การศึกษาพื้นที่ทางเดินหายใจส่วนต้นจากภาพรังสีวัดกะโหลกศีรษะด้านข้างในผู้ป่วยจัดฟันไทยที่มีการเจริญเติบโต ซึ่งมีโครงสร้างใบหน้าด้านข้างแบบต่างๆ

นางสาวเจนตา ชะวะนะเวช

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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คณะทันตแพทยศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2557

CEPHALOMETRIC STUDY OF UPPER PHARYNGEAL AIRWAY SPACE IN GROWING THAI ORTHODONTIC PATIENTS WITH DIFFERENT SAGITTAL SKELETAL PATTERNS

Miss Janeta Chavanavesh

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Orthodontics
Department of Orthodontics
Faculty of Dentistry
Chulalongkorn University
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Thesis Title	CEPHALOMETRIC STUDY OF UPPER PHARYNGEAL AIRWAY SPACE IN GROWING THAI ORTHODONTIC PATIENTS WITH DIFFERENT SAGITTAL SKELETAL PATTERNS
By	Miss Janeta Chavanavesh
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เจนตา ชะวะนะเวช : การศึกษาพื้นที่ทางเดินหายใจส่วนต้นจากภาพรังสีวัดกะโหลกศีรษะด้านข้างในผู้ป่วยจัดฟันไทยที่มีการเจริญเติบโต ซึ่งมีโครงสร้างใบหน้าด้านข้างแบบต่างๆ (CEPHALOMETRIC STUDY OF UPPER PHARYNGEAL AIRWAY SPACE IN GROWING THAI ORTHODONTIC PATIENTS WITH DIFFERENT SAGITTAL SKELETAL PATTERNS) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: รศ. ทญ. ดร.ศิริมา เพ็ชรดาชัย, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม: อ. ทญ. ดร.วรรณาภรณ์ ชื่นชมพูนุท{, 133 หน้า.

วัตถุประสงค์การศึกษา ส่วนที่หนึ่ง เพื่อประมาณค่าเฉลี่ยของขนาดทางเดินหายใจส่วนต้น ศึกษาอิทธิพลของเพศ อายุกระดูก และรูปแบบใบหน้าด้านข้างที่มีต่อขนาดทางเดินหายใจส่วนต้น และขนาดและตำแหน่งของอวัยวะรอบข้างของทางเดินหายใจ และหาความสัมพันธ์ระหว่างขนาดทางเดินหายใจส่วนต้นและอวัยวะรอบข้าง ส่วนที่สอง เพื่อศึกษาความสัมพันธ์ของการวัดขนาดทางเดินหายใจส่วนต้นโดยภาพรังสีวัดกะโหลกศีรษะด้านข้าง ภาพรังสีวัดกะโหลกศีรษะด้านข้างที่สร้างจากภาพรังสีสามมิติ และภาพรังสีสามมิติ

วัสดุและวิธีการ ส่วนที่หนึ่ง เก็บข้อมูลภาพรังสีวัดกะโหลกศีรษะด้านข้างจำนวน 418 ภาพ ของผู้ป่วยจัดฟันคณะทันตแพทยศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย ซึ่งมีการเจริญเติบโตอยู่ อายุ 6-20 ปี (เฉลี่ย 13.95±3.62 ปี) โดยแบ่งเป็น 3 กลุ่มตามอายุกระดูกต้นคอคือ ก่อนวัยเจริญพันธุ์ (CS 1,2) วัยเจริญพันธุ์(CS 3,4) และหลังวัยเจริญพันธุ์(CS 5,6) จากนั้นทำการวัดค่าตัวแปรต่างๆ ได้แก่ ระยะทาง 13 ตัวแปร มุม 12 ตัวแปร และพื้นที่ 3 ตัวแปร และวิเคราะห์ข้อมูลโดยใช้สถิติการวิเคราะห์ความแปรปรวนแบบหลายทาง การวิเคราะห์ปัจจัย การวิเคราะห์ความสัมพันธ์ชนิดเพียร์สันและสเปียร์แมน ในการเปรียบเทียบอิทธิพลของเพศ อายุกระดูก และรูปแบบใบหน้าด้านข้าง และความสัมพันธ์ของตัวแปรต่างๆ รวมทั้งตัวแปรเชิงมุมใหม่ที่ใช้วัดตำแหน่งของลิ้นและกระดูกไฮออยด์ กับตัวแปรเชิงระยะทางที่มีอยู่ ส่วนที่สอง เก็บข้อมูลภาพรังสีวัดกะโหลกศีรษะด้านข้าง 21 ภาพ และภาพรังสีสามมิติ 21 ภาพ ของผู้ป่วยจัดฟันคนเดียวกัน ซึ่งถ่ายในช่วงระยะเวลารักษาเดียวกัน และทำการศึกษาตัวแปรต่างๆ ได้แก่ ระยะทาง 5 ตัวแปร พื้นที่ 3 ตัวแปร และปริมาตร 3 ตัวแปร และวิเคราะห์ข้อมูล โดยใช้สถิติการทดสอบค่าเฉลี่ยสองกลุ่มที่สัมพันธ์กันในการเปรียบเทียบการวัดขนาดทางเดินหายใจจากภาพรังสีวัดกะโหลกศีรษะด้านข้าง และภาพรังสีวัดกะโหลกศีรษะด้านข้างที่สร้างจากภาพรังสีสามมิติ การวิเคราะห์ความสัมพันธ์ชนิดเพียร์สันเพื่อหาความสัมพันธ์ของการวัดขนาดทางเดินหายใจส่วนต้นโดยภาพรังสีวัดกะโหลกศีรษะด้านข้างและภาพรังสีสามมิติ

ผลการศึกษา ส่วนที่หนึ่ง พบว่าผู้ที่อยู่ในช่วงหลังวัยเจริญพันธุ์ มีโครงสร้างใบหน้าด้านข้างแบบที่ 3 และเพศชาย จะมีขนาดทางเดินหายใจใหญ่กว่ากลุ่มอื่น เนื่องจากอวัยวะโดยรอบมีตำแหน่งที่อยู่หน้ากว่ากลุ่มอื่น และยังพบว่าอายุกระดูก ตำแหน่งของขากรรไกรล่าง ลิ้นและกระดูกไฮออยด์ รวมทั้งขนาดของลิ้นมีความสัมพันธ์เชิงบวกอย่างมีนัยสำคัญกับขนาดทางเดินหายใจ การวัดขนาดทางเดินหายใจเชิงเส้นมีความสัมพันธ์อย่างมีนัยสำคัญกับการวัดขนาดทางเดินหายใจเชิงพื้นที่สูงปานกลาง และตำแหน่งเชิงมุมของลิ้นและกระดูกไฮออยด์มีความสัมพันธ์อย่างมีนัยสำคัญกับตำแหน่งเชิงเส้น ส่วนที่สอง พบว่า ไม่มีความแตกต่างของการวัดขนาดทางเดินหายใจแบบสองมิติ ระหว่างภาพรังสีวัดกะโหลกศีรษะด้านข้าง และภาพรังสีวัดกะโหลกศีรษะด้านข้างที่สร้างจากภาพรังสีสามมิติ และการวัดขนาดทางเดินหายใจแบบสองมิติมีความสัมพันธ์ที่ดีกับการวัดปริมาตรทางเดินหายใจแบบสามมิติ

สรุปผลการศึกษา แม้ขนาดทางเดินหายใจจะมีความแตกต่างกันในแต่ละบุคคล แต่พบความสัมพันธ์ระหว่างเพศ อายุกระดูก รูปแบบใบหน้าด้านข้าง ขนาดและตำแหน่งของอวัยวะรอบข้างของทางเดินหายใจ และขนาดทางเดินหายใจส่วนต้นในผู้ยังมีการเจริญเติบโตอยู่ โดยความกว้างทางเดินหายใจหลังเพดานและเพดานอ่อน และตำแหน่งเชิงมุมของลิ้นและกระดูกไฮออยด์จัดเป็นตัวแปรที่ดีในการศึกษาขนาดทางเดินหายใจและตำแหน่งของลิ้นและกระดูกไฮออยด์

ภาควิชา ทันตกรรมจัดฟัน	ลายมือชื่อนิสิต ....
สาขาวิชา ทันตกรรมจัดฟัน	ลายมือชื่อ อ.ที่ปรึกษาหลัก ....
ปีการศึกษา 2557	ลายมือชื่อ อ.ที่ปรึกษาร่วม ....

5675802332 : MAJOR ORTHODONTICS

KEYWORDS: GROWING / CONE-BEAM COMPUTED TOMOGRAPHY (CBCT) / PHARYNGEAL AIRWAY / PHARYNGEAL STRUCTURES / LATERAL CEPHALOMETRIC RADIOGRAPH / SEXUAL DIMORPHISM / SKELETAL AGE / SAGITTAL SKELETAL PATTERN

JANETA CHAVANAVESH: CEPHALOMETRIC STUDY OF UPPER PHARYNGEAL AIRWAY SPACE IN GROWING THAI ORTHODONTIC PATIENTS WITH DIFFERENT SAGITTAL SKELETAL PATTERNS. ADVISOR: ASSOC. PROF. DR.SIRIMA PETDACHAI, CO-ADVISOR: DR.VANNAPORN CHUENCHOMPOONUT{, 133 pp.

Objective: Part I aimed to estimate means of upper pharyngeal airway dimensions, evaluate the effects of sex, skeletal age, and sagittal skeletal patterns on the upper pharyngeal airway dimension, and position and dimension of surrounding structures, and to test the ability of new angular variables in measuring hyoid and tongue position. Part II aimed to correlate upper pharyngeal airway dimension measured by lateral cephalometric radiographs, reconstructed lateral cephalometric radiographs, and CBCT scans.

Materials and Methods: Part I consisted of 418 pretreatment lateral cephalometric radiographs of growing orthodontic patients [6-20 years old; mean age, 13.95±3.62 years; divided into 3 skeletal ages, pre-pubertal (CS 1,2), pubertal (CS 3,4), and post-pubertal (CS 5,6)], Faculty of Dentistry, Chulalongkorn University were collected. 12 angular, 13 linear, and 3 area cephalometric measurements were analyzed. The three-way ANOVA, Factor analysis, Pearson’s and Spearman’s correlation analysis were applied to compare sex, skeletal age, and sagittal skeletal pattern differences and variable correlations, including the new angular measurements and the existing linear measurements of tongue and hyoid. Part II consisted of 40 presurgical radiographs; 20 lateral cephalometric radiographs and 20 CBCT scans taken in the same period of treatment time. 5 linear, 3 area, and 3 volume airway measurements were analyzed. Paired *t*-test was applied to compare upper pharyngeal airway measurements from lateral cephalometric radiographs and reconstructed lateral cephalometric radiographs. Pearson’s correlation coefficient was applied to correlate 2D linear and area measurements and 3D volumetric measurements.

Results: Part I, Post-pubertal, Skeletal Class III, and male subjects had larger airway dimensions due to more anteriorly positioned surrounding structures than others. Skeletal ages, positions of mandible, tongue and hyoid, and tongue size significantly and positively correlated with pharyngeal airway dimensions. Linear airway measurements presented moderately high correlation with the area measurements. Angular measurements of tongue and hyoid position showed significantly moderate to high correlation with linear measurements. Part II, 2D airway measurements from lateral cephalometric radiographs were not different from reconstructed lateral cephalomeric radiographs, and correlated well with 3D volumetric measurements from CBCT.

Conclusion: Although there was inter-individual variability in upper pharyngeal airway, relationships among sex, skeletal ages, sagittal skeletal patterns, surrounding structures and upper pharyngeal airway dimensions in growing subjects were found. Airway widths behind the palate and soft palate, and angular hyoid and tongue positions were good parameters to measure nasopharyngeal and oropharyngeal airway width, and tongue and hyoid position.

Department: Orthodontics	Student's Signature ....
Field of Study: Orthodontics	Advisor's Signature ....
Academic Year: 2014	Co-Advisor's Signature ....

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Introduction

1.1. Background and rationale

Orthodontics is a branch of dentistry that involves changes of the position and alignment of the teeth. Orthopedic treatment or orthognathic surgery may be needed in some cases to modify growth or change the jaw position. The treatment affects the soft tissue profile, hyoid and tongue position, including upper pharyngeal airway. The nasopharynx and the oropharynx have significant locations and functions as they play vital roles in respiration and deglutination(1). The upper pharyngeal airway may be increased or decreased from orthopedic treatment or orthognathic surgery, which, in long term, affect the stability in the retention period. Moreover, the decreased pharyngeal airway may result in development of sleep-disordered breathing (SDB). SDB ranges from chronic or habitual snoring to upper airway resistance and to obstructive sleep apnea (OSA), in which many factors have been involved. The prevalence of OSA in children ranges from 0.7% to 2%(2), as well as in Thai children (0.69%)(3). OSA in childhood can lead to improper development of craniofacial complex and OSA in adulthood(4). Therefore, it might be useful if the assessment of the pharynx is included in the orthodontic diagnosis and treatment planning as well as the functional, positional, and structural assessment of the dentofacial pattern(1). During the past few decades, upper pharyngeal airway dimensions and their relationship to craniofacial complex in normal population(5, 6) and the patients with obstructive sleep apnea (OSA) has been interesting issues for orthodontists(4). Previous studies in Thai population aimed at comparison of airway dimensions among vertical and horizontal skeletal patterns, based on FMA and ANB angles, in non-growing normal population(7), and in patients with nasopharyngeal pathology(8). Means of upper pharyngeal airway width and area, including the skeletal and soft tissue variables in normal subjects without nasopharyngeal pathology(9), and in different sagittal and vertical skeletal patterns(7) were also reported. Jamsirirojrat et al(8) and Banhiran et al(10) compared the bony and soft tissue parameters in snoring patients with the OSA patients. However, there were some pharyngeal airway studies(1, 4, 5, 11-14) in growing population, but, mostly in nasopharyngeal region and a specific range of age group. However, limitations of lateral cephalometric radiograph which provides 2D data of the 3D structures, including pharyngeal airway, have been discussed(7, 15, 16). Moreover, it had been reported that the position of hyoid bone differed significantly between OSA patients and normal subjects(8, 10, 17, 18), and correlated with apnea-hypopnea index (AHI), i.e. index used in diagnosis of OSA severity, in children(4) and adults(19). The existing parameters used to describe hyoid position were linear measurements. Therefore, the purposes of this study were, firstly, to retrospectively compare the upper pharyngeal airway dimensions between sexes, among different skeletal ages, and sagittal skeletal patterns, including correlation among pharyngeal airway dimensions, bony and soft tissue variables, and skeletal ages; and to develop and test the ability of new parameters in measuring hyoid and tongue position; and secondly, to correlate the upper pharyngeal airway dimension measured from 2-dimesional (2D) radiographs; lateral cephalometric radiographs and reconstructed lateral cephalometric radiographs, and 3-dimesional (3D) radiographs; cone beam computed tomography (CBCT) in growing Thai orthodontic patients of Orthodontic department, Faculty of Dentistry, Chulalongkorn University.

1.2. Research questions

1.2.1. Were there any differences in upper pharyngeal airway dimensions and surrounding structures among growing Thai orthodontic patients with different sagittal skeletal patterns?

1.2.2. Were there any differences in upper pharyngeal airway dimensions measured by lateral cephalometric radiographs, reconstructed lateral cephalometric radiographs, and CBCT scans in growing Thai orthodontic patients?

1.3. Hypotheses

1.3.1. Upper pharyngeal airway dimensions and surrounding structures among growing Thai orthodontic patients with different sagittal skeletal patterns were different.

1.3.2. Upper pharyngeal airway dimensions in growing Thai orthodontic patients measured by lateral cephalometric radiographs, reconstructed lateral cephalometric radiographs, and CBCT scans were different.

1.4. Objectives

1.4.1. To estimate means of the upper pharyngeal airway dimensions among growing Thai children with different sagittal skeletal patterns

1.4.2. To compare means of the upper pharyngeal airway dimensions among growing Thai children with different sagittal skeletal patterns

1.4.3. To correlate upper pharyngeal airway dimensions of growing Thai children with bony and soft tissue variables

1.4.4. To compare upper pharyngeal airway dimensions measured by lateral cephalometric radiographs and reconstructed lateral cephalometric radiographs

1.4.5. To correlate upper pharyngeal airway dimensions measured by lateral cephalometric radiographs and CBCT scans

1.5. Conceptual framework

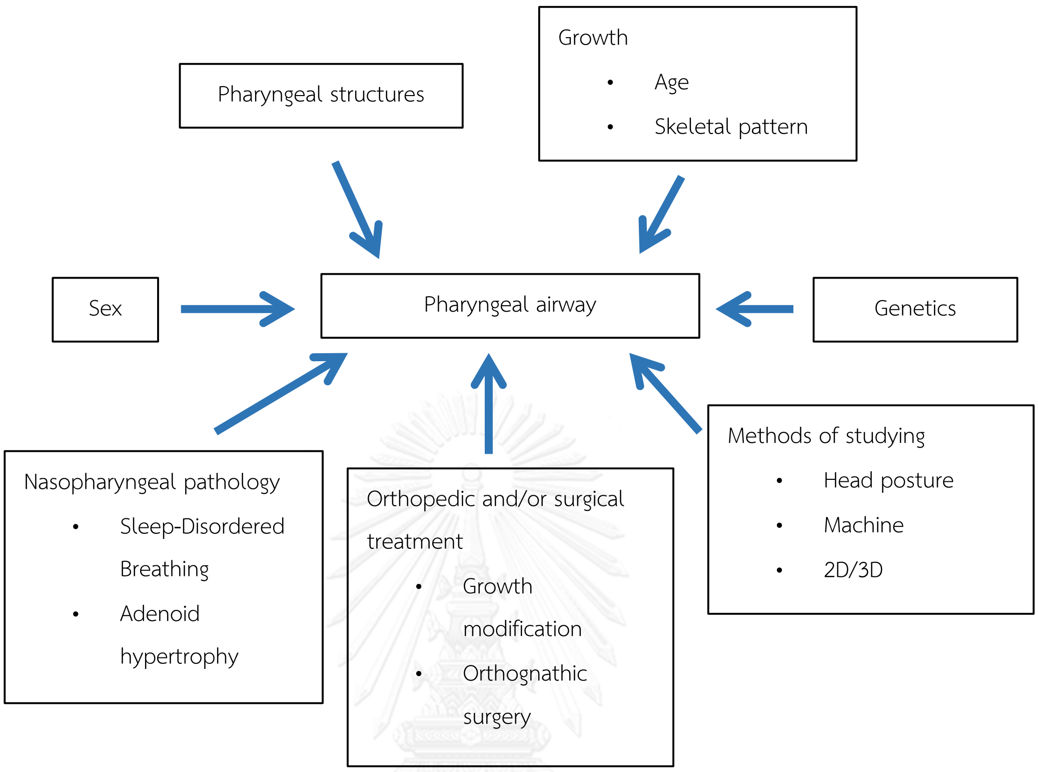

Figure 1 Conceptual framework of the present study

1.6. Ethical considerations

This research was approved by the ethical committee of Faculty of Dentistry, Chulalongkorn University on March 3, 2015 (HREC-DCU 2015-005).

Chapter 2

Review of literatures

2.1. Anatomy of Pharynx

The neonatal pharynx is a mere 4 centimeters long, which is about 1/3 of the adult pharynx. The pharynx gradually enlarges, and reaches adult size at the age of 6(20, 21). The pharyngeal tube extends from the base of skull to the lower border of cricoid cartilage.

The surrounding bony structures consist of :

- Superiorly: cranial base
- Posteriorly: cervical spine
- Antero-superiorly: nasal septum
- Anteriorly: jaws and hyoid bone
- Inferiorly: cricoid cartilage

Pharynx can be divided into 3 portions (figure 2). They are: -

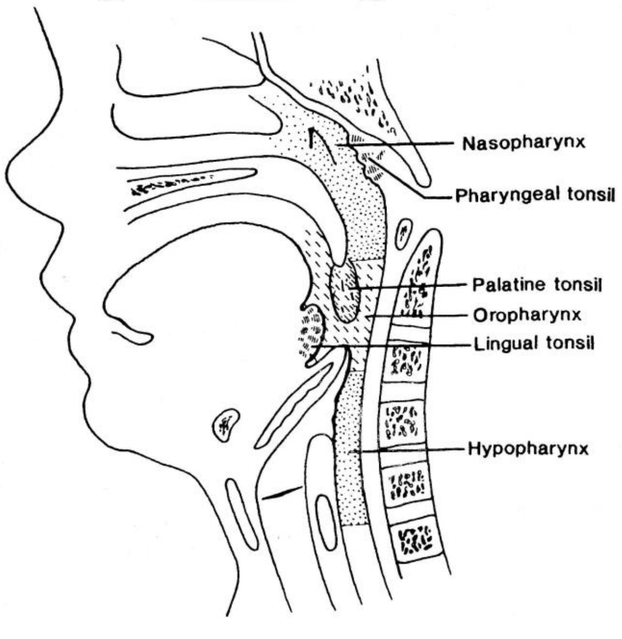

Figure 2 Anatomy of pharynx (21)

2.1.2. Nasopharynx: locates behind the nasal cavity

The boundaries of the nasopharynx are as follows.

