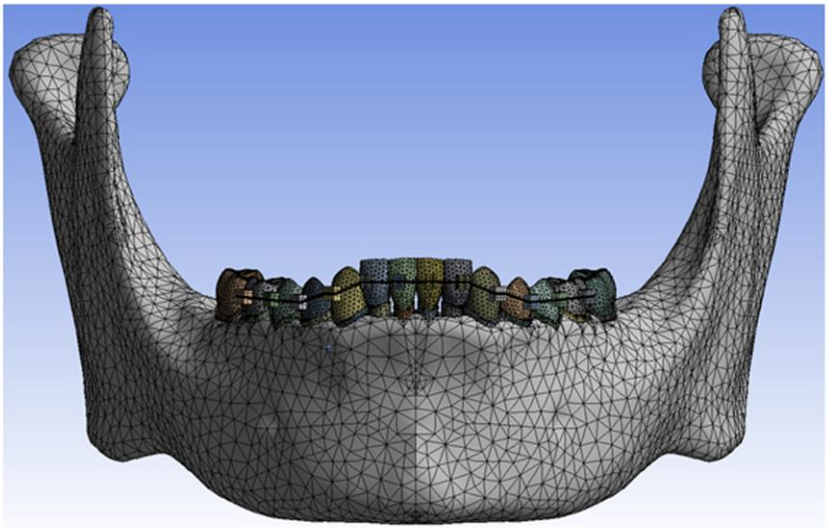

Figure 2 The constructed finite element model in this study

All teeth, alveolar bones and periodontal tissues were assumed to be homogeneous, isotropic, and linear elastic. The width of periodontal spaces assumed to be 0.2 millimeters thickness equally.[129] The mechanical properties of materials in this study obtained from Choi *et al*[130] and Razali *et al*[131] (Table 4).

Table 4 Mechanical properties of materials used in finite element analysis

Materials	Young's modulus	Poisson's ratio
Periodontal ligament	0.05	0.49
Alveolar bone	2,000	0.30
Tooth	20,000	0.30
Nickel-titanium	44,000	0.33
Stainless steel	200,000	0.30

The sources of force application were from the superelastic nickel titanium archwires which passively placed into bracket slots and buccal tubes of lower teeth with 4 mm of curve of Spee depth and pushed the archwire at the incisor bracket slot for 0.2 mm which equal to the width of periodontal spaces. There were 3 models of 0.016-inch height of nickel titanium archwires for analysis and comparison depended on its cross-sectional shapes. These three models were 0.016-inch round archwire, 0.016 x 0.016-inch square shaped archwire and 0.016 x 0.022-inch rectangular shaped archwire. All analyses were done as static structures by using both sides of coronoid processes and anterior portion of chin as the fixed part while other parts could be moved. The contacts between archwires and bracket slots were movable with 0.28 of friction coefficient[132].

The intrusive forces were applied at archwire in the positioned of four mandibular incisor bracket slots for 0.2 mm intrusion as the width of periodontal spaces. The measurement of stress distribution in each area of tooth structures and periodontal tissues would analyzed and reported as well as the amount of tooth displacement for described the tooth movement pattern.

Part 2

Clinical trial

The objective of clinical trial part was to propose the new technique which tried to separate the leveling phase from aligning phase for evaluation of mandibular incisor inclination change from lateral cephalometric analysis compared between the conventional leveling and aligning technique.

This study was a prospective, randomized, 2-arm parallel of clinical trial which was reviewed and approved by the Human Research Ethics Committee of the Faculty of Dentistry, Prince of Songkla University (No. EC6101-05-P-HR) and registered for Thai Clinical Trials Registry at ClinicalTrials.in.th (TCTR20180501003).

Study population

Patients who were in the waiting list for orthodontic treatment at Orthodontic clinic, Dental hospital, Faculty of Dentistry, Prince of Songkla University and qualified for inclusion and exclusion criteria.

Inclusion criteria were:

- Subjects who were 18-30 years old
- Healthy, no underlying diseases or drug use which affects bone metabolism

- Skeletal class I (ANB = 3±2 degree) with normodivergent pattern (FMA = 23±4 degree)
- All mandibular teeth are presented except third molar
- Mild to moderate crowding of mandibular anterior teeth (Little's irregularity index 3-5 mm and each contact not exceed 1 mm)
- Minimal or no crowding of mandibular posterior teeth (tooth size-arch length discrepancy less than 3 mm)
- Curve of Spee depth between 3-4 mm
- Normally inclined mandibular incisors (IMPA = 93±6 degree)[112]
- Attach gingiva at mandibular anterior teeth not less than 1.5 mm
- Treatment plan will be non-extraction orthodontic treatment by expert opinion

Exclusion criteria were:

- Subjects who allergic to metal materials or dental material that use in this study
- Subjects who have periodontal disease (clinical attachment level > 4 mm)
- Probing depth at mandibular anterior teeth > 4 mm
- Subjects who have bone dehiscence or fenestration in anterior mandibular areas
- Subjects who had previously treated orthodontic treatment or history of initiated orthodontic treatment
- Subjects with hypo- or hyper-active mentalis muscle (MLA deviates from 128.5±11degree)[133]

Withdrawal criteria were:

- Medical problems affect the treatment or alter bone metabolism
- Pregnancy patients
- Non-cooperative patients including absence from monthly appointment
- Crestal alveolar bone loss more than 2 mm from CBCT
- Gingival recession at labial mandibular incisors more than 2 mm from CEJ
- Attach gingiva at labial mandibular incisors less than 1 mm

Sampling

Thirty patients were random sampling from the waiting list for orthodontic treatment at Orthodontic clinic, Dental hospital, Faculty of Dentistry, Prince of Songkla University.

Sample size calculation

Sample size calculation was done by using the formula as followed for testing two independent means (two-tailed test).

$$n_1 = \frac{(z_{1-\frac{\alpha}{2}} + z_{1-\beta})^2 \left[\sigma_1^2 + \frac{\sigma_2^2}{r}\right]}{\Delta^2}$$

$$r = \frac{n_2}{n_1},\ \Delta = \mu_1 - \mu_2$$

The values of mean differences of lower incisor-mandibular plane angle in experimental group and control group were taken from the study of Tantikalyaporn[134] as followed;

Mean in group1 (μ_1) = 0.70, SD. in group1 (σ_1) = 0.20

Mean in group2 (μ_2) = 1.50, SD. in group2 (σ_2) = 0.70

Alpha (α) = 0.01, Z(0.99) = 2.575829

Beta (β) = 0.10, Z(0.90) = 1.281552

Sample size: Group1 (n_1) = 13, Group2 (n_2) = 13

Setting the drop-out rate at 20 percent, the sample size in the study would be 15 patients per group.

Materials and devices

- Gypsum orthodontic stone type 3 (Noritake SCG Plaster, Co. Ltd. Saraburi, Thailand)
- Bracket slot 0.018x0.025-inch for incisors, canines, first and second premolars (Ormco® Mini Diamond™, Orange, CA, USA) (Table 5)

Table 5 Bracket prescription used in clinical trial

Tooth	Torque	Angle	Bracket Type	M/D	In/Out
Anterior	-1°	0°	Vertical Slot, semi-wedge	2.3 mm	1.3 mm
Cuspid	-7°	+6°	Vertical Slot	3.2 mm	0.6 mm
1st Bicuspid	-11°	0°	Vertical Slot	3.2 mm	0.6 mm
2nd Bicuspid	-17°	0°	Vertical Slot	3.2 mm	0.6 mm

- Buccal tube slot 0.018x0.025-inch for first molars (Ormco® Optimesh™, Orange, CA, USA): torque -22°
- Nickel titanium archwires: size 0.014-inch, 0.016-inch, reverse curve of Spee 0.014-inch, reverse curve of Spee 0.016-inch (Great lakes®, NY, USA)
- Stainless steel archwires: size 0.016 x 0.016-inch, 0.016 x 0.022-inch (Highland Metals, IN, USA)
- Beta titanium archwires: size 0.016 x 0.022-inch (Highland Metals, IN, USA)
- PadLock® fluorescent light cure adhesive paste (Reliance Orthodontic Products Inc., IL, USA)
- Assure® Plus (Reliance Orthodontic Products Inc., IL, USA)

Patients who met the research criteria were invited to enter the trial and the orthodontist provided the patients both oral and written information in details of the study and consent form. The samples were randomization into 2 groups by drawing lots consisted of experimental group and control group.