2.1.2.1. Anteriorly: nasal cavity

2.1.2.2. Superiorly and posteriorly: posterior pharyngeal wall, which curves from sphenoidal air sinuses posteriorly to anterior arch of atlas (1^{st} cervical vertebra). This area lies the adenoids (pharyngeal tonsils), which are large in childhood and gradually decrease in size in adulthood. In childhood, the relatively large adenoids and relatively small nasopharynx can cause nasal and Eustachian tube obstruction.

2.1.2.3. Laterally: torus tubarius, a bulge of cartilage of the eustachian tube, which connects the middle ear and the nasopharynx.

2.1.2.4. Inferiorly: upper border of soft palate

2.1.3. Oropharynx : locates behind the oral cavity

The boundaries of the oropharynx are as follows.

2.1.3.1. Anteriorly: oral cavity and base of tongue. The lingual tonsil is found on the tongue base. Between the tongue and the epiglottis lies a median mucosal fold, glossoepiglottic fold. Laterally, two mucosal folds, pharyngoepiglottic folds, extend from the junction of the tongue and the lateral pharyngeal wall to the epiglottis. The epiglottic vallecula is between the pharyngoepiglottic folds.

2.1.3.2. Superiorly: junction between soft palate and posterior pharyngeal wall

2.1.3.3. Posteriorly : posterior pharyngeal wall at the level of 2^{nd} to 3^{rd} cervical vertebrae (CV2-CV3)

2.1.3.4. Laterally: posterior pharyngeal wall, palatine tonsils which are in the tonsillar fossa, the area between the palatoglossal arch and the palatopharyngeal arch.

2.1.3.5. Inferiorly: upper border of epiglottis

2.1.4. Hypopharynx (laryngopharynx): locates behind the oral cavity

The boundaries of the hypopharynx are as follows.

2.1.4.1. Anteriorly: epiglottis, laryngeal inlet, and larynx

2.1.4.2. Superiorly: upper border of epiglottis which connects to the oropharynx above

2.1.4.3. Posteriorly : posterior pharyngeal wall at the level of 4th to 6th cervical vertebrae (CV4-CV6)

2.1.4.4. Laterally: posterior pharyngeal wall

2.1.4.5. Inferiorly: lower border of cricoid cartilages, at the level of 6th cervical vertebra (CV6) which connects to the esophagus below.

2.2. Several factors affecting pharyngeal airway dimensions

2.2.1. Growth and Development of pharynx

2.2.1.1. Age: growing, non-growing

Many studies(13, 22, 23) of growth of nasopharynx in the growing subjects, the antero-posterior width of nasopharyngeal airway increases from age 4 to 16 years. The width is narrowest at age 4-5 years, slightly increased during age 5-10 years, and then, after the age of 11. The bony nasopharynx gradually increased in width from age 4 to 16 years. The maximal width is at age 14-15 years in boys, and age 12-13 years in girls, which is in consonant with general growth of the body. The bony nasopharynx is larger in boys than in girls. Tourne(6) found that the bony nasopharyngeal width reaches its peak at the age of 1-2, after that, the nasopharynx grows in vertical direction.(24, 25)

This is in the same pattern of the general growth of the body. The growth will cease around 20 years old(26).

The study of growth of oropharynx in growing samples, Mislik et al(5) found that the antero-posterior oropharyngeal airway width behind soft palate gradually increases from age 6 to 17 years. The antero-posterior oropharyngeal airway width behind the tongue base slightly decreases during age 6-12 years, then, gradually increases until age 17 years. Growth of the bony oropharynx is in the same direction as the bony nasopharynx, which will reach its maximal width at the age of 1-2, after that, the bony oropharynx grows mainly in vertical direction following the growth of the cervical vertebrae until adulthood. The rapid growth occurs in 2 periods, during age 5-7 years and age 12-17 years.(6)

The study of growth of nasopharynx in non-growing samples, Johnston et al(27) found that the antero-posterior bony nasopharyngeal width remains unchanged after 20 years, while the antero-posterior nasopharyngeal airway width increases as a result of the decreasing in soft tissue thickness of posterior nasopharyngeal wall. Moreover, the vertical growth of nasopharynx is found until adulthood.

The study of growth of oropharynx in non-growing samples, Johnston et al(27) found that the antero-posterior bony oropharyngeal width is constant, though, the oropharyngeal airway space behind the soft palate gradually decreases with increasing age. This explains the development of OSA, which correlates to the narrow bony oropharynx and oropharyngeal airway space(18, 28-30). The oropharyngeal airway space behind the tongue base remains unchanged, which reflects the adaptation of head and tongue position in order to maintain the airway patency. Whereas, McNamara(31) found that the oropharyngeal airway space behind the soft palate will become wider with increasing age. In addition, the soft palate length and thickness also increase with increasing age. This relates to many studies(18, 28, 30) which found that the soft palate of the OSA patient is longer and thicker than normal person. The incidence of OSA increases with increasing age as well.(32)

However, growth and maturation of an individual can be assessed by skeletal age from hand-wrist radiograph or lateral cephalometric radiograph (cervical vertebral maturation). The skeletal age does not correlate well with chronological age(33, 34). Preston et al(13) reported growth of nasopharynx in relation to chronological age compared with skeletal age, which measured by hand-wrist radiograph. They found that pubertal growth spurts were clearer when the data were arranged by skeletal age. Moreover, Suvanprateeb and Petdachai(35) found that peak mandibular growth in Thai skeletal Class III subjects occured during the cervical stage(CS) 3 and 4 according to cervical vertebral maturation(CVM) method described by Baccetti et al(36).

2.2.1.2. Skeletal patterns: sagittal, vertical

Because of the close relationship of the pharynx and dentofacial structures, including occlusion, a mutual interaction is expected to occur between the pharyngeal structures and the dentofacial pattern(37); and therefore it justifies orthodontic interest. Ceytan and Oktay(1) found that the pharyngeal structures are not affected by the changes of the ANB angle. On the contrary, many later studies(7, 38-42) found that pharyngeal airway distances, areas, and volumes have a close relationship with the increasing ANB angle and the mandibular prognathism(14). Battagel et al(43) found that the change in antero-posterior position of mandible affect hyoid position and pharyngeal airway space. Mislik et al(5) found that pharyngeal airway width correlates to the SNA and SNB angle. However, no relationship was found between pharyngeal airway width and the ANB angle. Iwasaki et al(44) also found that the subjects with Class III malocclusion have flat-shaped oropharynx in the antero-posterior dimension.

Joseph et al(45) found that the vertical skeletal patterns affect the pharyngeal airway dimension. The hyperdivergent facial pattern has a narrower pharyngeal airway width than the normodivergent facial pattern, especially in nasopharynx at the level of hard palate and oropharynx at the level of soft palate tip and mandible. Thinner posterior pharyngeal wall and lower level of tongue and hyoid bone are presented in the hyperdivergent facial pattern. Moreover, the hyperdivergent facial pattern has more posterior position of maxillary and mandibular dental bases and shows the characteristic of skeletal Class II discrepancy more than the normodivergent facial pattern. Later studies(7, 41) also found the same correlation that the pharyngeal airway decreases when the FMA increases.

2.2.2. Pharyngeal structures

2.2.2.1. Soft palate and tongue: movable structures

Since soft palate and tongue are movable structures, they could change their position coincidentally during speech or swallowing. These might affect the reliability of pharyngeal airway assessment from radiographs.

You et al(46) classified the morphology of soft palate from lateral cephalometric radiographs into 6 types; leaf-shaped (lanceolate), rat-tail shaped, butt-like shaped, straight line-shaped, S-shaped, crook-shaped (figure 3). They reported that most frequent type of soft palate morphology was leaf-shaped (40-53%)(46, 47), followed by rat-tail shaped (18.5%), butt-like shaped (13.5%), straight line-shaped (10%), S-shaped (3.5%), and least frequent type, crook-shaped (1.5%). In pre-adult group, there were more cases presented butt-like shaped soft palate, while, rat-tail shaped and straight line-shaped soft palates were more common in adult group. Other shape of soft palate, apart from these 6 types, could be assumed as abnormal. Pepin et al(48) reported that the soft palate with hooked or S-shaped appearance indicated a high risk for OSA.

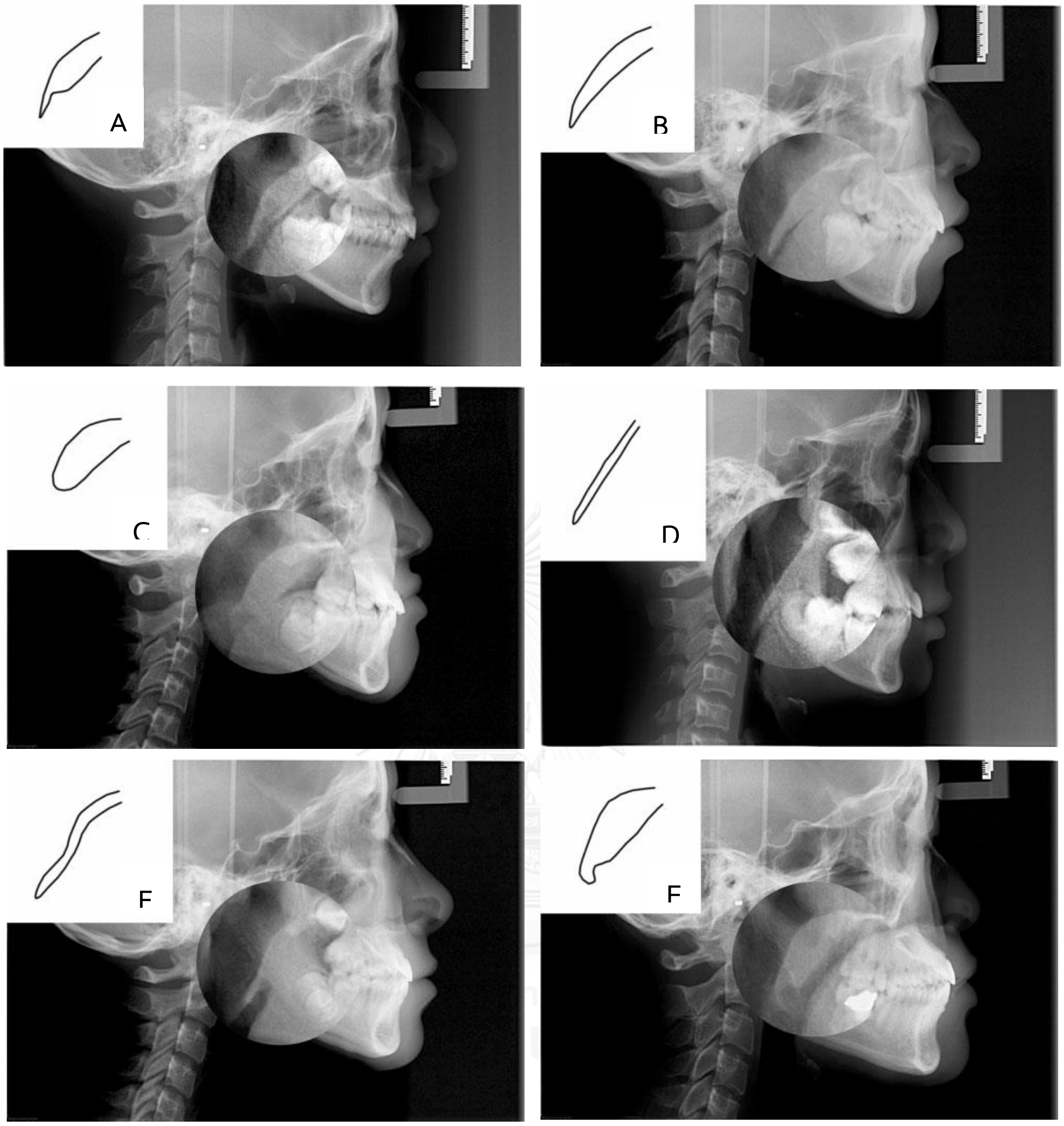

Figure 3 Soft palate morphology (46) A= type 1: ‘‘leaf-shaped’’ (lanceolate); the middle portion of the soft palate is elevated to both the naso- and oro-side; B=Type 2: ‘‘rat-tail shaped’’; the anterior portion is inflated and the free margin has an obvious coarctation; C= Type 3: a ‘‘butt-like shaped’’; the length of the soft palate in this type is about one-third to three-quarters of that of the leaf shape. The width has almost no distinct difference from the anterior portion to the free margin; D= Type 4: ‘‘straight line’’; E= Type 5: distorted soft palate, which presents the ‘‘S-shape’’; F= Type 6: ‘‘crook-shaped’’ appearance of the soft palate, in which the posterior portion of the soft palate crooks anterio-superiorly

Previous study(49) about habitual and relaxed tongue position from lateral cephalometric radiographs reported that there were three classification of tip-of-tongue contact (figure 4). Habitual postural position presented the tip of the tongue in contact with the incisor teeth and/or lips in 86.4 %, contact with both upper and lower incisor teeth in 61.3 %, not in contact with the incisors in 13.6 %; and the dorsum in contact with the hard palate in 33% and with the soft palate in 75.7 %. Relaxed postural position presented a more convex curvature of the dorsum, no contact of the tip of the tongue with the incisor teeth, and no contact of the dorsum with the hard palate, although soft palate contact is maintained in 72.8 %. During swallowing, tongue shape changes, the dorsum of tongue would not be smooth curve (figure 5)(50).

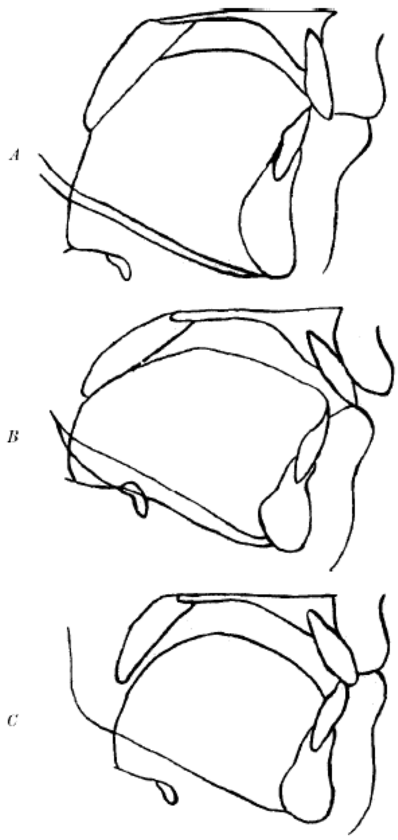

Figure 4 Classification of tip-of-tongue contact (49) *A*, contacting upper and lower incisor crowns; *B*, contacting lower incisor crown only; *C*, contacting neither crown

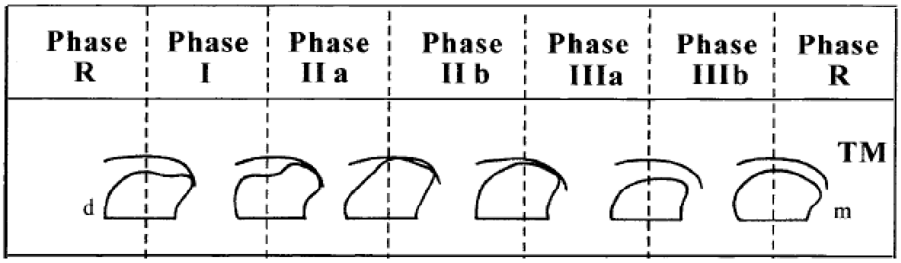

Figure 5 Tongue movement during swallowing (50) The dorsum of tongue would not be smooth convex curvature during swallowing

2.2.2.2. Adenoid and tonsils

Subtelny et al(51) found that the maximal thickness of soft tissue surrounding posterior nasopharyngeal wall (adenoids) occurs during age 9-15 years, then, gradually decreases. On the contrary, later studies(13, 22) found that the thickness of adenoid reaches its maximum at age 4-5 years, and gradually decreases to the age of 10, then, slightly increases during age 10-11 years, and continues to decrease after that. In individual cases, intact tonsils have been found in children as young as 3 years of age or as old as 14 years of age(2).

The tonsils and adenoids are very small at birth and enlarge as a result of increased immunologic activity(52). Adenoid hypertrophy generally leads to OSAS in patients between 2 and 5 years, whereas tonsillar hypertrophy is more often associated with OSAS in patients between 6 and 8 years. In younger children, the larger size of the adenoids due to the relatively small nasopharynx seems to cause a more significant obstruction than in older children(2). Moreover, enlargement of the lingual tonsils is also common in children with persistent obstructive sleep apnea after palatine tonsillectomy and adenoidectomy, particularly in patients with Down syndrome(53).

Tonsils were considered markedly enlarged when greater than 10 mm in anterior-posterior diameter and abutting both the posterior border of tongue and the posterior pharyngeal wall. The assessment and diagnosis of adenoidal hypertrophy is an important issue. Numerous methods have been used for this task (figure 6)(54), i.e. symptom score(54, 55) (frequency of snoring, mouth breathing or nasal obstruction, observed sleep apnea, acute otitis media, recurrent pharyngitis); transoral digital palpation and mirror examination (impractical with uncooperative younger children); lateral radiographs of the neck (subjective grading (figure 7)(56), adenoid thickness, adenoidal-nasopharyngeal (AN) ratio(57), airway to soft palate ratio(58), percentage of airway occlusion(54)); fibre-optic video rhinoscopy (percentage of airway obstruction caused by adenoids in the post nasal space(54)). Moreover, previous studies(22, 23) reported that adenoid size negatively correlated with nasopharyngeal airway dimensions.

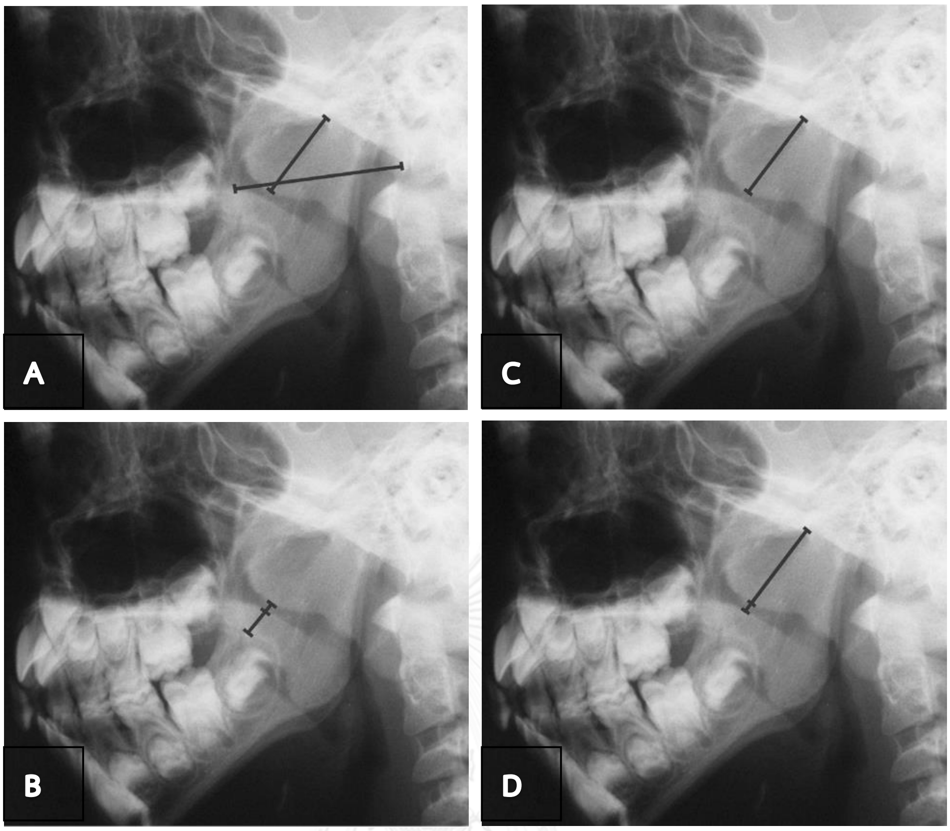

Figure 6 Methods of assessing adenoid enlargement on lateral neck radiography (54) *A*, Adenoid to nasopharynx ratio; *B*, airway to soft palate ratio; *C*, adenoid thickness; *D*, percentage of airway occlusion, measured as the ratio of adenoid thickness and the distance from the pharyngeal tubercle to the superior surface of the soft palate.

Figure 7 Adenoid grading (56) *A*, grade 1 indicates that less than 50% of the airway is obstructed; *B*, grade 2 indicates that more than 50% but less than 100% of the airway is obstructed; and C, grade 3 indicates that a near-total to total obstruction is observed.

2.2.3. Genetics

Billing et al(59) found that genetics had an influence on the pharyngeal airway dimension, adenoid thickness, and nasopharyngeal airway width. No statistically significant difference was found in the parameters of the nasopharyngeal airway between monozygotic and dizygotic twins. Genetics had more influence on bony structures than soft tissues. Moreover, Schawb et al(60, 61) reported that the volume of the lateral pharyngeal walls, tongue, and total soft tissue significantly demonstrated heritability when compared the OSA patients and their siblings with the normal controls and their siblings, after adjusting for sex, ethnicity, age, visceral neck fat, and craniofacial dimensions. These indicated that heritability of the upper airway soft tissue structures was found in both normal subjects and patients with apnea.

2.2.4. Sexual difference

Many studies(1, 24, 31) found that sex had an influence on the pharyngeal airway dimension. Males had larger pharyngeal airway size than females. Martin et al(23) also found that nasal fossa length, cranial base length, and adenoid thickness were larger in males than females. Samman et al(62) found that the angular and ratio measurements showed no different between sexes. Jeans et al(25) found that the area of nasopharyngeal soft tissue remained constant in boys after the age of 6, while gradually decreased in girls from age 9 to 19 years. On the other hand, many studies(5, 40) reported that sex had no effect on the pharyngeal airway dimension.

2.2.5. **Nasopharyngeal pathology** : SDB, OSA

Sleep-disordered breathing (SDB) ranges from chronic or habitual snoring to upper airway resistance and to OSA. The factors involved in OSA development are anatomic factors that predispose the airway to collapse during inspiration, such as narrow pharynx; insufficient neuromuscular compensation during sleep to maintain airway patency(5, 63); obesity; environmental factors; genetic and ethnicity(64). The prevalence of obstructive sleep apnea in children ranges from 0.7% to 2%(2), as well as in Thai children (0.69%)(3). Obstructive sleep apnea in childhood can lead to improper development of craniofacial complex and obstructive sleep apnea in adulthood(4). The results are adaptation of muscular system by head extension to preserve airway(65, 66), or changing from nose breather to mouth breather, achieved by lowering the mandible, that causes the tongue to move downward and forward, and the head to be more extensive.(16, 67) If this situation prolongs, especially, in the active growth period, the facial structures will grow more in vertical direction(1, 6, 68). In combination with short lip or weak lip muscle, this is called the long face syndrome or adenoid facies(1, 37).

The major cause of SDB in children is enlargement of adenoids and tonsils(4, 5, 52), and other common causes of obstructive sleep apnea in childhood that occurs at oral and oropharyngeal area are macroglossia, facial retrusion, neurologic deficit, glossoptosis, mass and cyst, tonsil and adenoid hypertrophy, inflammation of pharynx. Although adenotonsillar hypertrophy is the major cause of SDB in childhood(4, 5, 52), enlargement of the lingual tonsils is increasingly being recognized as a cause, even after adenotonsillectomy(69).

The gold-standard for diagnosis of OSA, both in children and adults, is overnight polysomnography in the sleep laboratory(2, 70). The parameters measured in polysomnography are total sleep time, distribution of sleep stages (hypnogram), sleep latency: time between going to bed and sleep; REM latency: time to the first REM phase; arousal index: incidence of arousals per hour of sleep; desaturation frequency; distribution of oxygen saturation; apnea index: apneas per hour of sleep; apnea-hyponea index (AHI): frequency of apneas and hypopneas per hour of sleep; mean respiratory rate in sleep; mean heart rate in sleep, variability in heart rate; attacks of bradycardia with desaturation; sleep positions; snoring(2). In children, OSA consists of shorter apnea and hyponea periods associated with pediatric respiration rates. An apneic event lasts for the duration of two lost breaths in children, about 6 seconds. Hyponea in children refers to a drop in airflow by at least 50% and associated with 3% desaturation of arterial oxygen. American Academy of Sleep Medicine (2005) defined that children with an AHI of 1-5 events per hour is indicated very mild OSA, 5-10 events per hour is mild OSA, 10-20 events per hour is moderately severe OSA, and greater than 20 event per hours is severe OSA(70).

Moreover, MRI studies revealed that parapharyngeal muscle hypertrophy and/or enlargement of non-adipose soft tissues cause lateral narrowing of pharyngeal airway in OSA(71). Shorter dimension of cranial base, shorter maxillary and mandibular length, maxilla-mandibular retrognathia related to nasion perpendicular plane, long lower face height, high mandibular plane angle, and downward and backward position of hyoid, reduced size of bony pharynx, decreased sagittal dimensions of upper pharyngeal airway, larger tongue and soft palate, and protrusion of inferior turbinates into nasopharyngeal airway(72) are also the craniofacial factors that relate to OSA(4, 10, 28-30).

2.2.6. Orthopedic and/or surgical treatment

2.2.6.2. The effect of growth modification on pharyngeal airway

Facemask, head gear, functional appliance have been used to promote maxillary growth and/or inhibit mandibular growth for many decades. Many studies also found that they caused changing in pharyngeal airway. Oktay et al(67) found that there were statistically significant increase in nasopharyngeal airway and oropharyngeal airway from maxillary protraction appliance in patients with retrusive maxilla. Sayinsu et al(73) reported the increase only in nasophayngeal airway. However, several studies(74, 75) found no statistically significant change in pharyngeal airway from promoting maxillary growth by growth modification appliance. Tuncer et al(76) found that the chin cup treatment increased nasopharyngeal airway area, while did not decrease the oropharyngeal airway.

2.2.6.3. The effect of orthognathic surgery on pharyngeal airway

Orthognathic surgery is one of the methods used to correct the skeletal discrepancies in adult, which can advance and/or set back the maxilla or mandible. Many studies found that orthognathic surgery affected size of pharyngeal airway. Because dental base, tongue base, hyoid bone, and pharyngeal airway are connected by muscles and tendons, mandibular setback operation will push the tongue posteriorly, resulting in narrowing the pharyngeal airway.(77, 78)

Cakarne et al(79) studied the effect of maxillary advancement in combination with mandibular setback operation on pharyngeal airway and concluded that, 8 months post-operation, nasopharyngeal airway size statistically significantly increased, while oropharyngeal airway and hypopharyngeal airway remained unchanged. On the contrary, Pereira-Filbo et al(80) found that the size of nasopharyngeal airway increased, but hypopharyngeal airway size decreased. The finding was constant after 1 year-follow-up. However, oropharyngeal airway size increased at first, then, gradually decreased to nearly original size before surgery. Panou et al(81) reported no change in pharyngeal airway dimension, except, the reduction in volume of lower and total pharyngeal airway 3.9 months post-operation in males. No correlation was found between the amount of mandibular setback and the change in pharyngeal airway volume.

Pereira-Filbo et al(80) studied the maxillary advancement operation and found that there were increase in nasopharyngeal airway and oropharyngeal airway without any change in hypopharyngeal airway. These were found to be constant even 1 year post-operation. Aydemir et al(82) reported only an increase in nasopharyngeal airway.

Some studies in the effects of mandibular setback operation(80, 83) found that hypopharyngeal airway dimension decreased non-significantly. Nevertheless, several studies(77, 84, 85) reported a statistically significant decrease in pharyngeal airway, a correlation between the amount of mandibular setback and the reduction in pharyngeal airway, including a change in hyoid position. Riley et al(86) also reported a development of obstructive sleep apnea in patients with prognathic mandible undergone mandibular setback surgery.

2.2.7. Methods of studying pharynx and head posture

Several methods used to study pharyngeal airway space are physical examination, nasopharyngoscopy, nasal airway resistance, and a number of imaging techniques, i.e. lateral cephalometric radiograph, postero-anterior (PA) cephalometric radiograph, and 3D radiography (CBCT: cone beam computed tomography or MRI : magnetic resonance imaging)(71). Lateral cephalometric radiograph is considered as an easy, non-invasive methods, giving less radiation dose than CBCT, and reliably showing both bony and soft tissue structures of upper pharyngeal airway(4). Several reports showed that studying nasopharyngeal airway using lateral cephalometry was as reliable as endoscopy(54, 87-89), CT (72, 90-92), and MRI(93). Major et al(89) concluded that lateral cephalometry was a useful screening tool to determine the need for more rigorous ENT follow-up. Jeans et al(25) suggested that area measurement was more trustworthy than distance measurement in studying upper pharyngeal airway from lateral cephalometric radiograph. However, limitations of lateral cephalometric radiograph which provides 2D data of the 3D structures, including pharyngeal airway, have been discussed(7, 15, 16). The difficulty in marking anatomical landmarks on lateral cephalometric radiograph(16) was also an obstacle. Supine or upright positioning, awake or asleep muscle tone, inspiration or expiration, duration of X-ray exposure, and mouth opening also affect the pharyngeal airway shape and pharyngeal airway dimension(94). Movement of tongue or soft palate also affected the pharyngeal airway dimension. Considering these circumstances, it becomes evident that even a 3D radiographic representation does not account for the true clinical circumstances under which SDB and particularly OSA may occur(5).

Moreover, there are several types of cephalometric measurements, i.e. linear, angular, area, and volumetric measurements. Numerous variables in each type of cephalometric measurement of the pharyngeal airway, bony and soft tissue structures surrounding the pharynx were established. Previous studies(5, 9, 28) showed good reliability in hard and soft tissue measurements from lateral cephalometric radiographs, including the soft palate and tongue, which are diverse in shapes, sizes, and positions.

Head position also has an effect on pharyngeal airway dimension. Hellsing(95) found that head extension 20 degrees more than normal position will increase the craniocervical angle (the angle formed by cranial base and the line through posterior border of 2nd cervical vertebra) and the pharyngeal airway distance, and change the hyoid position. Muto et al(96, 97) reported a 4 mm. increase in pharyngeal airway distance behind the tongue base if the craniocervical angle increased 10 degrees or the distance between menton to the antero-inferior point of 3rd cervical vertebra increase 10 mm. Later studies(38, 44) use the norm of craniocervical angle, 90-110 degrees, to reduce the error from head position.

Pirilä-Parkkinen et al(98) found that head position also had an influence on oropharyngeal and hypopharyngeal airway dimension. The flexer the head does, the narrower the pharyngeal airway is. On the opposite, the more extensive the head does, the wider the pharyngeal airway will be. However, head position had no influence on nasopharyngeal airway.

Chapter 3

Research methodology

3.1. Study design

Retrospective cross-sectional analytical study

3.2. Study population

Thai orthodontic patients

3.3. Sample size

3.3.1. The sample size estimation formula for testing means of two independent populations(99)

$$n = \frac{(\sigma_1^2 + \sigma_2^2)(Z_\alpha + Z_\beta)^2}{(\mu_1 - \mu_2)^2}$$

3.3.2. The mean and standard deviation of lower pharyngeal width from study of Takemoto et al(14) was calculated that the sample size in each independent group is 12. The sample size is set at 20 samples per group which would be totally 360 samples for the whole study. The sample size of CBCT data is set at 20 samples.

3.4. Inclusion criteria

3.4.1. Part I

3.4.1.1. Orthodontic patients with skeletal normal bite(FMA 21°-29°)(100) from Faculty of Dentistry, Chulalongkorn University in January 2007 - November 2014

3.4.1.2. Growing patients (age below 20 years old(26, 27, 70))

3.4.1.3. No history of nasopharyngeal pathology, tonsillectomy, or adenoidectomy

3.4.1.4. No history of systemic or congenital disease that affects maxillofacial structure

3.4.1.5. No history of accident that affect maxillofacial structure

3.4.1.6. No history of orthodontic treatment, orthognathic surgery or orthopedic treatment

3.4.1.7. Lateral cephalometric radiographs taken by usual standardized method (standing upright, head fixed with the cephalostat and ear rods, and oriented horizontally to the Frankfort plane, centric occlusion, relaxed lip and tongue, and not to swallow during radiographs taken), from Kodac 8000C or 9000C Digital panoramic and cephalometric system by usual standardized method (60-90 kVp, 2-12 mA, 0.1-3.2 seconds) from Kodak 8000C or 9000C Digital panoramic and cephalometric system (Caresteam, Rochester, New York) at department of radiology, faculty of dentistry, Chulalongkorn university

3.4.2. Part II

3.4.2.1. Orthodontic patients who were taken both lateral cephalometric radiographs by usual standardized method (as aforementioned) and CBCT scans by usual standardized method from 3DX Accuitomo 170 machine (J. Morita, Kyoto, Japan) with 60-90 kVp, 1-10 mA, and 17.5-second scanning time, and CB Mercuray (Hitachi Medical Systems America, Twinsburg, OH) with 120 kVp, 15 mA, and 9.8 second- second scanning time, at department of radiology, faculty of dentistry, Chulalongkorn university in January 2009 – March 2015

3.4.2.2. No history of nasopharyngeal pathology, tonsillectomy, or adenoidectomy

3.4.2.3. No history of systemic or congenital disease that affects maxillofacial structure

3.4.2.4. No history of accident that affect maxillofacial structure

3.5. Exclusion criteria

3.5.1. Unclear radiographs that could not identify all landmarks

3.5.2. Abnormal shape of soft palate beside from 6 types of soft palate classified by You et al(46)

3.5.3. Craniocervical angle below 90˚ or exceed 110˚ according to the suggestion of previous studies(38, 95-97) in order to reduce the effect of head position on the pharyngeal airway dimension

3.6. Cephalometric Landmarks and measurements

3.6.1. Cephalometric Landmarks (figure 8)

3.6.1.1. S(82, 100) (Sella) midpoint of hypophyseal fossa

3.6.1.2. N(82, 100) (Nasion) anterior point at frontonasal suture

3.6.1.3. A(82, 100) (A-point) deepest point in concavity of anterior maxilla

3.6.1.4. B(82, 100) (B-point) deepest point in concavity of anterior mandible

3.6.1.5. Po(62, 82) (Porion) most superior point of the outline of the external auditory meatus

3.6.1.6. Or(62, 82) (Orbitale) lowest point on the average of left and right inferior borders of the bony orbits

3.6.1.7. ANS(62) (Anterior nasal spine) most anterior point of the bony process of maxilla

3.6.1.8. PNS(23, 62) (Posterior nasal spine) most posterior point of bony hard palate

3.6.1.9. UPW(62) (Upper pharyngeal wal) intersection of the line through ANS-PNS to the posterior pharyngeal wall

3.6.1.10. U(62) (Uvula) tip of uvula

3.6.1.11. MPW(62) (Middle pharyngeal wall) intersection of the line parallel to ANS-PNS from U to the posterior pharyngeal wall

3.6.1.12. V(62) (Vallecula) intersection of epiglottis and base of tongue

3.6.1.13. LPW(62) (Lower pharyngeal wall) intersection of the line parallel to ANS-PNS from V to the posterior pharyngeal wall

3.6.1.14. T(62) tip of tongue

3.6.1.15. H(62) most superior point of tongue in relation to the line from V to T

3.6.1.16. Hy(62) (Hyoid) most antero-superior point of Hyoid

3.6.1.17. Cv2ig(96) most supero-posterior point on the Odontoid process of the second cervical vertebra

3.6.1.18. Cv2ip(96) most infero-posterior point on the body of the second cervical vertebra

3.6.1.19. Me(62) (Menton) most inferior point of bony chin

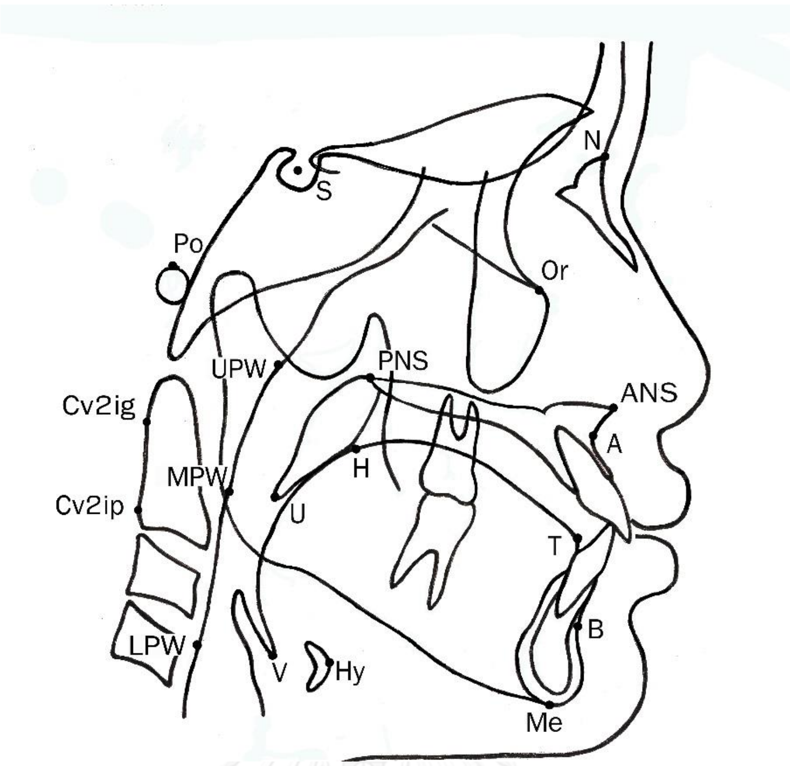

Figure 8 Cephalometric landmarks

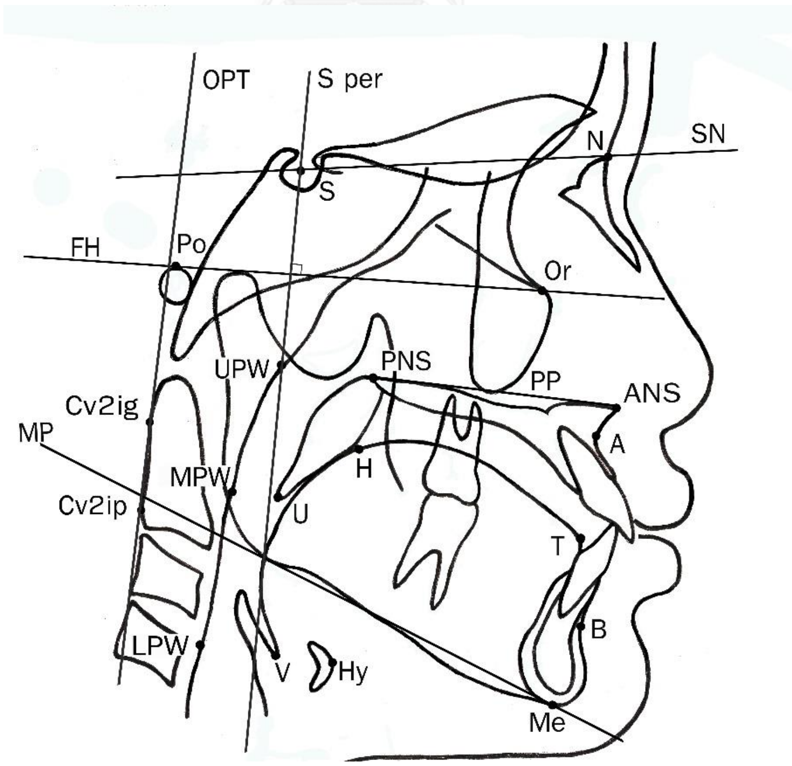

Figure 9 Cephalometric reference lines

3.6.2. Cephalometric reference lines (figure 9)

3.6.2.1. SN(82, 100) = line through sella and nasion

3.6.2.2. FH(82, 100) (Frankfort horizontal plane) = line through Po-Or

3.6.2.3. S per(5) = vertical line from S perpendicular to FH

3.6.2.4. PP(62) (Patatal plane) = line through ANS-PNS

3.6.2.5. OPT(96) = line through Cv2ig and Cv2ip

3.6.2.6. MP(100) (Mandibular plane) = line from Me tangent to the lower border of mandible behind antegonial notch

3.6.3. Cephalometric measurements (figures 10, 11, 12)

3.6.3.1. Maxillary position = SNA(82, 100) angle (the angle formed by SN and NA lines)

3.6.3.2. Mandibular position = SNB(82, 100) angle (the angle formed by SN and NB lines)

3.6.3.3. Antero-posterior skeletal patterns = ANB(82, 100) angle (the formed by Na and NB lines)

3.6.3.4. Vertical skeletal patterns = FMA(100) (the angle formed by FH and MP)

3.6.3.5. Head position = OPT-SN angle(96) (the angle formed by OPT and SN lines)

3.6.3.6. Horizontal hyoid position

3.6.3.6.1. S per-Hy (distance from Hy perpendicular to S per line) (modified from Mislik et al(5) and Samman et al(62))

3.6.3.6.2. N-S-Hy (angle formed by SN and line passing through S and Hy)

3.6.3.6.3. S-N-Hy (angle formed by SN and line passing through N and Hy)

3.6.3.7. Vertical hyoid position

3.6.3.7.1. Hy-FH(62) (distance from Hy perpendicular to FH)

3.6.3.7.2. MP-Me-Hy (angle formed by MP line and line passing through Me and Hy)

3.6.3.8. Soft palate length = PNS-U(62) (distance from PNS to U)

3.6.3.9. Soft palate thickness = SPT(62) (maximal thickness of soft palate measured perpendicular to PNS-U line)

3.6.3.10. Soft palate angulation = ANS-PNS-U(62) (angle formed by PP and PNS-U)

3.6.3.11. Tongue length = V-T(62) (distance from V to T)

3.6.3.12. Tongue height = H-VT(62) (distance from H perpendicular to VT line)

3.6.3.13. Horizontal tongue position

3.6.3.13.1. S per-V (distance from V perpendicular to S per line) (modified from Mislik et al(5) and Samman et al(62))

3.6.3.13.2. N-S-V (angle formed by SN and line passing through S and V)

3.6.3.13.3. S-N-V (angle formed by SN and line passing through N and V)

3.6.3.14. Vertical tongue position

3.6.3.14.1. V-FH(62) (distance from V perpendicular to FH)

3.6.3.14.2. MP-Me-V (angle formed by MP line and line passing through Me and V)

3.6.3.15. Nasopharyngeal area (between line from PNS perpendicular to PP and PP and roof of nasopharynx) (modified from Martin et al(23))