All study subjects were asked to take an initial orthodontic record by using the orthodontic charting form of Orthodontic clinic, Dental hospital, Faculty of Dentistry, Prince of Songkla University, extra and intra oral photo taken, bite registration with pink wax, upper and lower arch impression with alginate for study models fabrication, referred for routine radiographs for orthodontic treatment plan evaluation including panoramic radiograph, lateral cephalometric radiograph as T_0. Patients were referred for dental treatment in disease control phase such as filled decay teeth if needed. Figure 3 showed initial intra oral photos of participant.

Figure 3 Intra oral photos of participant at initial record (T_0)

Each subject was orthodontically treated with preadjusted edgewise fixed appliances using a Roth prescription with 0.018x0.025-inch slot size (Ormco®, Orange, CA, USA) followed the treatment protocol. All subjects were asked for an appointment for activation every 3-4 weeks.

The treatment protocol began with bracketing in upper teeth according to manufacturer's instruction with Assure® Plus (Reliance Orthodontic Products Inc., IL, USA) and PadLock® fluorescent light cure adhesive paste (Reliance Orthodontic Products Inc., IL, USA). Upper teeth were levelled and aligned with straight nickel titanium archwire (Great lakes®, NY, USA) until lower teeth could be bonded. The summary of archwire sequence for lower teeth was described in table 6.

Table 6 Archwire sequence used in the trial

Arch wire	Experimental group	Control group
0.014-inch NiTi (Great lakes®, NY, USA)	Straight	Accentuated
0.016-inch NiTi (Great lakes®, NY, USA)	Straight	Accentuated
0.016 x 0.016-inch SS (Highland Metals, IN, USA)	Straight	Passive accentuated
0.016 x 0.022-inch TMA (Highland Metals, IN, USA)	-	Passive accentuated and gradually flat for 1.5 mm
0.016 x 0.022-inch SS (Highland Metals, IN, USA)	Straight	Straight

Lower teeth were bonded and began the trial with 0.014-inch straight nickel titanium archwire in control group and same size of reverse curve of Spee archwire in an upside down positioned or accentuated curve for the experimental group. Lower teeth were aligned by using 0.014-inch and 0.016-inch nickel titanium archwires of straight archwires for control group and accentuated archwires for experimental group until crowding was corrected. Each archwire was decided to use 1-3 month(s) depended on the amount of crowding that was left over. After anterior crowding was resolved, the treatment record at T_1 was taken by recorded intra oral photos (figure 4) and lateral cephalometric radiograph.

Figure 4 Intra oral photos of participant after aligned (T_1)

After T_1 was taken, 0.016 x 0.016-inch stainless steel archwire (Highland Metals, IN, USA) was placed by using straight archwire in control group and passive accentuated archwire by bending as patient's curve of Spee in experimental group (figure 5). Then, the archwires were changed to rectangular, 0.016 x 0.022-inch stainless steel archwire (Highland Metals, IN, USA) by using straight archwire in control group for a month. For experimental group, passive accentuated archwire of 0.016 x 0.022-inch beta titanium archwire by bending as patient's curve of Spee and gradually reduced the curve for 1.5 mm visit by visit until straight archwire was achieved. Then, changed the archwire to 0.016 x 0.022-inch straight steel archwire for 3 months in both groups and treatment record at T_2 was taken (figure 6).

Figure 5 0.016 x 0.016-inch stainless steel archwire was bent as patient's curve of Spee in experimental group

Figure 6 Intra oral photos of participant after levelled (T_2)

All bendable archwires consisted of stainless steel archwire and beta titanium archwire were adjusted the arch width as same as the original arch width of each participant.

Data recording

Data recording for experimental group and control group at initial (T_0).

- Orthodontic charting record
- Extra and intra oral photos
- Study model
- Lateral cephalometric radiograph

Data recording for experimental group and control group after alignment (T_1).

- Intra oral photos
- Study model
- Lateral cephalometric radiograph

Data recording for experimental group and control group after levelled (T_2).

- Intra oral photos
- Study model
- Lateral cephalometric radiograph

Cephalometric analysis

The lateral cephalometric radiographs were taken for evaluating the treatment changes between T_0, T_1 and T_2. The lateral cephalometric radiographs were traced on acetate paper using 0.3-mm mechanical pencil and analyzed both linear and angulation to the nearest 0.5 mm and 0.5 degree, respectively.

The reference points, lines and analysis were defined according to the studies of Shannon and Nanda[55] and Yasutomi *et al*[17].

The constructed horizontal reference line x runs through sella turcica with minus 7^{O} from sella-nasion line and the constructed vertical reference line y is perpendicular to the reference line x at sella turcica. The reference line y will be used in linear measurement for antero-posterior changes of both dental and soft tissue.[17]

The superimposition of each time point of lateral cephalometric tracings use of the structural method which described by Bjork.[135] The stable anatomical structures for evaluation of change in mandibular area consists of the anterior contour of bony chin, the inner cortical outline at inferior border of symphysis, the trabecular structure in the symphysis and the trabecular structures related to mandibular canal.

Reference points and lines

- N (nasion): The fronto-nasal suture in midsaggital plane
- Or (orbitale): The most inferior point of orbit
- Po (porion): The most superior point of the outline of external auditory meatus
- Go (gonion): The most posterior-inferior of mandibular angle
- Me (menton): The most inferior of symphysis
- Point A (subspinale): The most posterior point in the concavity of maxilla
- Point B (supramentale): The most posterior point in the concavity of mandible
- $L1_{tip}$ (incisor inferius): Incisal tip of the most prominent mandibular central incisor
- FH (Po-Or): Frankfort horizontal plane
- MP (Go-Me): Mandibular plane

Cephalometric measurement

- ANB (^{O}): Antero-posterior relationship of maxilla and mandible
- FMA (^{O}): Frankfort-mandibular plane angle
- L1-NB (mm): Distance from $L1_{tip}$ perpendicular to NB line
- L1-NB (^{O}): Angle between L1 long axis to NB line
- ΔL1 vertical (mm): Difference of vertical distance between $L1_{tip}$ before and after

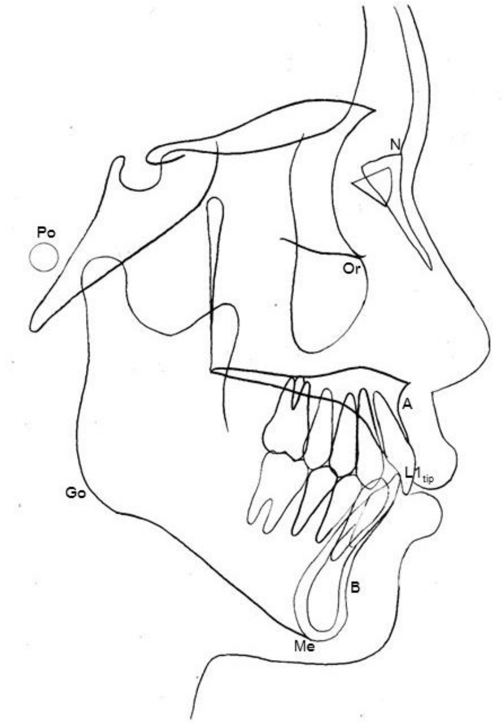

Figure 7 Cephalometric landmarks

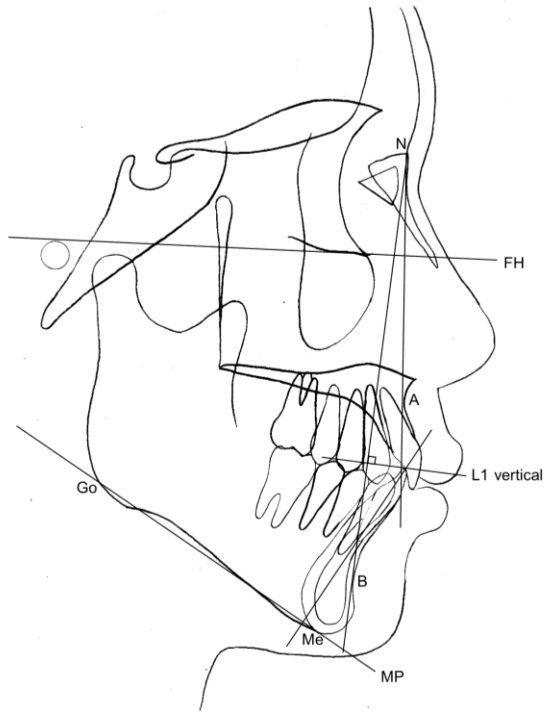

Figure 8 Cephalometric measurement

Model analysis

The mandibular models were used to measure the curve of Spee which referred to the mean distance of right and left cusp tip of the deepest mandibular teeth perpendicular to imaginary lines from incisal edges of central incisors to distal cusp tip of the second mandibular molars. The measurement were done by using a digital Vernier caliper which set to 0.00 mm before the next measurements. The distance was recorded to the nearest 0.01 mm.