3.6.3.16. Nasopharyngeal volume (between line from PNS perpendicular to PP and PP and roof of nasopharynx) (modified from Martin et al(23))

3.6.3.17. Nasopharyngeal width = PNS-UPW(62) (distance from PNS to UPW)

3.6.3.18. Oropharyngeal area(62) (between PP and V-LPW behind the tongue and soft palate)

3.6.3.19. Oropharyngeal volume (between PP and V-LPW behind the tongue and soft palate)

3.6.3.20. Oropharyngeal width

3.6.3.20.1. U-MPW(62) (distance from U to MPW)

3.6.3.20.2. V-LPW(62) (distance from V to LPW)

3.6.3.20.3. McNamara's upper pharynx dimension(31) (distance from posterior outline of anterior half of soft palate to the closest point on the posterior pharyngeal wall)

3.6.3.20.4. McNamara's lower pharynx dimension(31) (distance from intersection of posterior border of tongue and inferior border of mandible to the closest point on the posterior pharyngeal wall)

3.6.3.21. Total upper pharyngeal airway area : oropharyngeal area and nasopharyngeal area

3.6.3.22. Total upper pharyngeal airway volume : oropharyngeal volume and nasopharyngeal volume

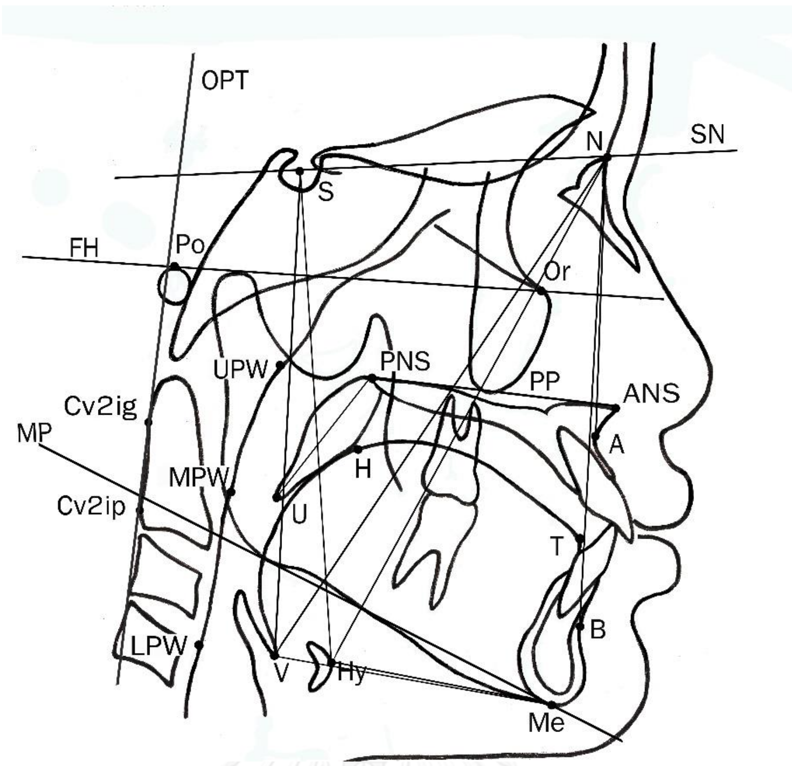

Figure 10 Cephalometric angular measurements

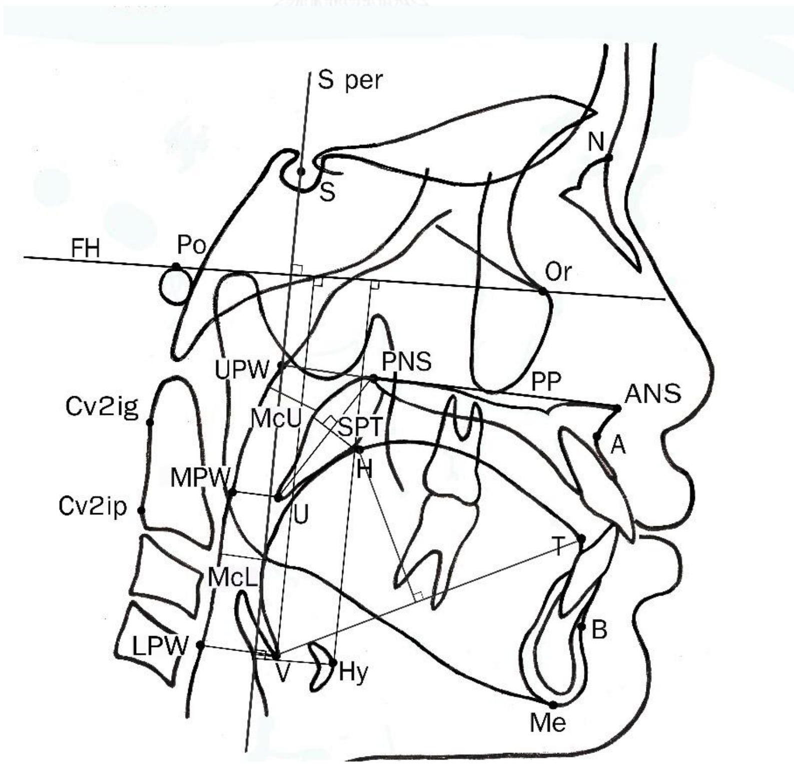

Figure 11 Cephalometric linear measurements

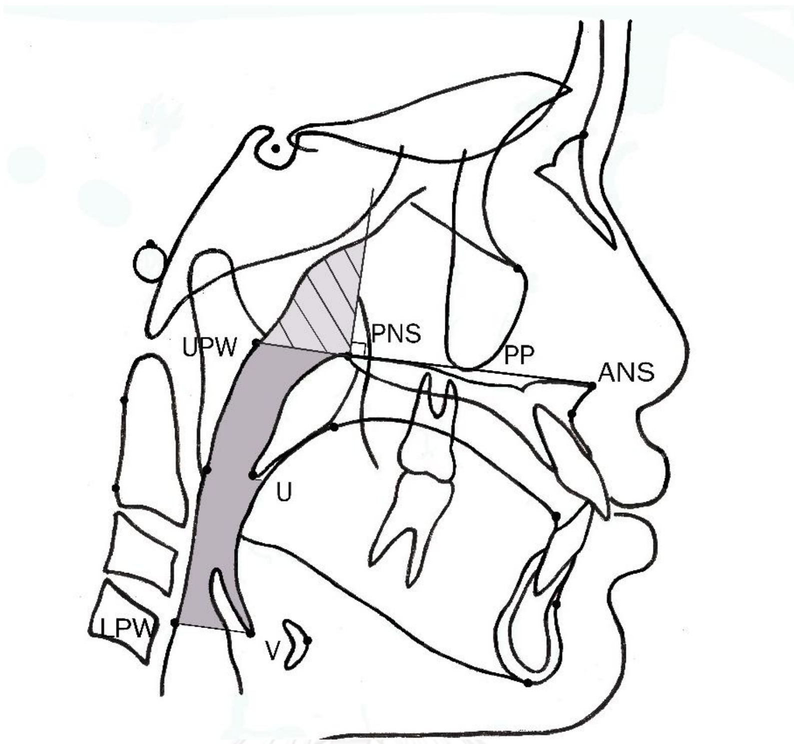

Figure 12 Cephalometric area and volumetric measurements

3.7. Data collection and preparation

3.7.1. Radiographs were collected following the inclusion and exclusion criteria

3.7.2. Pretreatment lateral cephalometric radiographs (JPEG format) of growing Thai orthodontic patients (Orthodontic department, Faculty of Dentistry, Chulalongkorn University), taken at the Department of Radiology during January 2007 - November 2014

3.7.3. CBCT scans (DICOM format) and lateral cephalometric radiographs (JPEG format) of the same patients, taken in the same period of treatment time (within 1 month)

3.7.4. Samples with skeletal normal bite (FMA=25±4°)(100) were divided into 3 groups according to ANB(100)

3.7.4.1. Skeletal Class I (2°≤ANB≤6°)

3.7.4.2. Skeletal Class II (ANB>6°)

3.7.4.3. Skeletal Class III (ANB<2°)

Then, each group was divided into 6 subgroups according to sex and skeletal age; pre-pubertal (CS 1,2), pubertal (CS 3,4), and post-pubertal (CS 5,6) according to previous studies(35, 36) (figure 13).

3.8. Programs

3.8.1. Image J software version 1.47 (National Institutes of Health, Bethesda, Maryland, USA)

3.8.2. Romexis software version 4.0 Demo (Planmeca, Helsinki, Finland)

3.8.3. IBM SPSS software version 22.0 for Windows (IBM Corporation, New York, USA)

3.9. Data analyses

3.9.1. Part I: upper pharyngeal airway measurements using lateral cephalometric radiographs

All cephalometric landmarks and 12 angular, 13 linear, and 3 area cephalometric measurements of upper pharyngeal airway dimensions, i.e. nasopharynx and oropharynx, and position and dimension of surrounding structures, i.e. soft palate, hyoid bone, and tongue were traced, calibrated and measured using Image J software. These measurements were done on Microsoft Window 7.0, wide screen laptop with resolution of 1600 x 900.

3.9.2. Part II: upper pharyngeal airway measurement using CBCT radiographs

Nasopharyngeal and oropharyngeal airway volumes were measured using Romexis software. Nasopharyngeal and oropharyngeal airway linear and area measurements were measured using Image J version 1.47. The 2D and 3D measurements were done on Microsoft Window 7.0, wide screen laptop with resolution of 1600 x 900.

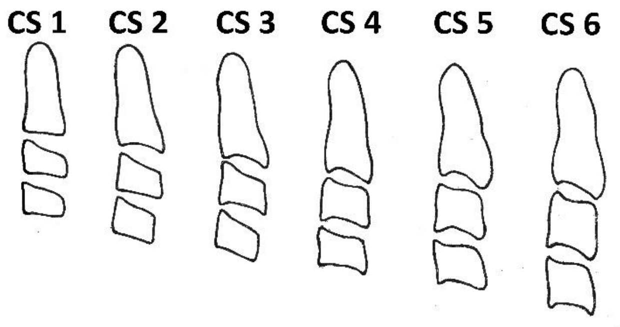

Figure 13 Schematic representation of the stages of cervical vertebral maturation (36) CS1 (The lower borders of all the three vertebrae (C2-C4) are flat. The bodies of both C3 and C4 are trapezoid in shape.) demonstrated that the peak in mandibular growth will occur on average 2 years after this stage; CS2 (A concavity is present at the lower border of C2. The lower borders of C3-C4 are flat. The bodies of both C3 and C4 remained trapezoid in shape.) demonstrated that the peak in mandibular growth will occur on average 1 year after this stage; CS3 (Concavities at the lower borders of both C2 and C3 are present. The bodies of C3 and C4 may be either trapezoid or rectangular horizontal in shape.) demonstrated that the peak in mandibular growth will occur during the year after this stage; CS4 (Concavities at the lower borders of C2, C3, and C4 now are present. The bodies of both C3 and C4 are rectangular horizontal in shape.) demonstrated that the peak in mandibular growth has occurred within 1 or 2 years before this stage; CS5 (The concavities at the lower borders of C2, C3, and C4 still are present. At least one of the bodies of C3 and C4 is squared in shape.) demonstrated that the peak in mandibular growth has ended at least 1 year before this stage; CS6 (The concavities at the lower borders of C2, C3, and C4 still are evident. At least one of the bodies of C3 and C4 is rectangular vertical in shape.) demonstrated that the peak in mandibular growth has ended at least 2 years before this stage.

3.10. Statistical analyses

3.10.1. The data were in ratio scale, except for skeletal ages which were in ordinal scale.

3.10.2. The mean and standard error, due to unequal number of samples in each subgroups, of each parameter was shown.

3.10.3. The parameters in ratio scale were tested their normal distribution with Kolmokorov-Smirnov test.

3.10.4. The variables were grouped according to their statistical relationship by Factor analysis.

3.10.5. The effects of sexes, skeletal ages and sagittal skeletal patterns and interaction among them were investigated by three-way ANOVA and least-significant difference (LSD) post hoc test, including independent *t–test* for sexual difference.

3.10.6. The correlation among upper pharyngeal airway dimensions and the bony and soft tissue parameters was examined using Pearson's and Spearman's correlation to explain variable correlations, including the new angular measurements and the existing linear measurements of tongue and hyoid positions

3.10.7. The correlation between upper pharyngeal airway volume from CBCT and upper pharyngeal airway area and linear measurements from lateral cephalometric radiographs was examined using Pearson's correlation.

3.10.8. The difference between upper pharyngeal airway area and linear measurements from reconstructed lateral skull radiographs from CBCT and lateral cephalometric radiographs was examined using Paired *t*-test.

3.10.9. Twenty samples were randomly selected and measured twice, 2 weeks apart, by the same investigator to estimate the intraobserver reliability using intraclass correlation coefficient (ICC).

Note: All statistical analyses were performed with 95% confidence intervals.

Chapter 4

Results

4.1. Part I: Interaction of sexes, skeletal ages, and sagittal skeletal patterns on upper pharyngeal airway dimensions, and position and dimensions of surrounding structures; Correlation among variables

Four hundred and eighteen radiographs of orthodontic patients, ranged in age from 6 to 20 years, were collected. The subjects consisted of 183 males and 235 females; 112 pre-pubertal, 167 pubertal, and 139 post-pubertal; 180 skeletal Class I, 108 skeletal Class II, and 130 skeletal Class III (table 1). ICC showed very good intra-observer reliability, ranged from 0.841 to 0.998, with the average of 0.959. Most variables showed normal distribution (see appendix). Means and standard errors of upper pharyngeal airway dimensions, and position and dimensions of surrounding structures were reported in tables 2-10. Factor analysis showed 5 groups of variables with strong statistical relationship among them (table 11). Factors 1 and 2 represented upper and lower parts of pharyngeal airway dimensions, respectively. Nevertheless, total pharyngeal area could be considered to correlate with both nasopharyngeal and oropharyngeal airway dimensions. Factor 3 represented horizontal positions of tongue, hyoid bone, and soft palate. Factor 4 represented vertical positions of tongue and hyoid. Factor 5 represented tongue and soft palate dimensions. HyFH and VFH correlated with both factors 4 and 5, however, they should be categorized into the factor 4 due to their clinical relationship.

4.1.1 The effects of sexes, skeletal ages, sagittal skeletal patterns, and interactions among them on upper pharyngeal airway dimensions, and surrounding structures

The effects of sexes, skeletal ages, sagittal skeletal patterns, and interactions among them on upper pharyngeal airway dimensions, and bony and soft tissue variables of pharynx were presented in table 12, grouped into 5 factors as described.

MP-Me-V was the only variable which showed three-way interaction among sexes, skeletal ages, and sagittal skeletal patterns (figure 14). Further investigation found that there was significant interaction between sexes and skeletal ages in skeletal Class II group ($p<0.001$) (table 13). Regarding the interaction with skeletal ages in skeletal Class II, males had significant smaller MP-Me-V in the pre-pubertal period, but greater MP-Me-V in the post-pubertal period. Considering the interaction with sexes in skeletal Class II, post-pubertal subjects had significant larger MP-Me-V than others in males. However, no skeletal age difference was found in females. On the contrary, there was no sexual dimorphism of MP-Me-V in other Classes in all skeletal ages. Moreover, in both genders, there was no skeletal-age difference in skeletal Class III subjects, whereas significant differences of MP-Me-V among skeletal ages in skeletal Class I were found.

Most variables in factors 1 and 2 showed two-way interaction between sexes-skeletal ages, except for PNS-UPW, U-MPW, and McL. All variables in these factors also showed interaction between skeletal ages-sagittal skeletal patterns. Other variables in factors 3, 4, and 5 showed two-way interaction between sexes-skeletal ages, except for S per-V and N-S-Hy which showed significant differences between sexes and among sagittal skeletal patterns, N-S-V which showed significant difference among sagittal skeletal patterns, and PNS-U and VT which showed significant differences between sexes, among skeletal ages, and sagittal skeletal patterns. Moreover, variables in factors

3, 4, and 5 also showed statistically significant difference among sagittal skeletal patterns, except for VFH, SPT, and H-VT.

The interactions between sexes and skeletal ages were presented in figure 15. The sexual dimorphism in each skeletal age was shown in table 14. Most variables in 5 factors presented no sexual dimorphism in the pre-pubertal and pubertal periods, except for VT, NasoA, and TotalA which showed significant sexual difference in the pre-pubertal period; and S per-Hy, SPT, and McU which showed significant sexual difference in the pubertal period. While, significant sexual dimorphism in most variables was found in the post-pubertal period, except for McU. However, vertical hyoid (HyFH) and tongue (VFH) position presented significant difference between sexes in every period. PNS-UPW, U-MPW, McL, and NSV, which had no interaction between sexes and skeletal ages, presented no sexual difference in all skeletal ages. While S per-V, NSHy, PNS-U, and VT which also had no interaction between sexes and skeletal ages, presented sexual difference in all skeletal ages. Moreover, the skeletal age difference in each gender was shown in table 15. There were significant skeletal age differences in most upper pharyngeal airway dimensions, and bony and soft tissue variables of pharynx in both genders. Upper pharyngeal airway had tendency to increase in dimensions with increasing skeletal ages, except for U-MPW and McL in both genders. Surrounding structures also positioned more anteriorly and inferiorly from the pre-pubertal to the post-pubertal periods, except for S per-V, NSHy and NSV in both genders; and ANS-PNS-U, S per-Hy and MP-Me-Hy in females.

The sagittal skeletal patterns showed different interaction with skeletal ages on pharyngeal airway dimensions as in figure 16. The sagittal skeletal pattern difference in each skeletal age was shown in table 16. In the pre-pubertal period, there were significant differences of sagittal skeletal patterns in McU, McL, OroA, and TotalA, showing tendency to increase in airway dimensions from skeletal Classes II, I, and III, respectively. In the pubertal period, there was no difference among sagittal skeletal patterns, except for PNS-UPW in which skeletal Class III had significant narrower airway width than skeletal Class II. Whereas, in the post-pubertal period, there were significant differences of sagittal skeletal patterns in all airway dimensions with a tendency to increase from skeletal Classes I, II, and III, respectively. Moreover, skeletal ages demonstrated significant effect on most upper pharyngeal airway dimensions in all sagittal skeletal patterns (table 17). In skeletal Classes I and II, there were significant differences of skeletal ages in almost all airway dimensions, except for U-MPW in skeletal Classes I and II, and McL in skeletal Class II, with a tendency to increase in dimensions of upper pharyngeal airway with increasing skeletal ages, except for McL in skeletal Class I which had narrowest airway width in the post-pubertal period. While in skeletal Class III, there were significant differences of skeletal ages in all airway dimensions with a tendency to remarkably increase in dimensions of upper pharyngeal airway from the pubertal to the post-pubertal periods.