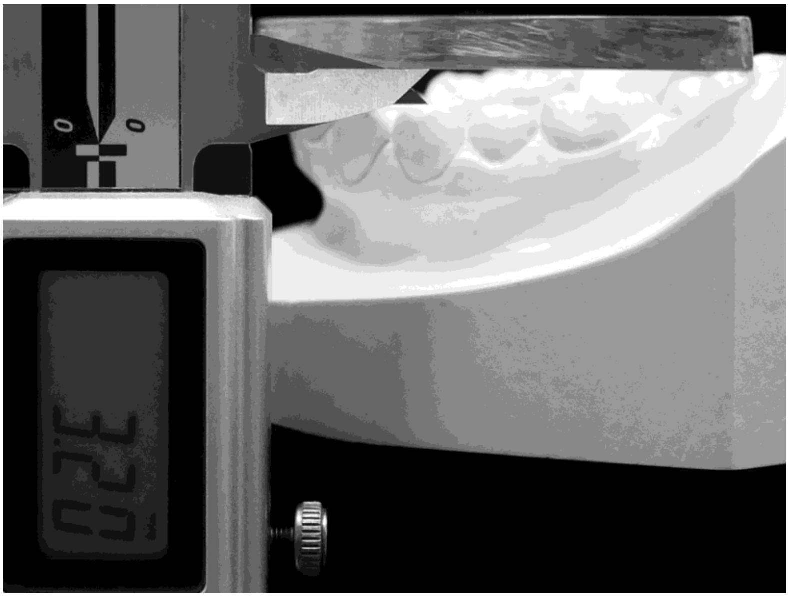

Figure 9 Curve of Spee measurement method using digital Vernier calliper

Statistical analysis

All data were reported as mean ± standard deviation for three time points consisted of T_0, T_1 and T_2. The data were analyzed using IBM SPSS Statistics 21 software (IBM software group, Chicago, IL, USA). Intra-examiner reliability was determined using paired t-tests by random selection of 10 cephalometric radiographs after 2 weeks. The radiographs were re-traced, and measurements were repeated.

Means and standard deviations were calculated for all lateral cephalometric radiograph parameters at T_0, T_1 and T_2. The distribution normality of parameters was tested by the Shapiro-Wilk test. Independent t-tests were used to analyze differences between the control and experimental groups. A significant difference level of $P<0.05$ was used for all statistical tests.

CHAPTER 3

RESULTS

Part 1

Determination of von Mises stress from different 0.016-inch-height nickel titanium archwires after initial leveling by using finite element model

The distribution of von Mises stress from 3 models of 0.016-inch archwire, 0.016 x 0.016-inch archwire and 0.016 x 0.022-inchi archwire after analysed by finite element method from clinical simulation of leveling mandibular teeth by applied an intrusive force at mandibular incisors for 0.2 mm. The results were analyzed as shown in table 7. Comparison between three models, the highest von Mises stress on labial root surface was found in 0.016-inch archwire of 2.598 MPa. While other 2 models of 0.016 x 0.016-inch archwire model and 0.016 x 0.022-inch archwire model found von Mises stress of 0.343 and 0.372 MPa respectively which were much lower than the round archwire. The von Mises stress on lingual root surface from round archwire model was 1.694 MPa compared to 0.208 and 0.200 MPa in square archwire and rectangular archwire respectively. The von Mises stress of periodontal tissues showed similar patterned of root which the areas of maximum stress were in the locations of cervical root areas both labial and lingual sides and 0.016-inch round archwire model found much higher von Mises stress at cervical regions on both labial and lingual surfaces than the other two models.

The locations in vertical dimension of maximum von Mises stress were evaluated by 40 equal horizontal rectangular boxes from incisal edge to root apex. The highest von Mises stress areas in labial root of all 3 models were found at the same box number 18th which were approximately on cervical root areas at the alveolar crest level while the lingual root surface, the level of maximum von Mises stress were found at the 21st box for 0.016-inch model and 20th boxes for 0.016 x 0.016-inch and 0.016 x 0.022-inch archwires. The locations on lingual roots were at the cervical third of root area but the locations were below the alveolar crestal bone level.

The type of tooth movement was assumed by evaluating labio-lingual displacement in Z-direction. The farthest distance of labial displacement was found in 0.016-inch round archwire model of 5.47×10^{-3} mm compared to the 0.016 x 0.016-inch archwire model and

0.016 x 0.022-inch archwire model which found incisal edge displaced much less amount than round archwire model of $0.72x10^{-3}$ mm and $0.80x10^{-3}$ mm respectively. The tooth movement in vertical dimension or Y-axis also found the farthest amount of intrusion in 0.016-inch round archwire model of $2.59x10^{-3}$, while other models were much lower. $0.35x10^{-3}$ for 0.016 x 0.016-inch archwire and $0.42x10^{-3}$ for 0.016 x 0.022-inch archwire. However, there were little changes of all 3 models for the amount of displacement in Y-axis.

Table 7 Von Mises stress and incisal edge displacement derived from a finite element analysis

Model	**Distance (mm)**		**Labial**			**Lingual**		
	Z	**Y**	**Max. root stress (MPa)**	**Max. PDL stress (MPa)**	**Level**	**Max. root stress (MPa)**	**Max. PDL stress (MPa)**	**Level**
Model 1 0.016”	+0.00547	-0.00259	2.598	$7.491x10^{-6}$	18	1.694	$3.257x10^{-6}$	21
Model 2 0.016”x 0.016”	+0.00072	-0.00035	0.343	$1.034x10^{-6}$	18	0.208	$4.232x10^{-7}$	20
Model 3 0.016”x 0.022”	+0.00080	-0.00042	0.3722	$1.093x10^{-6}$	18	0.2002	$4.833x10^{-7}$	20

Part 2

Clinical trial

This study had 30 patients who eligible for inclusion and exclusion criteria and were invited for the trial. The patients in this clinical trial were flowed followed the modified CONSORT 2010 diagram (Figure 10).

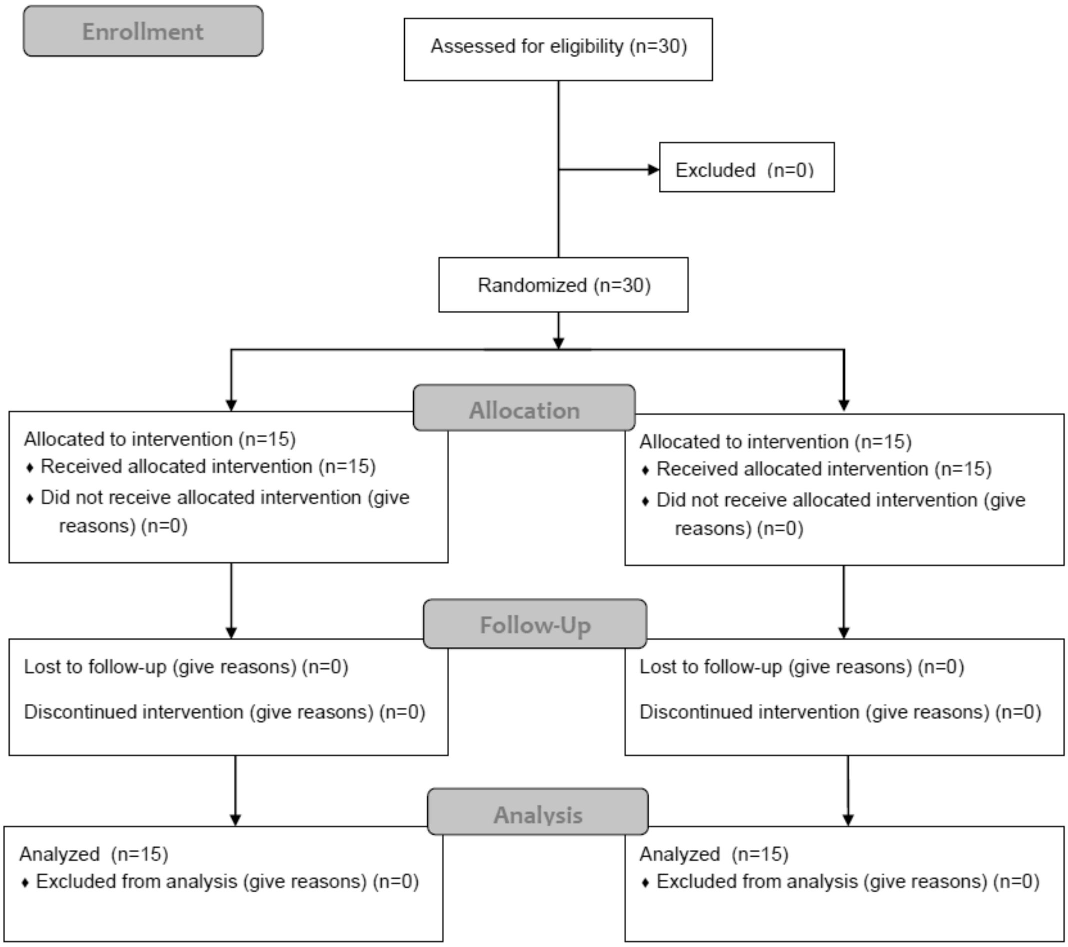

Figure 10 The modified CONSORT 2010 flow diagram

There was no dropped-out of patients in this trial. All thirty patients were divided into 2 groups of experimental group and control group. Both groups were treated orthodontically and this study focused on the leveling and aligning phase until 0.016 x 0.022-inch stainless steel was delivered. There were 15 patients for each group which divided into two groups using simple randomization by drawing lots. All patients were treated by only one operator. The blinding of patients and operator were not possible for this trial. However, assessment of study models and lateral cephalometric radiographs were coded to conceal information of patients.

Intra-examiner reliability revealed no significant differences between repeated measurements (P>.05). The demographic characteristics of patients in the trials were detailed in table 8. There were 5 males and 10 female in control group and 6 male and 9 female in experimental group. At pre-treatment, the mean age of patients in control group was 22.44±4.90

years and the mean age of patients in experimental group was 22.51±3.65 years with no statistically significant difference (*P*=0.968). The initial Irregularity index was 3.91±0.74 mm in control group and 3.59±0.73 mm in experimental group without statistically difference (*P*=0.235). Curve of Spee depth was 3.33±0.52 mm and 3.44±0.50 mm in control and experimental groups respectively. At T_0, all cephalometric analysis values for skeletal evaluation did not reveal any statistical significance (*P*>0.05). Only the treatment time which found a significant difference between two groups in which the experimental group (35.13 weeks) was significantly longer than the control group (26.63 weeks) (*P*<.0001).

Table 8 Descriptive statistics for control and experimental groups

Male : female ratio (%)	**Total (n=30)**		**Control (n=15)**		**Experiment (n=15)**		***P***
	11:19 (36.67%:63.33%)		5:10 (33.33%:66.67%)		6:9 (40.00%:60.00%)		
	mean	**SD**	**Mean**	**SD**	**mean**	**SD**	
Age (years)	22.48	4.17	22.44	4.90	22.51	3.65	0.968
Irregularity index (mm)	3.75	0.74	3.91	0.74	3.59	0.73	0.235
ANB (^{O})	2.38	0.88	2.40	0.91	2.37	0.88	0.749
COS (mm)	3.34	0.47	3.33	0.52	3.44	0.50	0.709
FMA (^{O})	25.88	3.52	24.75	2.93	27.00	3.88	0.284
Treatment time (weeks)	30.88	4.94	26.63	2.13	35.13	2.53	<0.0001*

*Significant difference between groups (P <0.05).

Evaluation of dental changes from model measurements and lateral cephalometric analyses at T_0, T_1 and T_2 are shown in table 9.

Irregularity index was almost resolved completely by 0.014-inch and 0.016-inch superelastic nickel titanium archwires in both groups before the data records at T_1 were taken. At

T_1, the crowding was reduced from 3.91±0.74 mm in the control group and 3.59±0.73 mm in the experimental group to 0.21±0.10 mm and 0.27±0.15 mm (P=0.166) respectively. The lower incisor inclination was increased in both groups. An increasing of 0.75±0.38° was found in the experimental group which significantly less than the control group of 4.38±0.44° (P<0.0001). The crown of lower incisors in both groups moved to labial 1.00±0.00 mm and 0.50±0.00 mm in the control and experimental groups respectively (P=0.655). At T_1-T_0, the lower incisors were intruded in the amount of –0.38±0.23 mm in the experimental group which was significantly less than the control group of –1.13±0.44 mm (P<0.0001) while the curve of Spee was reduced –0.19±0.37 mm in the experimental group and –1.19±0.37 mm in the control group (P>0.05).

For T_2-T_1, there were statistically significant differences in the amount of antero-posterior displacement of lower incisors (P<0.0001), the amount of lower incisor intrusion (P<0.0001) and reduction of the curve of Spee (P<0.001). Lower incisors moved forward for 0.13±0.23 mm in the experimental group while it moved backward for -0.38±0.23 mm in the control group. The intrusive amount of lower inciors was -1.75±0.38 mm in the experimental group and -0.63±0.23 mm in the control group. The curve of Spee was reduced for -2.69±0.37 mm in the experimental group while reduced only -0.50±0.00 mm in the control group. The lower inclination of both groups were proclined. The amount of proclinations were 1.81±0.80 mm and 1.38±0.44 mm in the experimental and control groups, respectively (P=0.408).

At the end of this study which flat 0.016 x 0.022-inch stainless steel archwires were placed for 3 months, the leveling and aligning were considered to be completed and data records at T_2 were taken. At this time point, the total amount of mandibular incisors moved forward was 0.63±0.23 mm in the experimental group which demonstrated labial movement equal to that of the control group (0.63±0.23 mm) (P>0.05). The lower incisor inclination was proclined 2.56±0.94° in the experimental group which was significantly less than in the control group of 5.75±0.89° (P<0.0001). The amount of intruded lower incisors were -2.13±0.35 mm in the experimental group and -1.75±0.60 mm in the control group (P>0.05). The total reduction in the curve of Spee –2.88±0.35 mm in the experimental group which was significantly greater than in the control group of –1.69±0.37 mm (P<0.0001). And neither group experienced the mandibular plane angle changes more than 0.5° (P>0.05).

Table 9 Dental changes from lateral cephalometric and model analysis

Variables		Control (n=15)		Experiment (n=15)		*P*-value
		mean	SD	Mean	SD	
L1 to NB (mm)	T_0	7.38	1.30	8.50	1.31	0.270
	T_1	8.38	1.30	9.00	1.31	0.652
	T_2	8.00	1.22	9.25	1.28	0.202
	T_1-T_0	1.00	0.00	0.50	0.00	0.655
	T_2-T_1	-0.38	0.23	0.13	0.23	<0.0001*
	T_2-T_0	0.63	0.23	0.63	0.23	0.215
L1 to NB (^{O})	T_0	27.38	4.41	33.00	2.00	0.020*
	T_1	31.75	4.12	33.75	2.17	0.419
	T_2	33.13	3.87	35.56	1.97	0.297
	T_1-T_0	4.38	0.44	0.75	0.38	<0.0001*
	T_2-T_1	1.38	0.44	1.81	0.80	0.408
	T_2-T_0	5.75	0.89	2.56	0.94	<0.0001*
FMA (^{O})	T_0	24.75	2.93	27.00	3.88	0.284
	T_1	25.00	2.84	27.25	3.78	0.271
	T_2	25.13	2.76	27.25	3.78	0.302
	T_1-T_0	0.25	0.42	0.25	0.38	0.709
	T_2-T_1	0.17	0.26	0.00	0.00	0.089
	T_2-T_0	0.42	0.49	0.25	0.38	0.486
Irregularity index (mm)	T_0	3.91	0.74	3.59	0.73	0.235
	T_1	0.21	0.10	0.27	0.15	0.166
	T_2	0.07	0.14	0.12	0.09	0.262
	T_1-T_0	-3.70	0.77	-3.31	0.71	0.161
	T_2-T_1	-0.11	0.17	-0.15	0.10	0.694
	T_2-T_0	-3.88	0.79	-3.68	0.74	0.155
Δ L1 vertical (mm)	T_1-T_0	-1.13	0.44	-0.38	0.23	<0.0001*
	T_2-T_1	-0.63	0.23	-1.75	0.38	<0.0001*

Table 9 (Continued)

Variables		**Control (n=15)**		**Experiment (n=15)**		***P*-value**
		mean	**SD**	**Mean**	**SD**	
Irregularity index (mm)	T_2-T_0	-3.88	0.79	-3.68	0.74	0.155
Δ L1 vertical (mm)	T_1-T_0	-1.13	0.44	-0.38	0.23	<0.0001*
	T_2-T_1	-0.63	0.23	-1.75	0.38	<0.0001*
	T_2-T_0	-1.75	0.60	-2.13	0.35	0.569
Δ COS (mm)	T_1-T_0	-1.19	0.37	-0.19	0.37	0.709
	T_2-T_1	-0.50	0.00	-2.69	0.37	0.001*
	T_2-T_0	-1.69	0.37	-2.88	0.35	<0.0001*

*Significant difference between groups (P <0.05)

CHAPTER 4

DISCUSSION

This study aimed to propose the new technique used for reducing lower incisor proclination from the biomechanics of treatment during leveling lower teeth in the early stage of corrective orthodontic treatment.