In addition, there were significant differences among sagittal skeletal patterns in surrounding structures, except for VFH, SPT, and H-VT (table 18). Hyoid and tongue positioned more anteriorly and superiorly; while soft palate angulation was more acute; and tongue and soft palate lengths were shorter in skeletal Class III subjects. No difference was found between skeletal Class I and skeletal Class II subjects, except for ANS-PNS-U. Moreover, MP-Me-V showed only significant difference between skeletal Classes III and I.

Table 1 Demographic data

Skeletal Age	Male		Female		Total	
	N	Mean±SD (yr.)	N	Mean±SD (yr.)	N	Mean±SD (yr.)
pre-pubertal	61	9.44±1.54	51	8.82±1.32	112	9.16±1.47
Class I	26	9.65±1.52	19	8.79±1.36	45	9.29±1.50
Class II	19	9.37±1.30	15	8.60±1.59	34	9.03±1.47
Class III	16	9.19±1.87	17	9.06±1.03	33	9.12±1.47
pubertal	67	12.55±1.77	100	12.68±2.49	167	12.63±2.22
Class I	29	13.00±1.93	47	12.64±2.14	76	12.78±2.06
Class II	20	12.15±1.57	22	13.50±2.92	42	12.86±2.45
Class III	18	12.28±1.64	31	12.16±2.57	49	12.20±2.25
post-pubertal	55	17.80±2.02	84	15.96±2.48	139	16.69±2.47
Class I	20	16.70±2.13	39	15.31±2.23	59	15.78±2.27
Class II	14	18.00±2.11	18	17.39±3.11	32	17.66±2.70
Class III	21	18.71±1.31	27	15.96±1.99	48	17.17±2.20
total	183	13.09±3.80	235	13.05±3.62	418	13.05±3.62

Table 2 Means and standard errors of airway dimensions in males with different sagittal skeletal patterns

		Males							
		SkeCl.I		SkeCl.II		SkeCl.III		Total	
		Mean	SE.	Mean	SE.	Mean	SE.	Mean	SE.
PnsUpw	Pre	21.69	0.82	20.96	0.89	21.50	0.95	21.41	0.50
(mm)	Pu	22.41	0.88	23.76	0.73	22.51	0.60	22.84	0.47
	Post	23.51	0.55	25.59	0.86	26.39	0.74	25.14	0.44
	Total	22.45	0.47	23.24	0.54	23.70	0.52	23.06	0.29
McU	Pre	8.60	0.47	7.11	0.39	9.67	0.62	8.42	0.31
(mm)	Pu	9.31	0.53	9.08	0.62	8.74	0.49	9.09	0.32
	Post	10.62	0.53	11.33	0.64	13.35	0.60	11.84	0.37
	Total	9.41	0.31	8.97	0.39	10.77	0.43	9.69	0.22
NasoA	Pre	282.34	11.60	256.75	15.06	301.47	18.57	279.39	8.52
(mm)	Pu	323.40	16.90	322.55	18.56	313.27	15.38	320.43	9.93
	Post	407.74	17.57	456.10	22.37	520.61	24.78	463.15	14.19
	Total	331.66	10.55	334.24	15.05	389.01	18.37	349.64	8.43
Umpw	Pre	9.92	0.64	8.49	0.67	11.41	0.65	9.86	0.40
(mm)	Pu	10.10	0.37	9.22	0.54	9.76	0.75	9.74	0.30
	Post	9.36	0.62	10.66	0.81	13.32	0.60	11.20	0.44
	Total	9.84	0.31	9.33	0.39	11.60	0.43	10.22	0.22
McL	Pre	10.73	0.63	10.03	0.65	12.08	0.84	10.87	0.41
(mm)	Pu	11.11	0.46	9.47	0.66	10.45	0.68	10.45	0.34
	Post	9.53	0.77	10.38	0.78	14.04	0.76	11.47	0.52
	Total	10.56	0.35	9.91	0.39	12.30	0.48	10.89	0.24
VLpw	Pre	14.16	0.52	12.01	0.71	12.64	0.80	13.09	0.39
(mm)	Pu	14.28	0.65	13.67	0.72	14.01	0.71	14.03	0.40
	Post	16.93	0.69	17.53	0.54	19.18	0.70	17.94	0.41
	Total	14.94	0.38	14.09	0.49	15.58	0.57	14.89	0.27
OroA	Pre	545.23	26.75	444.93	26.85	556.30	27.19	516.89	16.80
(mm)	Pu	629.50	26.13	538.19	37.95	581.68	35.86	589.40	18.99
	Post	692.34	39.60	745.91	45.14	915.58	36.02	791.21	26.34
	Total	617.04	18.34	559.63	26.32	701.79	30.01	625.88	14.50
Total	Pre	827.57	33.38	701.67	37.83	857.77	36.33	796.28	22.09
(mm)	Pu	952.90	37.15	860.74	48.43	894.96	41.77	909.82	24.49
	Post	1100.08	44.52	1202.01	55.69	1436.20	48.46	1254.36	34.39
	Total	948.70	24.89	893.86	38.09	1090.79	44.58	975.52	20.85

Table 3 Means and standard errors of airway dimensions in females with different sagittal skeletal patterns

		Females							
		SkeCl.I		SkeCll.II		SkeCl.III		Total	
		Mean	SE.	Mean	SE.	Mean	SE.	Mean	SE.
PnsUpw (mm)	Pre	19.52	0.87	20.47	0.89	21.07	0.62	20.32	0.47
	Pu	23.77	0.47	24.24	0.64	21.84	0.59	23.28	0.33
	Post	24.91	0.44	25.81	0.42	25.10	0.64	25.17	0.30
	Total	23.43	0.36	23.72	0.47	22.84	0.41	23.31	0.23
McU (mm)	Pre	7.71	0.56	7.05	0.60	9.68	0.60	8.17	0.37
	Pu	9.91	0.31	9.90	0.65	10.21	0.51	10.00	0.26
	Post	10.78	0.37	10.47	0.52	12.37	0.43	11.23	0.26
	Total	9.84	0.24	9.31	0.39	10.87	0.32	10.04	0.18
NasoA (mm)	Pre	229.03	14.92	240.43	12.65	271.47	13.33	246.53	8.29
	Pu	329.24	9.19	341.84	16.39	317.55	13.21	328.39	6.94
	Post	357.44	11.73	401.71	12.58	395.46	14.95	379.15	7.98
	Total	321.58	7.88	333.78	11.91	335.15	9.90	328.77	5.48
Umpw (mm)	Pre	9.74	0.71	9.34	0.75	9.76	0.52	9.63	0.38
	Pu	10.03	0.34	9.50	0.57	9.73	0.36	9.82	0.23
	Post	9.00	0.46	9.28	0.61	10.95	0.49	9.69	0.31
	Total	9.60	0.26	9.38	0.36	10.18	0.26	9.73	0.17
McL (mm)	Pre	10.85	0.59	9.47	0.77	11.19	0.59	10.56	0.38
	Pu	10.53	0.41	10.15	0.66	10.76	0.59	10.52	0.30
	Post	9.06	0.54	9.65	0.65	11.38	0.47	9.93	0.34
	Total	10.04	0.30	9.80	0.39	11.08	0.32	10.32	0.19
VLpw (mm)	Pre	12.86	0.52	12.75	0.58	13.98	0.79	13.20	0.37
	Pu	14.69	0.30	14.63	0.76	13.97	0.40	14.45	0.25
	Post	15.07	0.34	15.98	0.46	15.83	0.70	15.51	0.29
	Total	14.50	0.22	14.56	0.41	14.64	0.36	14.56	0.18
OroA (mm)	Pre	474.63	22.33	439.48	36.10	525.17	24.03	481.14	16.10
	Pu	595.42	17.87	584.06	38.43	568.77	21.75	584.66	13.58
	Post	590.96	21.75	590.24	28.92	679.62	29.22	619.30	15.62
	Total	571.90	12.77	546.65	22.09	598.79	16.40	574.58	9.35
Total (mm)	Pre	703.65	24.39	679.91	42.30	796.64	27.76	727.67	18.94
	Pu	924.66	21.75	925.90	48.12	886.33	31.58	913.05	17.56
	Post	948.40	27.70	991.95	32.65	1075.07	36.74	998.45	19.56
	Total	893.49	17.15	880.43	29.84	933.95	23.30	903.34	12.78

Table 4 Means and standard errors of airway dimensions in both genders with different sagittal skeletal patterns

		Both genders							
		SkeCl.I		SkeCl.II		SkeCl.III		Total	
		Mean	SE.	Mean	SE.	Mean	SE.	Mean	SE.
PnsUpw (mm)	Pre	20.77	0.61	20.74	0.63	21.28	0.55	20.91	0.35
	Pu	23.25	0.45	24.01	0.48	22.09	0.43	23.10	0.27
	Post	24.44	0.35	25.71	0.44	25.67	0.49	25.16	0.25
	Total	23.02	0.29	23.49	0.35	23.20	0.32	23.20	0.18
McU (mm)	Pre	8.22	0.36	7.08	0.34	9.67	0.43	8.30	0.24
	Pu	9.68	0.28	9.51	0.45	9.67	0.38	9.63	0.20
	Post	10.73	0.30	10.85	0.41	12.80	0.36	11.47	0.22
	Total	9.66	0.19	9.14	0.28	10.83	0.26	9.89	0.14
NasoA (mm)	Pre	259.83	9.92	249.55	10.05	286.02	11.45	264.43	6.15
	Pu	327.02	8.53	332.65	12.26	315.98	9.99	325.19	5.75
	Post	374.49	10.18	425.51	12.81	450.21	16.31	412.38	8.16
	Total	325.78	6.35	334.00	9.51	357.94	9.89	337.91	4.83
Umpw (mm)	Pre	9.84	0.47	8.86	0.50	10.56	0.43	9.76	0.28
	Pu	10.06	0.25	9.36	0.39	9.74	0.35	9.79	0.18
	Post	9.12	0.37	9.88	0.50	11.99	0.41	10.29	0.26
	Total	9.70	0.20	9.36	0.26	10.78	0.24	9.95	0.14
McL (mm)	Pre	10.78	0.44	9.79	0.49	11.62	0.50	10.73	0.28
	Pu	10.75	0.31	9.83	0.46	10.65	0.44	10.49	0.22
	Post	9.22	0.44	9.97	0.50	12.54	0.46	10.54	0.30
	Total	10.26	0.23	9.86	0.28	11.59	0.28	10.57	0.15
VLpw (mm)	Pre	13.61	0.38	12.34	0.47	13.33	0.56	13.14	0.27
	Pu	14.53	0.31	14.17	0.53	13.98	0.36	14.28	0.22
	Post	15.70	0.34	16.65	0.37	17.29	0.55	16.47	0.26
	Total	14.69	0.20	14.33	0.32	15.04	0.32	14.70	0.16
OroA (mm)	Pre	515.42	18.67	442.52	21.54	540.26	18.01	500.61	11.80
	Pu	608.42	14.90	562.22	26.96	573.52	18.84	586.56	11.11
	Post	625.32	20.47	658.35	28.71	782.85	28.26	687.32	15.73
	Total	590.71	10.77	553.02	17.06	642.37	16.39	597.04	8.33
TotalA (mm)	Pre	775.25	23.53	692.07	27.83	826.28	22.97	765.03	15.09
	Pu	935.44	19.46	894.87	34.13	889.50	24.93	911.76	14.34
	Post	999.81	25.32	1083.85	35.33	1233.06	39.24	1099.71	20.87
	Total	916.49	14.51	887.02	23.98	1000.30	24.04	934.94	11.73

Table 5 Means and standard errors of horizontal position of surrounding structures in males with different sagittal skeletal patterns

		Male							
		SkeCl.I		SkeCl.II		SkeCl.III		Total	
		Mean	SE.	Mean	SE.	Mean	SE.	Mean	SE.
AnsPnsU	Pre	130.46	1.10	132.08	1.57	126.48	1.02	129.92	0.77
(°)	Pu	128.05	0.97	130.96	1.38	126.38	1.35	128.47	0.72
	Post	126.26	1.14	128.47	1.58	123.10	1.85	125.62	0.94
	Total	128.41	0.64	130.71	0.88	125.16	0.90	128.10	0.48
SperHy	Pre	15.15	1.20	15.69	1.24	19.53	1.09	16.47	0.73
(mm)	Pu	19.89	0.96	17.09	1.23	22.37	1.18	19.72	0.68
	Post	19.89	1.36	18.31	1.32	25.90	1.39	21.78	0.90
	Total	18.25	0.71	16.91	0.73	22.89	0.80	19.26	0.47
SperV	Pre	2.84	1.08	2.10	1.14	5.04	0.86	3.19	0.63
(mm)	Pu	4.62	0.87	3.53	1.23	6.12	1.55	4.69	0.67
	Post	4.37	1.31	3.93	1.32	9.59	1.22	6.25	0.81
	Total	3.94	0.61	3.12	0.70	7.13	0.77	4.66	0.41
SNHy	Pre	56.91	0.65	56.00	0.96	58.47	0.65	57.04	0.45
(°)	Pu	58.08	0.60	57.62	0.61	60.55	0.82	58.60	0.41
	Post	60.09	0.62	60.32	0.88	63.16	0.67	61.32	0.45
	Total	58.21	0.39	57.75	0.52	60.94	0.48	58.90	0.28
SNV	Pre	50.85	0.67	49.08	0.91	51.04	0.40	50.35	0.42
(°)	Pu	50.68	0.62	50.77	0.62	53.30	0.79	51.41	0.41
	Post	53.66	0.64	54.48	0.88	56.50	0.52	54.95	0.41
	Total	51.53	0.40	51.15	0.54	53.86	0.46	52.12	0.28
NSHy	Pre	89.41	0.78	90.03	0.88	86.57	0.96	88.86	0.52
(°)	Pu	89.09	0.67	89.26	0.91	86.08	0.82	88.33	0.48
	Post	89.56	0.79	88.97	1.05	85.19	0.86	87.74	0.57
	Total	89.33	0.43	89.46	0.54	85.88	0.50	88.33	0.30
NSV	Pre	96.76	0.79	98.40	0.86	95.49	0.60	96.94	0.47
(°)	Pu	98.05	0.72	97.86	0.85	95.21	0.99	97.23	0.50
	Post	97.64	0.77	96.37	1.12	93.16	0.71	95.60	0.55
	Total	97.49	0.44	97.66	0.54	94.51	0.47	96.64	0.29

Table 6 Means and standard errors of horizontal position of surrounding structures in females with different sagittal skeletal patterns

		Female							
		SkeCl.I		SkeCll.II		SkeCl.III		Total	
		Mean	SE.	Mean	SE.	Mean	SE.	Mean	SE.
AnsPnsU	Pre	129.89	1.25	133.64	1.50	127.08	1.17	130.06	0.82
(°)	Pu	130.49	0.75	131.84	1.12	126.32	0.91	129.50	0.55
	Post	131.52	0.86	131.48	1.11	126.96	1.21	130.04	0.64
	Total	130.77	0.51	132.21	0.70	126.72	0.63	129.81	0.37
SperHy	Pre	15.01	1.21	13.14	1.46	18.76	1.53	15.71	0.85
(mm)	Pu	16.07	0.58	16.92	1.05	18.33	0.92	16.96	0.46
	Post	14.96	0.92	14.18	1.21	19.43	0.85	16.23	0.62
	Total	15.47	0.48	14.99	0.72	18.82	0.59	16.43	0.35
SperV	Pre	2.67	1.15	0.40	1.56	5.85	1.14	3.06	0.78
(mm)	Pu	3.00	0.51	3.85	1.11	5.40	0.84	3.93	0.44
	Post	2.16	0.87	2.05	1.14	5.74	0.95	3.29	0.59
	Total	2.63	0.44	2.32	0.73	5.63	0.55	3.51	0.33
SNHy	Pre	55.59	0.75	54.08	0.95	58.45	0.90	56.10	0.55
(°)	Pu	57.49	0.34	57.07	0.58	59.01	0.52	57.87	0.27
	Post	57.05	0.58	56.64	0.58	58.09	0.60	57.30	0.36
	Total	56.98	0.30	56.11	0.43	58.55	0.37	57.28	0.21
SNV	Pre	49.04	0.69	47.64	1.02	51.76	0.94	49.54	0.55
(°)	Pu	51.58	0.35	51.23	0.69	52.83	0.56	51.89	0.29
	Post	51.49	0.55	51.14	0.63	52.22	0.73	51.65	0.37
	Total	51.09	0.30	50.22	0.48	52.37	0.41	51.29	0.22
NSHy	Pre	89.07	0.81	91.91	1.06	86.46	1.11	89.03	0.64
(°)	Pu	89.49	0.43	89.71	0.96	87.70	0.53	88.98	0.34
	Post	90.28	0.56	90.84	0.89	88.13	0.57	89.71	0.39
	Total	89.71	0.32	90.68	0.56	87.57	0.39	89.25	0.24
NSV	Pre	97.19	0.78	100.37	1.14	94.48	0.98	97.22	0.63
(°)	Pu	97.15	0.43	97.50	1.04	95.37	0.52	96.67	0.35
	Post	97.83	0.54	97.90	0.88	96.31	0.70	97.35	0.39
	Total	97.41	0.31	98.41	0.61	95.51	0.40	97.04	0.25

Table 7 Means and standard errors of horizontal position of surrounding structures in both genders with different sagittal skeletal patterns

		Both genders							
		SkeCl.I		SkeCl.II		SkeCl.III		Total	
		Mean	SE.	Mean	SE.	Mean	SE.	Mean	SE.
AnsPnsU	Pre	130.22	0.82	132.77	1.09	126.79	0.77	129.98	0.56
(°)	Pu	129.56	0.61	131.43	0.87	126.34	0.75	129.09	0.44
	Post	129.74	0.76	130.16	0.95	125.27	1.08	128.29	0.57
	Total	129.78	0.41	131.47	0.56	126.06	0.53	129.06	0.30
SperHy	Pre	15.09	0.85	14.57	0.96	19.13	0.94	16.12	0.55
(mm)	Pu	17.53	0.55	17.00	0.79	19.81	0.77	18.06	0.40
	Post	16.63	0.82	15.99	0.95	22.26	0.90	18.43	0.56
	Total	16.62	0.42	15.94	0.52	20.54	0.51	17.67	0.29
SperV	Pre	2.77	0.78	1.35	0.94	5.46	0.71	3.13	0.49
(mm)	Pu	3.62	0.47	3.70	0.82	5.66	0.77	4.24	0.38
	Post	2.91	0.73	2.87	0.87	7.43	0.80	4.46	0.49
	Total	3.17	0.37	2.71	0.51	6.26	0.45	4.02	0.26
SNHy	Pre	56.35	0.50	55.16	0.69	58.46	0.55	56.61	0.35
(°)	Pu	57.71	0.31	57.33	0.42	59.57	0.46	58.16	0.23
	Post	58.08	0.47	58.25	0.59	60.30	0.57	58.89	0.32
	Total	57.49	0.24	56.92	0.34	59.56	0.31	57.99	0.18
SNV	Pre	50.09	0.50	48.45	0.68	51.41	0.52	49.98	0.34
(°)	Pu	51.24	0.32	51.01	0.46	53.00	0.45	51.70	0.24
	Post	52.23	0.44	52.60	0.60	54.09	0.56	52.96	0.31
	Total	51.27	0.24	50.68	0.36	53.00	0.31	51.66	0.18
NSHy	Pre	89.27	0.56	90.86	0.69	86.52	0.73	88.94	0.40
(°)	Pu	89.34	0.37	89.50	0.66	87.10	0.46	88.72	0.28
	Post	90.03	0.46	90.02	0.69	86.84	0.53	88.93	0.33
	Total	89.55	0.26	90.08	0.39	86.86	0.32	88.85	0.19
NSV	Pre	96.94	0.56	99.27	0.71	94.97	0.58	97.07	0.39
(°)	Pu	97.49	0.38	97.67	0.67	95.31	0.48	96.90	0.29
	Post	97.76	0.44	97.23	0.70	94.93	0.55	96.66	0.33
	Total	97.44	0.26	98.04	0.41	95.08	0.31	96.86	0.19

Table 8 Means and standard errors of vertical position and dimensions of surrounding structures in males with different sagittal skeletal patterns