The finite element study demonstrated the leveling lower teeth by nickel titanium archwires of continuous technique. Tooth leveling by intrusion of lower incisors with labial tipping and extrusion of lower posterior teeth[126] could reduce the curve of Spee and also reduce deep overbite. Relatively intrusion of front teeth by incisor flaring is one of the common occurrence for reducing the curve of Spee. Coincidence with the result from this finite element analysis which found much higher von Mises stress at cervical root area on labial surface than lingual surface in all analysed models. Furthermore, the sites of maximum von Mises stress on labial surface was found at the level which located more cervical than lingual. This pattern of stress distribution would refer to the tipping movement of the observed teeth which came from the intrusive force produced by the archwire that occurred within the incisal bracket slots from continuous archwire deflection when curve of Spee was presented. The explanation of this type of tooth movement could be done by referring to a biomechanics of force which applied labial to the center of resistance of incisors. Yan *et al*[65] confirmed the occurrence of lower incisor proclination by applying the intrusive force at labial crown of lower incisor and observed the generated von Mises stress by finite element analysis which had the highest von Mises stress at labial cervical root area and Lombardo *et al*[64] also studied in finite element model by applying intrusive force at labial crown of lower incisors and found labial displacement occurred which coincided with this result. But the differences were this study used all mandibular teeth with all brackets and buccal tubes were attached to all teeth connected with continuous archwire. The force in this study was applied from the archwire deflection for simulation of the clinical situation when nickel titanium archwire was placed on the teeth with curve of Spee.

In this study we noticed that square and rectangular shaped archwires presented lower von Mises stress than those of round archwire which caused by torque expression which reduced their tipping. Different torque expression is influenced from different archwire size, archwire and bracket materials[136] and bracket slot dimension.[137] This study used archwires with the same height of 0.016-in for better comparison among different cross-section shapes and we found square and rectangular archwires could express its torque effects by lowering distributed stress at labial side and found slightly superior level of maximum stress at lingual side in rectangular archwire. The displacement in Z-direction in square and rectangular archwires were less than round wire which assumed to be more pure intrusion and less labial crown tipping. Round archwire model found highest amount of displacement in Y-axis while the other two models found fewer amount indicated that curve of Spee leveling by round archwire affected mostly from relative intrusion of mandibular incisors by labial tipping movement compared to archwire leveling by square or rectangular archwires.

Tipping movement is a type of orthodontic tooth movement that usually occur.[64] Since this effect had been mentioned, there were many attempts to propose alternative methods for reducing labial tipping of lower incisors while intrusion. Segmented archwire which proposed by Burstone could reduce this effect but statistical test revealed insignificance.[126] Same as orthodontic miniscrew which also found high stress distribution at labial cervical root after performed various lower anterior teeth intrusion with finite element study.[138] This study proved the biomechanic which round wire tipped lower incisors labially when tooth leveling and torque effect from square or rectangular archwires could reduce this flaring.

The positions of maximum von Mises stress were observed at the cervical areas of both labial and lingual root surfaces in all three models which meant that observed teeth were intruded by the archwires made the cervical parts which larger than other parts of its root touched the alveolar socket from its root shape as a cone. However, the maximum von Mises stress at the labial was located higher than the lingual in all models referred to the tooth movement by labial tipping.

This study used the finite element methods to develop the virtual model of mandible with all teeth including the periodontal tissue for hopefully made the model realistically simulated the clinical findings by applying the intrusive force generated from the archwires. This study allowed the range of intrusion limited for 0.2 mm equal to the periodontal space for evaluating the situation of intrusive forces application to lower incisors before the bone remodeling would occur. The finite element analysis could be reproducible and it was available for further investigation of other interested findings.

This study was limited the activation amount of archwire within the periodontal spaces of 0.2 mm before alveolar bone remodeling takes place for further remodeling process and tooth movement can be observed obviously in the clinic. This study investigated of 0.016-inch, 0.016 x 0.016-inch and 0.016 x 0.022-inch nickel titanium archwires to investigate the effects of shape difference on the stress distribution. However, the 0.012-inch and 0.014-inch nickel titanium archwires which were smaller and could gave the lighter force should be evaluation for being the information for clinicians when looking for an appropriated archwire in the leveling stage.

This study generated the force from the archwire deflection passed to brackets, then transferred to teeth, respectively which referred to the clinical situation while previous studies[64, 65] applied the force at the center of crown at labial surface which was the position for labial bracket placement. This study set the intrusive force in certain millimeters of 0.2 mm equal to periodontal space due to the amount of force acted by continuous archwire system could not know.

All maximum von Mises stress observed in periodontal tissues from superelastic nickel titanium archwire deflection in this study were lower than the capillary pulse pressure of 20-26 gm per cm^3 which considered as optimal forces.

For periodontal tissues consideration, mandibular incisor proclination may be an undesirable effect from tooth leveling and aligning. Proclination of lower incisors could lead to the damages of periodontal tissues which effected as alveolar bone dehiscence or gingival recession.[93-95, 97] The results from this clinical trial which controlled lower incisor inclination by rectangular beta-titanium archwire for better torque control[139] and light force application might effectively reduce these risks. The experimental technique was more effective for reduced lower incisor proclination than the conventional technique. In both groups of conventional and experimental techniques in this study could effectively resolve mild degree of anterior dental crowding by round superelastic nickel titanium archwires in both straight and accentuated curve of Spee forms which usually be the main objective for this early stage of treatment.[140] The first archwire used in this study was a 0.014-inch round nickel titanium archwire in 0.018-inch brackets, was suggested to be suitable as an initial archwire due to its play in the slot.[141]

During tooth aligning with round archwires with accentuated curve of Spee was significantly less labial tipping than the straight archwire group. The straight round nickel titanium archwires in the control group could increase the degree of proclination of lower incisors during this phase due to the intrusive force was applied on the lower incisors which located labial to the center of resistance. This mechanic may be the main cause which to the control group showed more intrusion with flaring compared to another group at T_1. Nickel titanium archwires with preformed accentuated curve of Spee matched to an individual's occlusal curvature may be an appropriate alternative technique for achieving alignment when the lower incisor proclination is not indicated or in cases which a flat curve is undesirable.

The tooth leveling in early stage could help reducing an excessive overbite. In the experimental group, tooth leveling was achieved by gradually reduce the curve of Spee while maintaining torque control in a rectangular beta-titanium archwire. While in the control group, lower teeth were levelled along with aligned by increasing the archwire size progressively until flat rectangular 0.016 x 0.022-inch stainless steel. During this stage since square and rectangular archwires were used, several differences between groups were noted related to dental changes of lower incisors. Changes were minimal noticed in the control group compared to the changes at T_1. Conversely, the significant lower incisor intrusion in the experimental group was seen, accompanied by minimal proclination which found no statistically significant difference compared to those occurred in the control group. Thus, most of the curve of Spee reduction in the experimental group was achieved during this stage. While the control group, most of intrusion had already achieved at T_1 from the flaring of lower incisors.

At the end of this study that alignment and leveling were achieved at T_2, the total changes of the mandibular incisor inclinations between the two groups were statistically significant differences, but the amount of differences were small and may not be clinically significant. Both groups found lower incisors labial displaced with different patterns. In the control group, the results of tooth movements indicated lower incisors moved to labial during round archwire were used but they were slightly tipped back lingually after the rectangular archwires, exhibiting a round-tripping movement. While the experimental group exhibited lower incisors slightly moved labially during aligning with accentuated curve of Spee nickel titanium archwires and continued moved more labially after levelled with rectangular archwires, but the overall changes were less than the control group. Another finding was the curve of Spee correction in the experimental group was significantly flatter than in the control group from the archwire bending which gradually reduced the curve of Spee.

A previous study[42] reported the proclination effect of mandibular incisors was from the curve of Spee correction. This study found lower incisor proclination 5.75° after 1.69 mm of tooth leveling in the control group while, in the experimental group, lower incisor proclination was less due to the torque effect of rectangular archwires. A previous study of AlQabandi *et al*[109] initially levelled lower teeth with rectangular nickel titanium archwires. This archwire material was not stiff enough and could not express their torque control which the significant difference compared to conventional leveling was not found. The study of Meling and Odegaard[139] found rectangular beta-titanium archwire was stiffer than nickel titanium archwire for 1.6 times. This study used the rectangular beta-titanium archwires for curve of Spee leveling in the experimental group which may be more suitable from their torque effectiveness plus their ability to produce the light forces which was recommended for lower incisor intrusion.[142]

This study constructed the experiment as a prospective randomized clinical trial by separating the leveling and alignment stage into a two-part technique. This technique consisted of the firstly align the teeth and then flatten the curve of Spee by torque-controlled of the lower incisor methods. As the final result of this study, the controlled lower incisor torque technique exhibited a significantly less incisor inclination change despite of achieving more curve of Spee reduction. These amount of differences were small but may be important for patients in which larger amounts of incisor proclination are contraindicated. However, these results may only be applicable to patients with pre-treatment characteristics similar to those enrolled in this study: non-extraction patients with crowding in the mandibular anterior teeth of 3–5 mm and 3–4 mm COS.

CHAPTER 5

CONCLUSION

The intrusive forces from archwire leveling produced labial tipping of mandibular incisors especially when levelled with round archwires affected labial root surfaces and periodontal tissues with high von Mises stress. Separating aligning phase from leveling phase found when levelled with rectangular beta titanium archwire found less proclination of mandibular incisors compared to conventional leveling and alignment with straight archwires.

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APPENDICES

RESEARCH ETHICS COMMITTEE (REC)
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Documentary Proof of Ethical Clearance
Research Ethics Committee (REC)
Faculty of Dentistry, Prince of Songkla University

The Project Entitled	:	Reduction of Mandibular Incisor Proclination during Leveling and Aligning Phase in Non-Extraction Orthodontic Treatment
REC Project No.	:	EC6101-05-P-HR
Principal Investigator	:	Assoc.Prof.Dr.Chairat Charoemratrote
Affiliation	:	Department of Preventive Dentistry, Faculty of Dentistry, PSU
Co-Principal Investigator	:	Mr.Pornpat Theerasopon
Affiliation	:	Department of Preventive Dentistry, Faculty of Dentistry, PSU

Approved Documents :

- ☑ Submission Form
- ☑ Research Proposal
- ☑ Other ...
    1) Data Sheet

Approved by Research Ethics Committee (REC), Faculty of Dentistry, Prince of Songkla University.

This is to certify that REC is in full compliance with International Guidelines for Human Research Protection such as the Declaration of Helsinki, the Belmont Report, CIOMS Guidelines and the International Conference on Harmonization in Good Clinical Practice (ICH-GCP).

This review is documented in the meeting minutes of the meeting 2/2018
Agenda 4.2.3 on 22 FEBRUARY 2018

Please submit the Progress Report every 12 months. (Renewal must be submitted at least 30 days prior to expired date.)

(For Exemption Determination, Please submit a Final Report after study completion)

Surapong Vongvatcharanon

(Asst.Prof.Surapong Vongvatcharanon)

Acting on Behalf of Chairman of Research Ethics Committee

Date of Approval : 30 MARCH 2018

Date of Expiration : 29 MARCH 2019

คณะกรรมการจริยธรรมการวิจัยในมนุษย์
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คณะทันตแพทยศาสตร์
มหาวิทยาลัยสงขลานครินทร์
15 ถนนกาญจนวณิชย์
อ.หาดใหญ่ จ.สงขลา 90110

หนังสือฉบับนี้ให้ไว้เพื่อรับรองว่า

โครงการวิจัยเรื่อง การลดยื่นของฟันตัดล่างในขั้นตอนการปรับระดับและเรียงฟันในการรักษาทางทันตกรรมจัดฟันโดยไม่ถอนฟัน

รหัสโครงการ EC 6101-05-P-HR

หัวหน้าโครงการ รองศาสตราจารย์ ดร.ทพ.ไชยรัตน์ เฉลิมรัตนโรจน์

สังกัด ภาควิชาทันตกรรมป้องกัน คณะทันตแพทยศาสตร์

ผู้ร่วมวิจัย ทันตแพทย์พรพัฒน์ ธีรโสภณ

สังกัด ภาควิชาทันตกรรมป้องกัน คณะทันตแพทยศาสตร์

เอกสารที่รับรอง:

- ☑ แบบเสนอโครงการวิจัย
- ☑ โครงร่างการวิจัย
- ☑ อื่น ๆ
  1) แบบบันทึกการเก็บข้อมูล

ได้ผ่านการพิจารณาและได้รับความเห็นชอบจากคณะกรรมการจริยธรรมในการวิจัย (Research Ethics Committee) ซึ่งเป็นคณะกรรมการพิจารณาศึกษาการวิจัยในคนของคณะทันตแพทยศาสตร์ มหาวิทยาลัยสงขลานครินทร์ ดำเนินการให้การรับรองโครงการวิจัยตามแนวทางหลักจริยธรรมการวิจัยในคนที่เป็นสากล ได้แก่ Declaration of Helsinki, the Belmont Report, CIOMS Guidelines และ the International Conference on Harmonization in Good Clinical Practice (ICH-GCP)

บรรจุในวาระการประชุมครั้งที่ 2/2562 **วาระที่** 3.2.5 **วันที่** 28 กุมภาพันธ์ 2562

ขอให้ผู้วิจัยรายงานความก้าวหน้าโครงการวิจัย ทุก ๆ 12 เดือน และยื่นต่ออายุก่อนถึงวันหมดอายุอย่างน้อย 30 วัน (กรณีโครงการวิจัยเข้าข่าย Exemption Determination ไม่ต้องรายงานความก้าวหน้าต่อคณะกรรมการจริยธรรม แต่ขอให้รายงานสรุปโครงการวิจัยเมื่อสิ้นสุดโครงการ)

(รองศาสตราจารย์ ดร.ทพ.ไชยรัตน์ เฉลิมรัตนโรจน์)
ประธานคณะกรรมการจริยธรรมในการวิจัย

วันที่รับรอง : 30 มีนาคม 2562

วันหมดอายุ : 29 มีนาคม 2563

ใบเชิญชวน

ขอเชิญเข้าร่วมโครงการวิจัยเรื่อง การลดยื่นของฟันตัดล่างในขั้นตอนการปรับระดับและเรียงฟันในการรักษาทางทันตกรรมจัดฟันโดยไม่ถอนฟัน

เรียน ท่านผู้อ่านที่นับถือ

ข้าพเจ้า ทพ.พรพัฒน์ ธีรโสภณ นักศึกษาหลักสูตรปรัชญาดุษฎีบัณฑิต สาขาวิทยาศาสตร์สุขภาพช่องปาก (ทันตกรรมจัดฟัน) คณะทันตแพทยศาสตร์ มหาวิทยาลัยสงขลานครินทร์ ซึ่งอยู่ภายใต้การดูแลของ รศ.ดร.ทพ.ไชยรัตน์ เฉลิมรัตนโรจน์ และ รศ.ดร.ทพญ. ชิดชนก ลีธนะกุล ใคร่ขอเล่าถึงโครงการวิจัยที่กำลังทำอยู่และขอเชิญชวนท่านเข้าร่วมโครงการนี้

การรักษาทางทันตกรรมจัดฟันโดยไม่ถอนฟันเพื่อแก้ไขปัญหาฟันหน้าซ้อนเก มักพบฟันหน้าล่างที่เอียงออกไปทางด้านริมฝีปากมากขึ้นจากการปรับระดับและเรียงฟัน ซึ่งจะเพิ่มความเสี่ยงต่อการละลายของสันกระดูกเบ้าฟันในด้านใกล้ริมฝีปากโดยเฉพาะในผู้ป่วยที่มีลักษณะเหงือกที่บาง และอาจพบสภาวะของเหงือกที่ร่นตามมาในอนาคต โครงการวิจัยนี้จึงนำเสนอวิธีแก้ไขปัญหาฟันหน้าซ้อนเกที่สามารถลดการเอียงไปด้านริมฝีปากในฟันตัดล่าง เพื่อศึกษาประสิทธิผลของเทคนิคที่ใช้ และผลต่อระดับของกระดูกเบ้าฟันภายหลังการปรับระดับและเรียงฟัน