		Male							
		SkeCl.I		SkeCl.II		SkeCl.III		Total	
		Mean	SE.	Mean	SE.	Mean	SE.	Mean	SE.
HyFH (mm)	Pre	76.40	1.08	72.96	1.09	72.93	1.54	74.42	0.72
	Pu	84.52	1.27	80.38	1.74	81.29	1.27	82.42	0.85
	Post	93.80	1.34	93.06	1.64	94.45	1.42	93.86	0.83
	Total	84.18	1.06	81.07	1.39	83.89	1.46	83.19	0.74
VFH (mm)	Pre	73.33	1.00	69.26	1.04	69.99	1.38	71.19	0.68
	Pu	81.27	1.39	78.18	1.88	80.49	1.27	80.14	0.89
	Post	92.63	1.24	92.40	1.38	93.55	1.35	92.92	0.76
	Total	81.55	1.12	78.74	1.52	82.42	1.52	81.00	0.79
MpMeHy (°)	Pre	18.55	1.30	16.43	1.53	17.75	2.01	17.68	0.89
	Pu	20.56	1.40	17.50	1.92	16.26	1.32	18.49	0.92
	Post	24.04	2.32	25.43	2.01	17.92	1.71	22.06	1.25
	Total	20.79	0.96	19.21	1.16	17.33	0.96	19.29	0.60
MpMeV (°)	Pre	16.72	0.84	14.35	1.19	16.70	1.49	15.98	0.65
	Pu	18.36	1.09	17.33	1.50	17.48	1.06	17.82	0.70
	Post	22.97	1.56	24.11	1.66	18.64	1.27	21.61	0.90
	Total	19.02	0.71	18.05	0.98	17.70	0.73	18.34	0.46
PnsU (mm)	Pre	29.97	0.46	29.42	0.55	27.58	0.82	29.17	0.35
	Pu	31.49	0.76	31.72	0.75	31.06	0.86	31.45	0.45
	Post	33.80	0.81	33.20	0.53	32.58	0.73	33.18	0.43
	Total	31.58	0.43	31.29	0.42	30.63	0.53	31.21	0.27
SPT (mm)	Pre	8.43	0.21	8.26	0.21	8.39	0.23	8.37	0.12
	Pu	9.49	0.29	9.25	0.30	9.49	0.21	9.42	0.16
	Post	10.10	0.24	10.01	0.35	9.72	0.38	9.93	0.19
	Total	9.28	0.17	9.10	0.19	9.26	0.19	9.22	0.10
VT (mm)	Pre	62.57	1.14	61.78	1.29	59.94	0.86	61.63	0.67
	Pu	69.88	1.07	66.91	1.52	64.87	1.84	67.65	0.84
	Post	72.63	1.11	74.07	1.43	70.59	1.19	72.22	0.72
	Total	68.08	0.80	66.96	1.05	65.62	0.98	67.02	0.54
Hvt (mm)	Pre	29.66	0.59	28.63	0.53	28.62	0.65	29.06	0.35
	Pu	33.58	0.72	32.78	0.74	33.81	1.07	33.40	0.47
	Post	36.49	0.74	36.42	0.69	37.06	0.89	36.69	0.46
	Total	33.00	0.50	32.25	0.57	33.54	0.70	32.94	0.34

Table 9 Means and standard errors of vertical position and dimensions of surrounding structures in females with different sagittal skeletal patterns

		Female							
		SkeCl.I		SkeCll.II		SkeCl.III		Total	
		Mean	SE.	Mean	SE.	Mean	SE.	Mean	SE.
HyFH (mm)	Pre	69.68	1.37	70.40	1.91	71.08	1.14	70.36	0.84
	Pu	79.47	0.61	80.03	1.23	77.27	1.21	78.91	0.55
	Post	81.74	0.94	81.77	0.97	79.26	0.81	80.95	0.56
	Total	78.54	0.66	77.97	1.00	76.58	0.72	77.79	0.44
VFH (mm)	Pre	66.68	1.39	67.83	1.64	69.22	1.40	67.87	0.84
	Pu	78.22	0.74	79.58	1.49	75.85	1.34	77.78	0.64
	Post	81.33	0.84	80.21	1.19	80.04	1.10	80.68	0.58
	Total	77.29	0.72	76.58	1.10	75.86	0.88	76.67	0.50
MpMeHy (°)	Pre	15.54	1.76	20.34	2.58	14.63	1.73	16.65	1.18
	Pu	18.95	0.77	17.82	1.76	15.91	1.43	17.76	0.69
	Post	18.13	1.30	16.49	1.24	13.43	1.14	16.27	0.78
	Total	18.03	0.68	18.07	1.07	14.73	0.82	16.98	0.48
MpMeV (°)	Pre	14.67	1.37	18.67	1.34	15.51	1.23	16.13	0.79
	Pu	18.97	0.63	19.55	1.51	16.54	1.04	18.34	0.56
	Post	19.46	0.93	16.87	1.22	16.69	1.06	18.02	0.62
	Total	18.37	0.53	18.43	0.81	16.36	0.63	17.74	0.37
PnsU (mm)	Pre	28.43	0.75	29.38	0.69	28.49	0.69	28.73	0.41
	Pu	31.11	0.43	31.99	0.53	28.93	0.65	30.63	0.33
	Post	32.62	0.52	33.58	0.77	30.69	0.46	32.21	0.34
	Total	31.18	0.33	31.80	0.43	29.46	0.36	30.78	0.22
SPT (mm)	Pre	8.35	0.31	8.05	0.22	7.65	0.25	8.03	0.16
	Pu	8.55	0.15	8.61	0.31	8.77	0.27	8.63	0.13
	Post	8.66	0.21	9.07	0.23	8.73	0.22	8.77	0.13
	Total	8.55	0.12	8.61	0.16	8.50	0.15	8.55	0.08
VT (mm)	Pre	59.36	1.25	58.72	1.38	58.42	1.37	58.86	0.76
	Pu	67.11	0.75	68.07	1.07	63.10	0.96	66.08	0.55
	Post	68.43	0.85	68.98	1.18	67.18	1.13	68.15	0.59
	Total	66.20	0.60	65.82	0.90	63.51	0.74	65.25	0.42
Hvt (mm)	Pre	26.93	0.77	27.74	0.72	30.31	0.93	28.30	0.51
	Pu	32.89	0.44	33.57	0.59	32.76	0.77	33.00	0.34
	Post	33.54	0.52	32.93	0.69	33.39	0.56	33.36	0.33
	Total	32.06	0.39	31.77	0.50	32.43	0.45	32.11	0.25

Table 10 Means and standard errors of vertical position and dimensions of surrounding structures in females with different sagittal skeletal patterns

		Total							
		SkeCl.I		SkeCl.II		SkeCl.III		Total	
		Mean	SE.	Mean	SE.	Mean	SE.	Mean	SE.
HyFH (mm)	Pre	73.56	0.98	71.83	1.05	71.98	0.95	72.57	0.58
	Pu	81.40	0.67	80.20	1.04	78.75	0.93	80.32	0.49
	Post	85.83	1.07	86.71	1.34	85.91	1.34	86.06	0.71
	Total	80.89	0.62	79.49	0.86	79.67	0.81	80.15	0.43
VFH (mm)	Pre	70.52	0.95	68.63	0.92	69.59	0.97	69.68	0.55
	Pu	79.38	0.71	78.92	1.18	77.55	1.01	78.73	0.53
	Post	85.16	0.98	85.55	1.40	85.95	1.29	85.52	0.69
	Total	79.06	0.65	77.64	0.94	78.63	0.86	78.56	0.46
MpMeHy (°)	Pre	17.28	1.06	18.15	1.44	16.14	1.33	17.21	0.72
	Pu	19.56	0.72	17.67	1.28	16.04	1.02	18.05	0.56
	Post	20.13	1.21	20.40	1.36	15.40	1.03	18.56	0.72
	Total	19.18	0.57	18.63	0.79	15.83	0.63	17.99	0.38
MpMeV (°)	Pre	15.85	0.76	16.26	0.95	16.09	0.95	16.05	0.50
	Pu	18.74	0.57	18.49	1.07	16.88	0.76	18.13	0.44
	Post	20.65	0.84	20.04	1.17	17.54	0.82	19.44	0.54
	Total	18.64	0.43	18.25	0.63	16.93	0.48	18.01	0.29
PnsU (mm)	Pre	29.32	0.42	29.40	0.42	28.05	0.53	28.97	0.27
	Pu	31.25	0.39	31.86	0.44	29.71	0.53	30.96	0.27
	Post	33.02	0.44	33.41	0.49	31.52	0.43	32.59	0.27
	Total	31.35	0.26	31.55	0.30	29.96	0.31	30.97	0.17
SPT (mm)	Pre	8.40	0.18	8.17	0.15	8.01	0.18	8.21	0.10
	Pu	8.91	0.16	8.92	0.22	9.03	0.19	8.95	0.11
	Post	9.15	0.18	9.48	0.21	9.16	0.21	9.23	0.12
	Total	8.86	0.10	8.85	0.13	8.82	0.12	8.84	0.07
VT (mm)	Pre	61.21	0.87	60.43	0.96	59.16	0.82	60.37	0.52
	Pu	68.17	0.63	67.51	0.91	63.75	0.91	66.71	0.48
	Post	69.86	0.72	71.21	1.01	68.67	0.85	69.76	0.49
	Total	66.98	0.49	66.38	0.69	64.40	0.60	66.02	0.34
Hvt (mm)	Pre	28.51	0.51	28.24	0.43	29.49	0.59	28.71	0.30
	Pu	33.16	0.39	33.19	0.47	33.15	0.62	33.16	0.28
	Post	34.54	0.46	34.46	0.57	35.00	0.56	34.68	0.30
	Total	32.45	0.31	32.01	0.38	32.90	0.39	32.48	0.21

Table 11 Factor analysis of all variables

	Component				
	1	2	3	4	5
PnsUpw_mm			.894		
UMpw_mm		.893			
VLpw_mm		.584			
McU_mm		.407	.731		
McL_mm		.900			
NasoA_mm			.789		
OroA_mm		.818			
TotalA_mm		.665	.608		
AnsPnsU	-.570				
SperHy_mm	.849				
SperV_mm	.838				
SNHy	.874				
SNV	.835				
NSHy	-.910				
NSV	-.923				
HyFH_mm				.650	.564
VFH_mm				.600	.574
MpMeHy					.875
MpMeV					.915
PnsU_mm				.610	
SPT_mm				.759	
VT_mm				.681	
Hvt_mm				.558	

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 11 iterations.

Table 12 The effects of sexes, skeletal ages, sagittal skeletal patterns, and interaction among them (p-values of variables; grouped into 5 factors by Factor analysis)

Factor	Variable	Sex	SkeAge	SkeCl	Sex*age	Sex*Cl	Age*Cl	Sex*Age*Cl
1	PNS-UPW	0.889	<0.001**	0.272	0.118	0.259	0.041*	0.234
	McU	0.953	<0.001**	<0.001**	0.027*	0.947	0.003**	0.534
	Naso A	<0.001**	<0.001**	0.005*	<0.001**	0.190	0.001**	0.229
2	U-MPW	0.059	0.116	<0.001**	0.087	0.142	<0.001**	0.472
	McL	0.072	0.686	<0.001**	0.163	0.463	0.001**	0.388
	V-LPW	0.037*	<0.001**	0.457	<0.001**	0.400	0.043*	0.193
	Oro A	<0.001**	<0.001**	<0.001**	<0.001**	0.257	<0.001**	0.182
	Total A	<0.001**	<0.001**	<0.001**	<0.001**	0.124	<0.001**	0.084
3	ANS-PNS-U	0.001**	0.040*	<0.001**	0.017*	0.647	0.912	0.694
	Sper-Hy	<0.001**	<0.001**	<0.001**	0.007**	0.461	0.269	0.359
	S per-V	0.014*	0.066	<0.001**	0.127	0.944	0.359	0.580
	SNHy	<0.001**	<0.001**	<0.001**	<0.001**	0.615	0.757	0.400
	SNV	<0.001**	<0.001**	<0.001**	<0.001**	0.689	0.444	0.157
	NSHy	0.005**	0.638	<0.001**	0.268	0.306	0.462	0.640
	NSV	0.195	0.798	<0.001**	0.061	0.334	0.152	0.260
4	Hy-FH	<0.001**	<0.001**	0.024*	<0.001**	0.058	0.855	0.217
	V-FH	<0.001**	<0.001**	0.223	<0.001**	0.097	0.832	0.092
	MP-Me-Hy	0.001**	0.079	<0.001**	0.004**	0.566	0.260	0.190
	MP-Me-V	0.062	<0.001**	0.037*	0.001**	0.588	0.249	0.021*
5	PNS-U	0.020*	<0.001**	<0.001**	0.742	0.164	0.978	0.212
	SPT	<0.001**	<0.001**	0.865	0.037*	0.724	0.500	0.674
	Hvt	<0.001**	<0.001**	0.460	<0.001**	0.519	0.706	0.067
	VT	<0.001**	<0.001**	<0.001**	0.104	0.530	0.262	0.552

* The mean difference is significant at the 0.05 level.

** The mean difference is significant at the 0.01 level.

Definition: SkeAge or Age = skeletal age, Ske Cl or Cl = sagittal skeletal pattern

Table 13 Interaction of sexes and skeletal ages, and simple main effects on MPMeV in each sagittal skeletal pattern (p-values)

		Interaction	Main effect	pre-pu	pre-post	pu-post
Class I	Sex	0.055	0.458			
	SkeAge	<0.001**	<0.001**	0.006**	<0.001**	0.046*
	Sex*SkeAge	0.104				
Class II	Sex	0.843				
	SkeAge	0.033				
	Sex*SkeAge	<0.001**				
	Sex	*Pre*	0.022*			
		Pu	0.305			
		Post	0.001**			
	SkeAge	*M*	<0.001**	0.132	<0.001**	0.002**
		F	0.375			
Class III	Sex	0.173	0.170			
	SkeAge	0.460	0.503			
	Sex*SkeAge	0.900				

* The mean difference is significant at the 0.05 level.

** The mean difference is significant at the 0.01 level.

Definition: SkeAge or Age = skeletal age, Ske Cl or Cl = sagittal skeletal pattern, Pre = pre-pubertal, Pu = pubertal, Post = post-pubertal

Table 14 Sexual dimorphism of variables in each skeletal age (*p*-values)

		Pre-pubertal	Pubertal	Post-pubertal
Factor	Variable	M-F	M-F	M-F
1	PNS-UPW^{ns}		0.889	
	McU	0.608	0.027*	0.161
	Naso A	0.007**	0.499	<0.001**
2	U-MPW^{ns}		0.059	
	McL^{ns}		0.072	
	V-LPW	0.838	0.369	<0.001**
	Oro A	0.132	0.835	<0.001**
	Total A	0.023*	0.913	<0.001**
3	ANS-PNS-U	0.902	0.254	<0.001**
	Sper-Hy	0.499	0.001**	<0.001**
	Sper-V^{ns}		0.014*	
	SNHy	0.185	0.118	<0.001**
	SNV	0.235	0.324	<0.001**
	NSHy^{ns}		0.005*	
	NSV^{ns}		0.195	
4	Hy-FH	<0.001**	0.001**	<0.001**
	V-FH	0.002**	0.029**	<0.001**
	MP-Me-Hy	0.480	0.519	<0.001**
	MP-Me-V	-	-	-
5	PNS-U^{ns}		0.020*	
	SPT	0.087	<0.001**	<0.001**
	Hvt	0.203	0.480	<0.001**
	VT^{ns}		<0.001**	

^{ns} the variables with no significant sex-skeletal age interaction

* The mean difference is significant at the 0.05 level.

** The mean difference is significant at the 0.01 level.

Table 15 Skeletal age difference of variables in each sex (*p*-values)

		Male				Female			
Factor	Variable	ANOVA	Pre-Pu	Pre-Post	Pu-Post	ANOVA	Pre-Pu	Pre-Post	Pu-Post
1	PNS-UPW^{ns}	<0.001**	<0.001**	<0.001**	<0.001**				
	McU	<0.001**	0.343	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	0.005**
	Naso A	<0.001**	0.007**	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**
2	U-MPW^{ns}	0.212							
	McL^{ns}	0.816							
	V-LPW	<0.001**	0.241	<0.001**	<0.001**	<0.001**	0.022*	<0.001**	0.025*
	Oro A	<0.001**	0.012*	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	0.083
	Total A	<0.001**	0.003**	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	0.001**
3	ANS-PNS-U	0.001**	0.194	<0.001**	0.013*	0.766			
	Sper-Hy	<0.001**	0.002**	<0.001**	0.059	0.368			
	Sper-V^{ns}	0.066							
	SNHy	<0.001**	0.010*	<0.001**	<0.001**	0.006**	0.001**	0.036*	0.229
	SNV	<0.001**	0.066	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	0.624
	NSHy^{ns}	0.638							
	NSV^{ns}	0.798							
4	Hy-FH	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	0.013*
	V-FH	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	0.001**
	MP-Me-Hy	.008**	0.563	0.003**	0.014*	0.370			
	MP-Me-V	-	-	-	-	-	-	-	-
5	PNS-U^{ns}	<0.001**	<0.001**	<0.001**	<0.001**				
	SPT	<0.001**	<0.001**	<0.001**	0.025*	0.002**	0.004**	0.001**	0.434
	Hvt	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	0.463
	VT^{ns}	<0.001**	<0.001**	<0.001**	<0.001**				

^{ns} the variables with no significant sex-skeletal age interaction

* The mean difference is significant at the 0.05 level.

** The mean difference is significant at the 0.01 level.

Table 16 Difference of sagittal skeletal patterns of airway dimensions in each skeletal ages (*p*-values)

		Pre-pubertal				Pubertal				Post-pubertal			
Factor	**Variable**	ANOVA	Class I-II	Class I-III	Class II-III	ANOVA	Class I-II	Class I-III	Class II-III	ANOVA	Class I-II	Class I-III	Class II-III
1	**PNS-UPW**	0.796				0.029*	0.257	0.067	0.009**	0.048*	0.049*	0.032*	0.945
	McU	<0.001**	0.032*	0.007**	<0.001**	0.937				<0.001**	0.825	<0.001**	<0.001**
	Naso A	0.059				0.545				<0.001**	0.011*	<0.001**	0.234
2	**U-MPW**	0.057				0.308				<0.001**	0.227	<0.001**	0.001**
	McL	0.038*	0.135	0.209	0.011*	0.227				<0.001**	0.285	<0.001**	0.001**
	V-LPW	0.130				0.553				0.025*	0.150	0.007**	0.352
	Oro A	0.003**	0.008**	0.366	0.001**	0.186				<0.001**	0.358	<0.001**	0.002**
	Total A	0.002**	0.018*	0.146	<0.001**	0.319				<0.001**	0.092	<0.001**	0.004**

* The mean difference is significant at the 0.05 level.

** The mean difference is significant at the 0.01 level

Table 17 Difference of skeletal ages of airway dimensions in each sagittal skeletal pattern (*p*-values)

		Class I				Class II				Class III			
Factor	**Variable**	**ANOVA**	**Pre-Pu**	**Pre-Post**	**Pu-Post**	**ANOVA**	**Pre-Pu**	**Pre-Post**	**Pu-Post**	**ANOVA**	**Pre-Pu**	**Pre-Post**	**Pu-Post**
1	PNS-UPW	<0.001**	<0.001**	<0.001**	0.060	<0.001**	<0.001**	<0.001**	0.022*	<0.001**	0.264	<0.001**	<0.001**
	McU	<0.001**	0.001**	<0.001**	0.012*	<0.001**	<0.001**	<0.001**	0.023*	<0.001**	0.994	<0.001**	<0.001**
	Naso A	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	0.131	<0.001**	<0.001**
2	U-MPW	0.121				0.324				<0.001**	0.166	0.018*	<0.001**
	McL	0.006**	0.963	0.009**	0.003**	0.964				0.012*	0.163	0.189	0.003**
	V-LPW	<0.001**	0.065	<0.001**	0.011*	<0.001**	0.007**	<0.001**	<0.001**	<0.001**	0.372	<0.001**	<0.001**
	Oro A	<0.001**	<0.001**	<0.001**	0.482	<0.001**	0.001**	<0.001**	0.010*	<0.001**	0.337	<0.001**	<0.001**
	Total A	<0.001**	<0.001**	<0.001**	0.036*	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	0.179	<0.001**	<0.001**

* The mean difference is significant at the 0.05 level.