โครงการวิจัยนี้จะแบ่งผู้เข้าร่วมโครงการออกเป็น 2 กลุ่มโดยวิธีการสุ่ม ได้แก่ กลุ่มศึกษา และกลุ่มควบคุม โดยผู้ป่วยทุกคนจะได้รับการรักษาทางทันตกรรมจัดฟันตามมาตรฐานการรักษาของคลินิกทันตกรรมจัดฟัน โรงพยาบาลทันตกรรม คณะทันตแพทยศาสตร์ มหาวิทยาลัยสงขลานครินทร์ โดยโครงการวิจัยนี้จะเก็บข้อมูลเฉพาะในช่วงแรกของการรักษาทางทันตกรรมจัดฟัน คือ ในขั้นตอนการปรับระดับและเรียงฟัน ซึ่งขั้นตอนนี้มีวัตถุประสงค์เพื่อแก้ไขปัญหาฟันซ้อนเก และทำให้ระดับของฟันเรียงเรียบในแนวระนาบ โดยทั้งสองกลุ่มจะใช้อุปกรณ์การจัดฟันแบบติดแน่น (แบร็กเกต) และลวดชนิดเดียวกัน ต่างกันเฉพาะรูปร่างของลวดที่ใช้ โดยในกลุ่มควบคุมจะใช้ลวดตรงตลอดการรักษาตามมาตรฐานการรักษาปกติ ส่วนในกลุ่มศึกษาจะใช้ลวดที่มีความโค้งในแนวดิ่งตามลักษณะความโค้งของฟันเพื่อเรียงฟันแก้ไขการซ้อนเก จากนั้นจึงค่อยๆลดความโค้งในแนวดิ่งลงในลวดที่สามารถควบคุมแนวแกนฟันซึ่งคาดว่าจะช่วยลดการเอียงของแกนฟันตัดล่างไปทางด้านริมฝีปากซึ่งเป็นผลดีต่ออวัยวะปริทันต์ของกลุ่มตัวอย่างได้

ถ้าท่านตัดสินใจเข้าร่วมในโครงการนี้จะมีขั้นตอนของการวิจัยที่เกี่ยวข้องกับท่านคือได้รับการเก็บประวัติและถ่ายภาพรังสีตามมาตรฐานการรักษาของคลินิกทันตกรรมจัดฟัน โรงพยาบาลทันตกรรม คณะทันตแพทยศาสตร์ มหาวิทยาลัยสงขลานครินทร์ และเพิ่มการถ่ายภาพรังสีส่วนตัดอาศัยคอมพิวเตอร์ชนิดโคนบีม ซึ่งเป็นภาพรังสี 3 มิติที่จะทำให้เห็นรายละเอียดของกระดูกรอบรากฟันได้ชัดเจนยิ่งขึ้น จำนวน 2 ครั้ง คือ ก่อนการรักษา และหลังการปรับระดับและเรียงฟัน โดยภาพรังสี 3 มิติที่เพิ่มเติมนี้ ทางคณะผู้วิจัยจะเป็นผู้รับผิดชอบค่าใช้จ่ายแทนผู้เข้าร่วมโครงการ โดยประโยชน์จากภาพรังสีนี้จะสามารถใช้ประเมินลักษณะของกระดูกเบ้าฟันได้ชัดเจนกว่าภาพรังสีตามปกติ และสามารถใช้ติดตามลักษณะของกระดูกรอบรากฟันซึ่งอาจเปลี่ยนแปลงได้จากการเปลี่ยนแกนฟันตัดล่างได้ และนอกจากท่านจะได้รับการรักษาตามวิธีมาตรฐานอย่างครบถ้วนแล้ว ท่านจะได้รับการตรวจสภาวะปริทันต์ และตรวจฟันอย่างสม่ำเสมอในทุกๆเดือนที่เข้ารับการรักษา และภายหลังการเก็บข้อมูลในขั้นตอนการปรับระดับและเรียงฟันเสร็จสิ้น ผู้ป่วยจะได้รับการรักษาที่เหมาะสมจนเสร็จสมบูรณ์ ระหว่างการดำเนินโครงการหากมีการตรวจพบความผิดปกติเกิดขึ้น ผู้ป่วยจะได้รับการรักษาในรูปแบบอื่นที่เหมาะสมตามมาตรฐานต่อไปทันที

ในการถ่ายภาพรังสีทุกครั้งผู้ป่วยจะได้รับการสวมเสื้อตะกั่วป้องกันรังสี อีกทั้งปริมาณรังสีที่ใช้ในทางทันตกรรม และในโครงการวิจัยนี้มีปริมาณที่น้อย ซึ่งไม่ส่งผลกระทบต่ออวัยวะใดอันเนื่องมาจากการได้รับรังสี ผู้ป่วยที่ยินยอมเข้าร่วมโครงการจะได้รับการรักษาโดยที่ไม่ต้องรอคิวจัดฟัน แต่ต้องเสียค่าใช้จ่ายในการจัดฟันตามปกติ โดยมีค่าใช้จ่ายในการเก็บข้อมูล, พิมพ์ปาก, ถ่ายรูป, การจัดฟันแบบติดแน่น และ ภาพถ่ายรังสีในการรักษา ซึ่งเป็นค่ารักษาในอัตราปกติของคลินิกทันตกรรมจัดฟัน และแผนกรังสี โรงพยาบาลทันตกรรม คณะทันตแพทยศาสตร์ มหาวิทยาลัยสงขลานครินทร์ ส่วนค่าใช้จ่ายในการถ่ายภาพรังสี 3 มิติ ซึ่งเพิ่มเติมจากการรักษาตามมาตรฐาน ทางคณะผู้วิจัยจะรับผิดชอบค่าใช้จ่ายในส่วนนี้ให้จำนวน 6,000 บาท (หกพันบาทถ้วน)

ทั้งนี้ผู้รับผิดชอบโครงการวิจัยนี้คือ ทพ.พรพัฒน์ ธีรโสภณ สถานที่ติดต่อ ภาควิชาทันตกรรมป้องกัน คณะทันตแพทยศาสตร์ มหาวิทยาลัยสงขลานครินทร์. เบอร์โทรศัพท์ 0-7442-9875 หรือ 08-6860-1500 โดยมี รศ.ดร.ทพ.ไชยรัตน์ เฉลิมรัตนโรจน์ และ รศ.ดร.ทพญ. ชิดชนก ลีธนะกุล เป็นอาจารย์ที่ปรึกษา สถานที่ติดต่อ ภาควิชาทันตกรรมป้องกัน คณะทันตแพทยศาสตร์ มหาวิทยาลัยสงขลานครินทร์. เบอร์โทรศัพท์ 0-7442-9875 หรือเมื่อมีปัญหาใดๆ เกิดขึ้นเนื่องจากการทำวิจัยในเรื่องนี้สามารถร้องเรียนไปที่คณะกรรมการจริยธรรมในการวิจัย

หน่วยส่งเสริมและพัฒนางานวิจัย คณะทันตแพทยศาสตร์ มหาวิทยาลัยสงขลานครินทร์ อ. หาดใหญ่ จ.สงขลา 90112 โทรศัพท์ 0-7428-7504

ไม่ว่าท่านจะเข้าร่วมในโครงการวิจัยนี้หรือไม่ ท่านจะยังคงได้รับการรักษาตามมาตรฐานเช่นเดียวกับผู้ป่วยคนอื่นๆ และถ้าท่านต้องการที่จะถอนตัวออกจากการศึกษานี้เมื่อใด ท่านก็สามารถกระทำได้อย่างอิสระ

หากท่านมีคำถามใด ๆ ก่อนที่จะตัดสินใจเข้าร่วมโครงการนี้ โปรดซักถามคณะผู้วิจัยได้อย่างเต็มที่

ขอขอบคุณเป็นอย่างสูง

ทพ.พรพัฒน์ ธีรโสภณ
ผู้ดำเนินโครงการวิจัย

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ภาควิชาทันตกรรมป้องกัน คณะทันตแพทยศาสตร์
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หมายเหตุ :- กรุณาอ่านข้อความให้เข้าใจก่อนเซ็นชื่อยินยอมเข้าร่วมโครงการ

แบบยินยอมเข้าร่วมการศึกษา

โครงการวิจัยเรื่อง

"การลดยื่นของฟันตัดล่างในขั้นตอนการปรับระดับและเรียงฟันในการรักษาทางทันตกรรมจัดฟันโดยไม่ถอนฟัน"

วันที่……..เดือน……………..………พ.ศ………..……

ข้าพเจ้า………………………………………..…….. อายุ ………………. ปี

อาศัยอยู่บ้านเลขที่ …………….. ถนน ……………..……… ตำบล…………………..……….....

อำเภอ …………………..….……….. จังหวัด ……........…………………………………......

ได้อ่าน/ได้รับการอธิบายจากผู้วิจัยถึงวัตถุประสงค์ของการวิจัย วิธีการวิจัย อันตรายหรืออาการที่อาจเกิดขึ้นจากการวิจัย รวมทั้งประโยชน์ที่จะเกิดขึ้นจากการวิจัยอย่างละเอียดและมีความเข้าใจดีแล้ว

หากข้าพเจ้าได้รับผลข้างเคียงจากการวิจัย ข้าพเจ้าจะได้รับการปฏิบัติ/การชดเชย โดยจะได้รับการรักษาที่เหมาะสมจนเสร็จสมบูรณ์ แม้จะล่วงเลยเวลาการทำวิจัย โดยที่ไม่มีค่าใช้จ่ายเพิ่มเติม โครงการวิจัยนี้มีผู้รับผิดชอบโครงการฯ คือ ทพ.พรพัฒน์ ธีรโสภณ ภาควิชาทันตกรรมป้องกัน คณะทันตแพทยศาสตร์ มหาวิทยาลัยสงขลานครินทร์ เบอร์โทรศัพท์ 0-7442-9875 หรือ 08-6860-1500 ซึ่งมี รศ.ดร.ทพ.ไชยรัตน์ เฉลิมรัตนโรจน์ และ รศ.ดร.ทพญ.ชิดชนก ลีธนะกุล ภาควิชาทันตกรรมป้องกัน คณะทันตแพทยศาสตร์ มหาวิทยาลัยสงขลานครินทร์ เบอร์โทรศัพท์ 0-7442-9875 เป็นอาจารย์ที่ปรึกษา หรือเมื่อมีปัญหาใดๆ เกิดขึ้นเนื่องจากการทำวิจัยในเรื่องนี้ ข้าพเจ้าสามารถร้องเรียนไปที่ คณะกรรมการจริยธรรมในการวิจัย หน่วยส่งเสริมและพัฒนางานวิจัย คณะทันตแพทยศาสตร์ มหาวิทยาลัยสงขลานครินทร์ อ.หาดใหญ่ จ.สงขลา 90112 โทรศัพท์ 0-7428-7504

หากผู้วิจัยมีข้อมูลเพิ่มเติมทั้งด้านประโยชน์และโทษที่เกี่ยวข้องกับการวิจัยนี้ ผู้วิจัยจะแจ้งให้ข้าพเจ้าทราบอย่างรวดเร็ว โดยไม่ปิดบัง

ข้าพเจ้ามีสิทธิที่จะของดการเข้าร่วมโครงการวิจัยโดยมิต้องแจ้งให้ทราบล่วงหน้าโดยการงดการเข้าร่วมการวิจัยนี้ จะไม่มีผลกระทบต่อการได้รับบริการหรือการรักษาที่ข้าพเจ้าจะได้รับแต่ประการใด

ผู้วิจัยรับรองว่าจะเก็บข้อมูลเฉพาะที่เกี่ยวกับตัวข้าพเจ้าเป็นความลับ จะไม่เปิดเผยข้อมูลหรือผลการวิจัยของข้าพเจ้าเป็นรายบุคคลต่อสาธารณชน จะเปิดเผยได้เฉพาะในรูปที่เป็นสรุปผลการวิจัย หรือการเปิดเผยข้อมูลต่อผู้มีหน้าที่ที่เกี่ยวข้องกับการสนับสนุนและกำกับดูแลการวิจัย

ข้าพเจ้าได้อ่าน/ได้รับการอธิบายข้อความข้างต้นแล้ว และมีความเข้าใจดีทุกประการ จึงได้ลงนามในใบยินยอมนี้ด้วยความเต็มใจโดยนักวิจัยได้ให้สำเนาแบบยินยอมที่ลงนามแล้วกับข้าพเจ้าเพื่อเก็บไว้เป็นหลักฐาน จำนวน 1 ชุด

ลงชื่อ...ผู้ยินยอม วันที่ ....

ลงชื่อ..หัวหน้าโครงการ วันที่ ....

ลงชื่อ...พยาน วันที่ ....

ลงชื่อ...พยาน วันที่ ....

แบบยินยอมเข้าร่วมการศึกษา

โครงการวิจัยเรื่อง

“การลดยื่นของฟันตัดล่างในขั้นตอนการปรับระดับและเรียงฟันในการรักษาทางทันตกรรมจัดฟัน โดยไม่ถอนฟัน”

วันที่…………..เดือน……………………..……พ.ศ……….……

ข้าพเจ้า...
ผู้ปกครองของ ด.ช./ด.ญ./นาย/น.ส.. อายุ.............ปี
อาศัยอยู่บ้านเลขที่……….ถนน……………………...……ตำบล……….……..……….….……
อำเภอ…….……….…….………..จังหวัด…….……….……….…….……….…….………….....
ได้อ่าน/ได้รับการอธิบายจากผู้วิจัยถึงวัตถุประสงค์ของการวิจัย วิธีการวิจัย อันตรายหรืออาการที่อาจเกิดขึ้นจากการวิจัยหรือจากยาที่ใช้ รวมทั้งประโยชน์ที่จะเกิดขึ้นจากการวิจัยอย่างละเอียดและมีความเข้าใจดีแล้ว

หากข้าพเจ้าได้รับผลข้างเคียงจากการวิจัย ข้าพเจ้าจะได้รับการปฏิบัติ/การชดเชย โดยจะได้รับการรักษาที่เหมาะสมจนเสร็จสมบูรณ์ แม้จะล่วงเลยเวลาการทำวิจัย โดยที่ไม่มีค่าใช้จ่ายเพิ่มเติม โครงการวิจัยนี้มีผู้รับผิดชอบโครงการฯ คือ ทพ.พรพัฒน์ ธีรโสภณ ภาควิชาทันตกรรมป้องกัน คณะทันตแพทยศาสตร์ มหาวิทยาลัยสงขลานครินทร์ เบอร์โทรศัพท์ 0-7442-9875 หรือ 08-6860-1500 ซึ่งมี รศ.ดร.ทพ.ไชยรัตน์ เฉลิมรัตนโรจน์ และ รศ.ดร.ทพญ.ชิดชนก ลีธนะกุล ภาควิชาทันตกรรมป้องกัน คณะทันตแพทยศาสตร์ มหาวิทยาลัยสงขลานครินทร์ เบอร์โทรศัพท์ 0-7442-9875 เป็นอาจารย์ที่ปรึกษา หรือเมื่อมีปัญหาใดๆ เกิดขึ้นเนื่องจากการทำวิจัยในเรื่องนี้ ข้าพเจ้าสามารถร้องเรียนไปที่ คณะ กรรมการจริยธรรมในการวิจัย หน่วยส่งเสริมและพัฒนางานวิจัย คณะทันตแพทยศาสตร์ มหาวิทยาลัยสงขลานครินทร์ อ.หาดใหญ่ จ.สงขลา 90112 โทรศัพท์ 0-7428-7504

หากผู้วิจัยมีข้อมูลเพิ่มเติมทั้งด้านประโยชน์และโทษที่เกี่ยวข้องกับการวิจัยนี้ ผู้วิจัยจะแจ้งให้ข้าพเจ้าทราบอย่างรวดเร็ว โดยไม่ปิดบัง

ข้าพเจ้ามีสิทธิที่จะของดการเข้าร่วมโครงการวิจัยโดยมิต้องแจ้งให้ทราบล่วงหน้าโดยการงดการเข้าร่วมการวิจัยนี้ จะไม่มีผลกระทบต่อการได้รับบริการหรือการรักษาที่ข้าพเจ้าจะได้รับแต่ประการใด

ผู้วิจัยรับรองว่าจะเก็บข้อมูลเฉพาะที่เกี่ยวกับตัวข้าพเจ้าเป็นความลับ จะไม่เปิดเผยข้อมูลหรือผลการวิจัยของข้าพเจ้าเป็นรายบุคคลต่อสาธารณชน จะเปิดเผยได้เฉพาะในรูปที่เป็นสรุปผลการวิจัย หรือการเปิดเผยข้อมูลต่อผู้มีหน้าที่ที่เกี่ยวข้องกับการสนับสนุนและกำกับดูแลการวิจัย

ข้าพเจ้าได้อ่าน/ได้รับการอธิบายข้อความข้างต้นแล้ว และมีความเข้าใจดีทุกประการ จึงได้ลงนามในใบยินยอมนี้ด้วยความเต็มใจโดยนักวิจัยได้ให้สำเนาแบบยินยอมที่ลงนามแล้วกับข้าพเจ้าเพื่อเก็บไว้เป็นหลักฐาน จำนวน 1 ชุด

ลงชื่อ………..……….………………ผู้ยินยอม

ลงชื่อ…………………………………บิดา/มารดา/ผู้ใช้อำนาจปกครอง

ลงชื่อ…………………....……………หัวหน้าโครงการ

ลงชื่อ…………………………..………พยาน

ลงชื่อ……………………….…………..พยาน

หมายเหตุ : ผู้เข้าร่วมโครงการที่ยังไม่บรรลุนิติภาวะและสามารถเขียนหนังสือได้ให้เซ็นชื่อยินยอมเข้าร่วมโครงการด้วย

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List of Publication and Proceeding

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