** The mean difference is significant at the 0.01 level

Table 18 Difference of sagittal skeletal patterns of surrounding structures (*p*-values)

Factor	Variable	ANOVA	Class I-II	Class I-III	Class II-III
3	ANS-PNS-U	<0.001**	0.016*	<0.001**	<0.001**
	Sper-Hy	<0.001**	0.315	<0.001**	<0.001**
	Sper-V	<0.001**	0.460	<0.001**	<0.001**
	SNHy	<0.001**	0.168	<0.001**	<0.001**
	SNV	<0.001**	0.157	<0.001**	<0.001**
	NSHy	<0.001**	0.234	<0.001**	<0.001**
	NSV	<0.001**	0.180	<0.001**	<0.001**
4	Hy-FH	0.024*	.081	0.009**	0.49
	V-FH	0.223			
	MP-Me-Hy	<0.001**	0.556	<0.001**	0.005**
	MP-Me-V	0.037*	0.581	0.012*	0.085
5	PNS-U	<0.001**	0.636	<0.001**	<0.001**
	SPT	0.865			
	Hvt	0.460			
	VT	0.001**	0.466	0.001**	0.026*

* The mean difference is significant at the 0.05 level.

** The mean difference is significant at the 0.01 level.

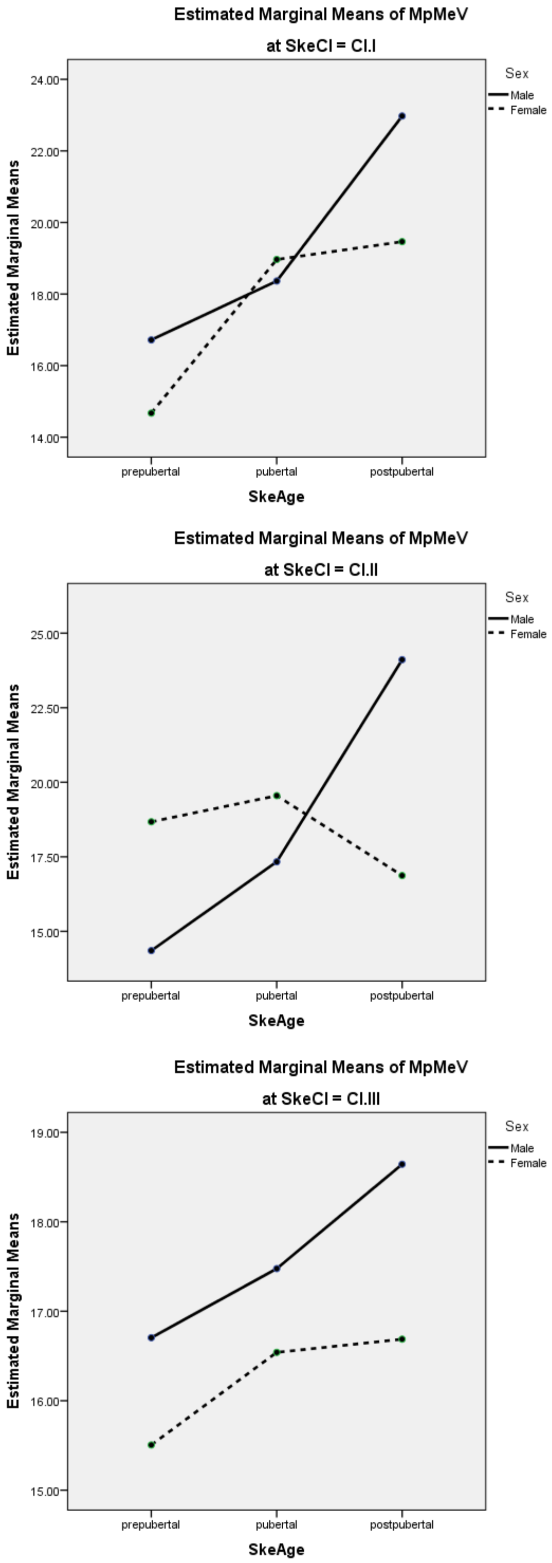

Figure 14 Three-way interaction among sexes, skeletal ages, and sagittal skeletal patterns on MP-Me-V.

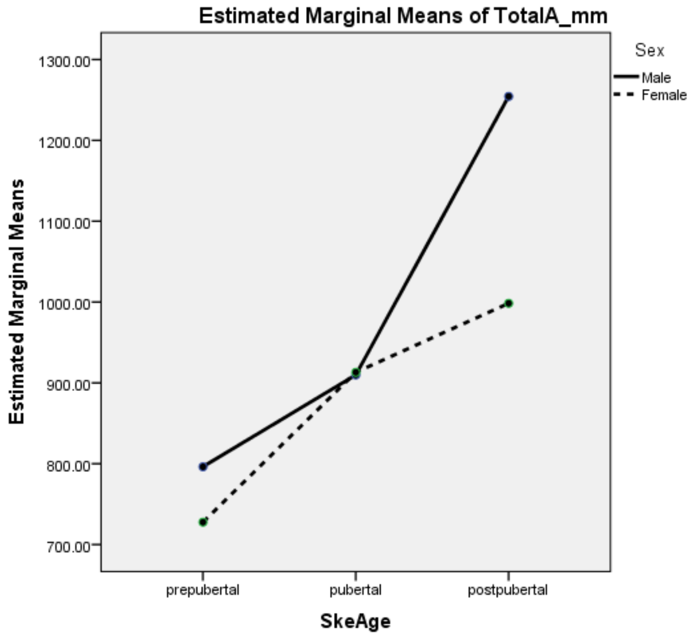

Figure 15 Interaction of skeletal ages and sexes on total airway area (the other variables showed resemble graphs, see appendix)

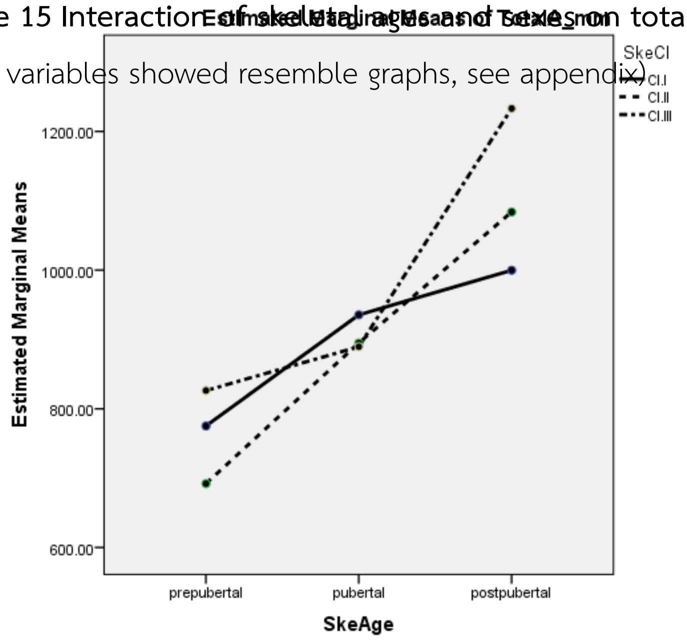

Figure 16 Interaction of skeletal ages and sagittal skeletal patterns of total airway area (the other airway dimension variables showed resemble graphs, see appendix)

4.1.2. Correlation among upper pharyngeal airway dimensions, skeletal ages, and surrounding structures

Correlation between upper pharyngeal airway dimensions, and position and dimensions of surrounding structures; and skeletal ages and sagittal skeletal patterns were presented in tables 19. There was significantly moderate correlation between vertical linear tongue and hyoid positions (HyFH and VFH), tongue dimensions(H-VT and VT), nasopharyngeal (NasoA) area, and total pharyngeal (TotalA) area; and skeletal ages ($p<0.01$). Other variables showed mild, but significant correlation between dimensions of upper pharyngeal airway, tongue, and soft palate, including the positions of tongue and hyoid; and skeletal ages ($p<0.01$), except for ANS-PNS-U, NSHy, NSV, MP-Me-Hy, S per-V, U-MPW, and McL. SNHy and SNV revealed significantly moderate correlation with SNA and SNB ($p<0.01$). NSHy and NSV also correlated with SNB, moderately and significantly. Pharyngeal airway dimensions and other surrounding structures also presented significantly mild correlation to SNA ($p<0.01$), except for ANS-PNS-U, MP-Me-Hy, MP-Me-V, PNS-U, U-MPW, McL, V-LPW, and OroA; SNB ($p<0.01$), except for HyFH, PNS-U, SPT, and VT; and ANB ($p<0.01$), except for HyFH, VFH, SPT, H-VT, PNS-UPW and NasoA.

Correlation between upper pharyngeal airway dimensions; and position and dimensions of surrounding structures were presented in tables 20. Three area measurements and airway width at the level of tongue significantly and moderately correlated with vertical tongue and hyoid position, tongue length ($p<0.01$). Other airway variables showed mild, but significant, correlation to mandibular position, vertical and horizontal hyoid and tongue position, and tongue thickness ($p<0.01$).

Correlation among pharyngeal airway dimensions was shown in table 21. Linear airway measurements presented moderately high correlation with the area measurements (PNS-UPW and nasopharyngeal area, $R=0.738$; U-MPW, V-LPW and oropharyngeal area, $R=0.725$, 0.722; McU and total pharyngeal area, $R=0.755$, $p<0.01$). Oropharyngeal area presented nearly perfect correlation to total pharyngeal area ($R=0.929$, $p<0.01$).

Correlation among bony and soft tissue variables was shown in tables 22-23. New angular measurements of horizontal and vertical position of tongue and hyoid significantly correlated with the existing linear measurements ($p<0.01$) as shown in table 22. Tongue position showed high and significant correlation with hyoid position ($p<0.01$). Horizontal position of hyoid and tongue showed moderate to high, and significant correlation with maxillary (SNA) and mandibular position (SNB), soft palate angulation, and tongue thickness ($p<0.01$). Vertical linear position of hyoid and tongue showed moderate to high correlation with dimensions of tongue and soft palate ($p<0.01$). Soft palate length moderately correlated with tongue dimensions ($p<0.01$).

Table 19 Correlation coefficients between upper pharyngeal airway dimensions and surrounding structures; and skeletal ages and sagittal skeletal patterns

	SkeAge [n]	SNA	SNB	ANB
AnsPnsU	-.082	-.015	-.333**	.377**
SNHy	.223**	.539**	.705**	-.279**
SNV	.313**	.530**	.683**	-.263**
NSHy	.004	-.472**	-.685**	.325**
NSV	-.044	-.492**	-.694**	.314**
MpMeHy [n]	.064	-.086	-.234**	.192**
MpMeV	.204**	-.007	-.109*	.122*
SperHy	.122*	.203**	.458**	-.332**
HyFH [n]	.586**	.125*	.090	.041
SperV	.076	.177**	.406**	-.299**
VFH	.658**	.162**	.191**	-.059
PnsU	.395**	.083	-.091	.193**
SPT	.287**	.109*	.094	.001
VT	.518**	.175**	.047	.125*
Hvt	.538**	.160**	.194**	-.065
PnsUpw	.432**	.207**	.176**	.004
McU	.434**	.188**	.385**	-.261**
NasoA [n]	.601**	.245**	.304**	-.086
Umpw	.079	.033	.265**	-.279**
McL	-.033	-.033	.229**	-.304**
VLpw	.400**	.085	.237**	-.192**
OroA [n]	.414**	.088	.281**	-.235**
TotalA [n]	.547**	.174**	.322**	-.185**

[n] The Spearman's correlation

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Table 20 Correlation coefficients between upper pharyngeal airway dimensions and surrounding structures

	PnsUpw	McU	NasoA^n	Umpw	McL	VLpw	OroA^n	TotalA^n
AnsPnsU	.309**	-.105*	-.004	-.097*	-.096*	-.020	-.126**	-.077
SNHy	.044	.257**	.344**	-.035	-.044	.131**	.164**	.255**
SNV	.102*	.309**	.405**	-.011	-.015	.351**	.276**	.359**
NSHy	.029	-.144**	-.167**	.046	.040	.037	.041	-.036
NSV	.024	-.180**	-.200**	.046	.007	-.133**	-.040	-.106*
MpMeHy^n	-.099*	-.079	-.023	-.132**	-.055	.065	.092	.054
MpMeV	.018	.052	.122*	-.098*	-.086	.295**	.236**	.216**
SperHy	.010	.180**	.227**	-.009	-.016	.028	.061	.127**
HyFH^n	.303**	.324**	.530**	.049	-.003	.389**	.507**	.581**
SperV	-.045	.141**	.158**	-.040	-.002	.118*	.033	.078
VFH	.375**	.413**	.603**	.111*	.034	.542**	.576**	.661**
PnsU	.328**	.097*	.339**	-.260**	-.183**	.187**	.141**	.240**
SPT	.087	-.046	.208**	.005	.005	.013	.106*	.161**
VT	.413**	.320**	.444**	.259**	.136**	.322**	.509**	.555**
Hvt	.309**	.305**	.466**	-.019	-.061	.393**	.384**	.463**

^{n} The Spearman’s correlation

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Table 21 Correlation coefficients among upper pharyngeal airway dimensions

	PnsUpw	McU	NasoA^n	Umpw	McL	VLpw	OroA^n	TotalA^n
PnsUpw	1	.707**	.738**	.351**	.196**	.373**	.525**	.685**
McU	.707**	1	.698**	.452**	.298**	.418**	.653**	.755**
NasoA^n	.738**	.698**	1	.242**	.122*	.407**	.525**	.789**
Umpw	.351**	.452**	.242**	1	.753**	.436**	.725**	.613**
McL	.196**	.298**	.122*	.753**	1	.493**	.677**	.520**
VLpw	.373**	.418**	.407**	.436**	.493**	1	.722**	.682**
OroA^n	.525**	.653**	.525**	.725**	.677**	.722**	1	.929**
TotalA^n	.685**	.755**	.789**	.613**	.520**	.682**	.929**	1

^{n} The Spearman's correlation

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Table 22 Correlation coefficients among angular positions of tongue, hyoid, and soft palate; and surrounding structures

	AnsPnsU	SNHy	SNV	NSHy	NSV	MpMeHy^{n}	MpMeV
AnsPnsU	1	-.475**	-.436**	.385**	.403**	.065	-.003
SNHy	-.475**	1	.896**	-.794**	-.773**	.039	.137**
SNV	-.436**	.896**	1	-.681**	-.808**	.052	.340**
NSHy	.385**	-.794**	-.681**	1	.927**	.341**	.199**
NSV	.403**	-.773**	-.808**	.927**	1	.255**	.040
MpMeHy^{n}	.065	.039	.052	.341**	.255**	1	.766**
MpMeV	-.003	.137**	.340**	.199**	.040	.766**	1
SperHy	-.462**	.701**	.559**	-.753**	-.654**	-.183**	-.051
HyFH ^{n}	-.151**	.394**	.412**	.065	.003	.490**	.457**
SperV	-.434**	.572**	.589**	-.674**	-.715**	-.176**	.028
VFH	-.199**	.436**	.562**	.000	-.101*	.357**	.591**
PnsU	-.018	.068	.095	.164**	.146**	.231**	.253**
SPT	-.222**	.223**	.151**	-.098*	-.037	-.026	.000
VT	.036	.017	.067	.242**	.243**	.166**	.248**
Hvt	-.260**	.405**	.494**	-.172**	-.228**	.048	.274**

^{n} The Spearman's correlation

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Table 23 Correlation coefficients among linear dimensions and positions of tongue and hyoid; and surrounding structures

	SperHy	HyFH [n]	SperV	VFH	PnsU	SPT	VT	Hvt
AnsPnsU	-.462**	-.151**	-.434**	-.199**	-.018	-.222**	.036	-.260**
SNHy	.701**	.394**	.572**	.436**	.068	.223**	.017	.405**
SNV	.559**	.412**	.589**	.562**	.095	.151**	.067	.494**
NSHy	-.753**	.065	-.674**	.000	.164**	-.098*	.242**	-.172**
NSV	-.654**	.003	-.715**	-.101*	.146**	-.037	.243**	-.228**
MpMeHy[n]	-.183**	.490**	-.176**	.357**	.231**	-.026	.166**	.048
MpMeV	-.051	.457**	.028	.591**	.253**	.000	.248**	.274**
SperHy	1	.175**	.877**	.248**	-.043	.247**	-.086	.368**
HyFH [n]	.175**	1	.066	.912**	.524**	.347**	.615**	.610**
SperV	.877**	.066	1	.190**	-.091	.128**	-.184**	.338**
VFH	.248**	.912**	.190**	1	.502**	.333**	.628**	.714**
PnsU	-.043	.524**	-.091	.502**	1	.251**	.452**	.449**
SPT	.247**	.347**	.128**	.333**	.251**	1	.332**	.188**
VT	-.086	.615**	-.184**	.628**	.452**	.332**	1	.517**
Hvt	.368**	.610**	.338**	.714**	.449**	.188**	.517**	1

[n] The Spearman's correlation

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

4.2. Part II: Correlation between 2D and 3D measurements of pharyngeal airway dimensions

There are 21 subjects ranged in ages from 14 to 30 years. The samples consisted of 7 males and 14 females. All variables showed normal distribution (see appendix). ICC presented high intra-observer reliability of linear and area measurements from reconstructed lateral cephalometric radiographs (R= 0.913-0.995, average 0.962), as well as volumetric CBCT measurements (R = 0.971)**.** Paired *t*-test showed that sagittal measurements of linear and area airway dimensions from lateral cephalometric radiographs were not statistically different from reconstructed lateral cephalometric radiographs (p>0.05), except for airway width at the level of uvula tip (U-MPW) (p= 0.047) (table 24). Pearson's correlation coefficients between 2D and 3D pharyngeal airway measurements were shown in table 25. All sagittal linear and area measurements from lateral cephalometric radiographs significantly showed good to nearly perfect correlation with the corresponding reconstructed lateral cephalometric radiographs (R= 0.726-0.915; p< 0.01). Moreover, linear and area measurements from lateral cephalometric radiographs significantly presented moderate to high correlation with volumetric measurements from CBCT scans. Among all linear variables from lateral cephalometric radiographs, PNS-UPW and McU showed highest correlation with nasopharyngeal volume (R=0.507 and 0.525, respectively; p< 0.01), and U-MPW showed highest correlation with oropharyngeal and total pharyngeal volume (R=0.706 and 0.719, respectively; p< 0.01) Among three area variables from lateral cephalometric radiographs, nasopharyngeal area presented good correlation with nasopharyngeal volume (R= 0.708; p< 0.01), and total pharyngeal area showed highest correlation with oropharyngeal and total pharyngeal volume (R= 0.761 and 0.799, respectively; p< 0.01).

Table 24 Comparison between 2D airway measurements from lateral cephalometric radiographs and reconstructed lateral cephalometric radiographs

Variables		Paired Differences			Sig. (2-tailed)
LC	CBCT	Mean	SD	SE Mean	
PnsUpw	PnsUpw	-.44	1.97	.43	.317
Umpw	UMpw	-1.08	2.35	.51	.047*
VLpw	VLpw	-.72	2.64	.58	.227
McU	McU	-.24	2.07	.45	.602
McL	McL	-.69	2.90	.63	.288
NasoA	NasoA	-17.49	47.83	10.44	.109
OroA	OroA	-41.66	157.71	34.41	.240
TotalA	TotalA	-60.81	172.62	37.67	.122

LC; lateral cephalometric radiograph

CBCT; cone-beam computed tomography

* The mean difference is significant at the 0.05 level.

Table 25 Correlation coefficients among 2D and 3D airway measurements

CBCT/LC	PnsUpw	UMpw	VLpw	McU	McL	NasoA	OroA	TotalA
PnsUpw	.893**	.334	.061	.455*	-.004	.743**	.010	.292
UMpw	.454*	.738**	.434*	.579**	.615**	.581**	.628**	.730**
VLpw	.457*	.635**	.726**	.446*	.433*	.509*	.723**	.773**
McU	.545*	.726**	.365	.773**	.447*	.767**	.522*	.722**
McL	.353	.671**	.475*	.474*	.813**	.471*	.686**	.735**
NasoA	.741**	.424	.170	.621**	.200	.915**	.215	.536*
OroA	.294	.714**	.647**	.483*	.591**	.488*	.797**	.828**
TotalA	.501*	.719**	.574**	.607**	.540*	.718**	.708**	.850**
NasoVol	.507*	.235	.096	.525*	-.034	.708**	.055	.329
OroVol	.215	.706**	.543*	.458*	.524*	.527*	.688**	.761**
TotalVol	.359	.719**	.526*	.586**	.467*	.708**	.645**	.799**

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Chapter 5
Discussion

5.1. Part I: Interaction of sexes, skeletal ages, and sagittal skeletal patterns; Correlation among variables

5.1.1 Influences of sexes, skeletal ages, and sagittal skeletal patterns on upper pharyngeal airway dimensions and surrounding structures

There was 1 variable, MP-Me-V, showed three-way interaction among sexes, skeletal ages and sagittal skeletal patterns. This suggested that skeletal Class II males in the post-pubertal period had tendency to have lowest position of tongue, followed by skeletal Class I in both genders. Two-way interactions were found between sexes and skeletal ages in all variables, and also between skeletal ages and sagittal skeletal patterns in airway variables. However, there was no interaction between sexes and sagittal skeletal patterns, which was in agreement with Ceylan and Oktay(1).

The result of present study suggested that males had greater airway dimension, especially airway area, larger and longer tongue and soft palate, more antero-inferior position of hyoid and tongue, and less obtuse soft palate angulation than females. Nevertheless, airway width at the level of palate and tip of uvula (PNS-UPW and U-MPW), McNamara's upper and lower pharynx dimension (McU and McL), angular horizontal position of hyoid and tongue (NSHy and NSV), and soft palate length(PNS-U) showed no sexual dimorphism. Although there was statistically significant sexual difference in McU in the pubertal period, NSHy, and soft palate length; the discrepancy of 0.4-0.9 mm might not be clinically significant. These sexual difference in airway, tongue and soft palate dimensions was in agreement with previous studies in growing population. However, airway width at the level of palate(1) and McNamara's upper and lower pharynx dimension(5, 31) presented no sexual dimorphism as confirmed in the present study. The studies in non-growing ones also revealed no sexual dimorphism of airway width at the level of palate(23), minimal airway width behind soft palate(62) and tongue(62), and McNamara's upper and lower pharynx dimension(23). On the contrary, Ceylan and Oktay found that there was no sexual difference in airway area. Abu Allhaija and Al-Khateeb(11) reported no sexual difference in tongue and soft palate dimensions in growing subjects, although difference in hyoid position was presented. The age of subjects in those studies were in the pre-pubertal period that presented no sexual dimorphism in airway area and no clinical significant in sexual difference in tongue and soft palate dimensions in the present study. Martin et al(23) found no sexual dimorphism in nasopharyngeal airway area in non-growing subjects. Moreover, present study also found that horizontal tongue positions in relation to SN plane (NSV) showed neither sexual dimorphism nor interaction of sexes and other factors. Females' linear tongue position might be lesser than males' both vertically and horizontally in the same proportion that lead to no difference of NSV between sexes.

Skeletal ages also affected most airway dimensions, positions and dimensions of surrounding structures, but not airway width at the level of uvula tip (U-MPW) and McNamara's lower pharynx dimension (McL), angular horizontal positions of hyoid and tongue in relation to SN (NSHy and NSV), and linear tongue position in relation to S perpendicular to Frankfort horizontal (FH) plane (S per-V). Nevertheless, S per-V almost showed skeletal ages difference. The constant angular horizontal positions of hyoid and tongue might result from the steady growth of hyoid and tongue in downward and forward direction, as previously described by Tourné(6) that hyoid descended together with mandible and cervical vertebrae. The airway, tongue, and soft palate dimensions increased, while tongue and hyoid moved more anteriorly and inferiorly with advancing skeletal ages according to cervical maturation stage. The changes in dimensions and positions were obvious during the pre-pubertal and the pubertal period in females, while males presented differently to remarkably increase from the pubertal to the post-pubertal periods. Moreover, males had tendency to have insignificantly larger upper pharyngeal airway dimensions in the pre-pubertal, but smaller upper pharyngeal airway dimensions in the pubertal period, then significantly larger upper pharyngeal airway dimensions in the post-pubertal period. These were relevant to general growth that females reached puberty earlier than males(26), as well as the study of Preston et al(13), who reported that nasopharyngeal airway width in growing patients highly correlated with skeletal ages, measured by hand-wrist radiograph, and presented the pubertal growth spurt pattern and sexual dimorphism. Mislik et al(5) found slight increase in McNamara's upper pharynx dimension (McU) with increasing chronological age, but not in the lower (McL) one. Preston et al(13) demonstrated that airway width from PNS to adenoid tissue on the PNS-Basion line decreased during puberty, measured by skeletal age from hand-wrist radiograph, which might be the influence of increasing in adenoid thickness during this period(22).

Most variables were also affected by sagittal skeletal patterns, except for vertical distance of hyoid and tongue from FH plane (Hy-FH and V-FH), soft palate thickness (SPT), and tongue height (H-VT). The airway dimensions increased; tongue and hyoid positioned more anteriorly; and soft palate angulation decreased from skeletal Classes II, I, and III, respectively. The correlation among variables revealed the tendency that these were the result of more anterior mandibular position (SNB) than the difference in maxillo-mandibular relationship (ANB). Tongue and soft palate lengths were shorter in skeletal Class III than skeletal Classes I and Class II. Therefore, the dimensions and positions of surrounding structures might be the reason why the airway dimensions in skeletal Class III were larger than the others. These were in accordance with the study of Zhong et al(41) who presented that airway widths of growing subjects (aged 11-16 years old) at the level of uvula tip and tongue base were wider in skeletal Class III than the others. Takemoto et al(14) reported that the girls (aged 6-8 years old) with mandibular prognathism had wider lower pharyngeal airway. On the contrary, Abu Allhaija and Al-Khateeb(11) reported no difference in airway width of adolescents (aged 14-17 years old) among three sagittal skeletal patterns, although tongue length was shortest, and hyoid position was most anterior in skeletal Class III. The disagreement might be explained by the present result that there was no sagittal skeletal pattern difference in the pubertal period. The difference in severity of mandibular prognathism might also explain this disagreement as well.

Pornsuksiri et al(7) found that the airway dimension in non-growing Thai subjects decreased from skeletal Classes III, I, and II, respectively. However, overall airway dimension of the post-pubertal group in our study had tendency to decrease from skeletal Classes III, II, and I, respectively. The differences in facial size, obesity, muscle thickness(101) as well as the tone, and genetic background of each individual(5) might explain the study discrepancy. For further study, other factors that affect the airway dimension should be monitored, the prospective design is required in order to control more factors, and ratio of airway dimension to facial dimension should be considered instead of direct airway measurement. However, due to the time limitation of the present study, the retrospective basis was performed.

The study of Ping-Ying Chiang et al(4) in Asian children with OSA found that the increase in distance between hyoid and mandibular plane (MP-H), wider angle between mandibular plane and hyoid (Gn-Go-H), and the larger proportion of adenoid (Ad/Na) were related to the increase in apnea-hypopnea index. Moreover, OSA patients had significantly larger ANB due to decrease in SNB(102), narrower nasopharyngeal airway width(102), transverse airway width(101) and antero-posterior oropharyngeal diameter of smallest cross-sectional area(103, 104); smaller minimum cross-sectional area(101, 104); and lesser total airway volume(103) compared with normal subjects. At the minimum airway area, thickness of the lateral pharyngeal muscular walls rather than enlargement of the parapharyngeal fat pads was the predominant anatomic factor causing airway narrowing in patients with OSA(101). Furthermore, comparing with the previous airway study(8) in adult Thai patients with primary snoring and OSA, the airway width at the level of uvula tip (U-MPW) in the post-pubertal group from our study (11.2±3.28 mm in males, 9.69±2.82 mm in females) was larger than that of Jamsirirojrat et al(8) both males (9.3±1.8 mm in primary snoring, 9.5±3.3 mm in OSA) and females (8.9±2.3 mm in primary snoring, 7.1±2.5 mm in OSA). Nevertheless, the reference points and the ages of the patients used in our study and that of Jamsirirojrat et al(8) were different. Therefore, a further study using the same age group and reference points may be needed to compare the difference in airway dimensions at several levels, and hyoid and tongue position between the normal subjects and patients with compromised airway who had tendency to develop OSA.

5.1.2. Influences of dimensions and position of surrounding structures on upper pharyngeal airway dimensions

Maxillary position (SNA) and mandibular position (SNB) positively and significantly correlated with nasopharyngeal airway dimensions. Mandibular position (SNB) positively, and maxilla-mandibular relationship (ANB) negatively, correlated with oropharyngeal airway dimensions. These were in accordance with previous studies reporting that ANB angle and SNB angle correlated with cross-sectional oropharyngeal area (44), sagittal oropharyngeal area(1) and volume(12), but not sagittal nasopharyngeal area(1) or volume(12). However, some studies found that nasopharyngeal and oropharyngeal airway width or volume had no significant correlation with ANB angle(5, 39), but significant correlation with SNA and SNB(5).

Moreover, upper pharyngeal airway dimensions significantly correlated with surrounding structures of pharynx. We found that the more obtuse soft palate angulation (ANS-PNS-U) was, the smaller nasopharyngeal and upper oropharyngeal width, and oropharyngeal area would be. The exception was found in airway width at the level of palate, which might be an effect of shorter palate length. The more anterior position of hyoid and tongue (SNHy, NSHy, and S per-Hy; and SNV, NSV, and S per-V), and the lower hyoid and tongue position (HyFH, VFH, and MP-Me-V) resulted in the larger nasopharyngeal and lower oropharyngeal width and area. Soft palate length, tongue length and height (PNS-U, VT, and H-VT) positively correlated with nasopharyngeal and lower oropharyngeal airway dimensions. Nevertheless, the shorter soft palate and longer tongue correlated with larger upper oropharyngeal airway dimensions. The subject with thicker soft palate thickness (SPT) tended to have more acute soft palate angulation and more anteriorly positioned hyoid and tongue, causing larger pharyngeal airway area. These supported previous studies (4, 8) reporting that patients with compromised airway had more retruded maxilla, larger ratio of adenoid to nasopharyngeal length, shorter airway width at the level of uvula tip, and inferiorly and posteriorly positioned hyoid in relation to mandibular plane. Moreover, narrow upper pharyngeal airway, large tongue and soft palate, posterior position of cranial base, short mandible and/or retrognathia, long lower face height, high mandibular plane angle, and downward and backward position of hyoid were also the causes of OSA(4, 11). This study confirmed that not only the ANB angle, but also dimension and position of surrounding structures that correlated with upper pharyngeal airway dimensions. Future work may focus on the validity of these bony and soft tissue variables in predicting airway dimensional changes from orthodontic treatment.

5.1.3. Correlation among upper pharyngeal airway dimensions

Jean et al(25) suggested the use of area measurement to explain pharyngeal airway growth and dimensions. Nevertheless, all upper pharyngeal airway dimensions from our study significantly correlated to each other in various degrees. PNS-UPW, U-MPW, V-LPW, and McU showed the highest correlation to nasopharyngeal area, oropharyngeal area, and total pharyngeal area, respectively. Oropharyngeal area presented nearly perfect correlation to total pharyngeal area. These demonstrated that linear measurements can be used as screening parameters in recognizing orthodontic patients at risk of compromised airway.

5.1.4. Correlation among dimensions and position of surrounding structures

Horizontal position of hyoid and tongue negatively correlated with soft palate angulation, but positively correlated with tongue thickness. Vertical position of hyoid and tongue showed moderate to high correlation with dimensions of tongue and soft palate. Soft palate length moderately correlated with tongue dimensions. These might explain that the subjects with more inferior position of tongue and hyoid, which correlated with greater airway dimensions, had tendency to develop OSA due to the larger tongue and soft palate.

Linear vertical position of hyoid and tongue (HyFH and VFH) positively correlated with angular position related to SN plane (SNHy and SNV) and mandibular plane (MP-Me-Hy and MP-Me-V). Linear horizontal hyoid and tongue position (S per-Hy and S per-V) positively correlated with SNHy and SNV, and negatively correlated with

NSHy and NSV. These suggested that NSHy, NSV, MP-Me-Hy, and MP-Me-V, which showed the highest correlation to the linear measurements, might be able to explain horizontal and vertical position of hyoid and tongue.

Controversy in airway dimension difference between normal subjects and airway compromised patients still presented, however the hyoid position was found to be significantly different in all studies. Therefore, in order to recognize the patients with underlying airway problem, we suggested that the airway width behind palate and soft palate, together with tongue and hyoid positions should be evaluated.

5.2. Part II: Correlation between 2D and 3D measurements of pharyngeal airway dimensions

Intra-observer reliability (ICC) of linear, area, and volumetric measurements of upper pharyngeal airway from reconstructed lateral cephalometric radiographs and CBCT scans in the present study was good, as well as both intra-observer and inter-observer reliability based on ICC and Bland-Altman method from previous studies(105, 106). CBCT, though its low efficacy in differentiating various types of soft tissue, was proved as an accurate method to assess pharyngeal airway space (107). Previous studies(15, 108) found that CBCT airway volume showed more variability (based on coefficient of variation) than lateral cephalometric airway area, therefore, more information would be obtained from CBCT scans.

The present study found that all sagittal linear, with the exception of airway width at the level of uvula tip (U-MPW), and area measurements from lateral cephalometric radiographs significantly showed good to nearly perfect correlation with the corresponding reconstructed lateral cephalometric radiographs, and moderate to high correlation with volumetric measurements from CBCT scans. These were in agreement with many previous studies that nasopharyngeal airway dimensions presented significant correlation between measurements from lateral cephalometric radiographs (sagittal linear(92) and area(72) measurements) and measurements from 3D radiographs (2D sagittal linear measurements from reconstructed lateral cephalometric radiographs(92, 109); cross-sectional area measurements from CBCT axial slices(92, 109) and MRI(93); and 3D volumetric measurements from CBCT scans taken in supine(72) and upright position(92, 109)). Moreover, sagittal airway widths behind soft palate, i.e. minimal distance and at the level of uvula tip, from lateral cephalometric radiographs also significantly correlated with cross-sectional area from MRI(93).

On the contrary, Lenza et al(109) found that linear sagittal oropharyngeal widths showed weak and insignificant correlation with corresponding cross-sectional areas and volumetric measurements, while, correlation among linear transversal widths, corresponding cross-sectional areas, and volumetric measurements of oropharyngeal airway was found. Vizzotto et al(92) reported that sagittal oropharyngeal airway distance was different between CBCT axial slice and lateral cephalometric radiograph. Moreover, sagittal linear measurements from three methods, i.e. reconstructed lateral cephalometric radiograph, CBCT axial slice, and lateral cephalometric radiograph, revealed positive correlation with cross-sectional area measurements.

Supine or upright position, awake or asleep muscle tone, inspiration or expiration, duration of X-ray exposure, and mouth opening affected the pharyngeal airway shape and pharyngeal airway dimensions. However, Pracharktam et al(94) found that only the airway width behind soft palate showed statistically significant difference between supine and upright positions. Moreover, differences in pharyngeal airway space, tongue length, and hyoid position between normal subjects and OSA patients were found in both upright and supine positions(94). Considering these circumstances, it becomes evident that sagittal measurements from 2D radiographs may be used to preliminarily assess pharyngeal airway dimensions.

However, airway width at the level of uvula tip (U-MPW) showed significant difference between conventional lateral cephalometric radiograph and reconstructed lateral cephalometric radiograph. Differences in head position from the 2 methods (CBCT scan and lateral cephalometric radiograph) might be the reason for this discrepancy, as reported in the study of Pirilä-Parkkinen et al(98) that the head angulation had an effect on airway dimension behind soft palate and tongue. Therefore, head positioning during radiograph taking is crucial in investigation of pharyngeal airway measurements between subjects, especially in oropharyngeal region.

5.3. Clinical application

5.3.1. Special care should be performed when treating patients with deficient airway, and postero-inferiorly positioned hyoid and tongue who might be at risk of developing OSA, especially in the post-pubertal males. Orthopedic treatment and orthognathic surgery in skeletal Class III patients, whose mandible will be push backward from the treatment, should be carefully planned. Two-jaw surgery might be another option.

5.3.2. To recognize the patients with underlying airway problem, we suggested that the airway widths behind palate and soft palate (PNS-UPW and U-MPW), and hyoid and tongue positions (NSHy, NSV, MP-Me-Hy) should be evaluated.

5.4. Limitations and suggestion

5.4.1. The patients included in this study were based on the history taking from orthodontic chart of the department. None had done the questionnaire, nor undergone the overnight polysomnography to confirm the absence of OSA.

5.4.2. The effect of vertical skeletal patterns might also affect the upper pharyngeal airway space of the growing patients, which need further investigation.

5.4.3. This study was based mainly on the 2D data which lacks the transverse information of the pharynx.

5.4.4. The correlation between 2D and 3D measurements of pharynx was a preliminary study, mainly base on skeletal Class III patients. Therefore, larger sample size with various sagittal skeletal patterns is needed to confirm this relationship.

5.4.5. Appropriate variables should be further investigated to compare these variables between normal subjects and patients with compromised airway.

Chapter 6

Conclusion

Upper pharyngeal airway dimensions showed interaction between sexes and skeletal ages, and skeletal ages and sagittal skeletal patterns. They also revealed the pubertal growth pattern. The dimensions and positions of surrounding structures also presented interaction between sexes and skeletal ages. Skeletal ages, positions and dimensions of surrounding structures, and sagittal mandibular positions correlated with upper pharyngeal airway dimensions at almost all levels, and both linear and area measurements. The post-pubertal males had tendency to have larger airway, tongue, and soft palate dimensions; more antero-inferior position of hyoid and tongue, and less obtuse soft palate angulation. Hyoid and tongue positioned more anteriorly; while soft palate angulation was more acute; and tongue and soft palate lengths were shorter in skeletal Class III subjects.

Two dimensional pharyngeal airway measurements from lateral cephalometric radiographs presented no difference of those from reconstructed lateral cephalometric radiographs, and good correlation with 3D pharyngeal airway measurements. We suggested the use of linear airway measurements, i.e. PNS-UPW and U-MPW, which presented good correlation with area and volumetric measurements, together with angular tongue and hyoid positions, i.e. N-S-V, N-S-Hy, and MP-Me-Hy, which showed good relationship with the existing linear measurements, as screening parameters to early recognize the patients who might be at risk of OSA in orthodontic treatment planning. However, further research is needed to compare these new parameters between normal subjects and airway compromised patients in order to assess the effectiveness of parameters.

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APPENDIX

Table 26 Normality test of each variable in Part I

	N	Normal Parameters		Kolmogorov-Smirnov Z	Asymp. Sig. (2-tailed)
		Mean	SD		
SNA (°)	418	83.101	3.330	.660	.776
SNB (°)	418	79.692	3.830	.627	.827
ANB (°)	418	3.409	3.249	.998	.272
AnsPnsU (°)	418	129.062	6.115	.591	.876
SNHy (°)	418	57.987	3.585	.393	.998
SNV (°)	418	51.656	3.585	.616	.843
NSHy (°)	418	88.849	3.914	.590	.877
NSV (°)	418	96.864	3.868	.686	.734
MpMeHy (°)	418	17.994	7.766	1.522	.019*
MpMeV (°)	418	18.007	5.923	.886	.413
SperHy (mm)	418	17.665	5.942	.667	.765
SperV (mm)	418	4.015	5.304	.824	.506
HyFH (mm)	418	80.152	8.743	1.398	.040*
VFH (mm)	418	78.562	9.325	1.026	.243
PnsU (mm)	418	30.967	3.501	.766	.601
SPT (mm)	418	8.843	1.352	.979	.293
VT (mm)	418	66.023	6.874	.718	.680
Hvt (mm)	418	32.476	4.198	.479	.976
PnsUpw (mm)	418	23.198	3.758	.987	.284
UMpw (mm)	418	9.946	2.784	1.289	.072*
VLpw (mm)	418	14.703	3.198	.907	.384
McU (mm)	418	9.889	2.840	.615	.844
McL (mm)	418	10.569	3.125	1.323	.060
NasoA (mm^2)	418	337.905	98.734	1.457	.029*
OroA (mm^2)	418	597.038	170.267	1.646	.009*
TotalA (mm^2)	418	934.944	239.854	1.371	.047*

*Normal distribution was rejected when $p < 0.05$.

Table 27 Normality test of each variable in part I, gender= male

	N	Normal Parameters		Kolmogorov-Smirnov Z	Asymp. Sig. (2-tailed)
		Mean	SD		
AnsPnsU (°)	183	128.096	6.472	.547	.926
SNHy (°)	183	58.897	3.792	.414	.995
SNV (°)	183	52.122	3.747	.742	.640
NSHy (°)	183	88.330	4.080	.623	.833
NSV (°)	183	96.643	3.986	.361	.999
MpMeHy (°)	183	19.292	8.093	.981	.291
MpMeV (°)	183	18.344	6.238	.851	.464
SperHy (mm)	183	19.256	6.303	.486	.972
SperV (mm)	183	4.661	5.598	.734	.654
HyFH (mm)	183	83.190	9.982	1.059	.212
VFH (mm)	183	80.997	10.660	1.402	.039*
PnsU (mm)	183	31.208	3.621	.833	.492
SPT (mm)	183	9.222	1.393	.760	.610
VT (mm)	183	67.016	7.270	.756	.617
Hvt (mm)	183	32.945	4.552	.922	.363
PnsUpw (mm)	183	23.056	3.971	.875	.428
UMpw (mm)	183	10.221	3.015	.812	.524
VLpw (mm)	183	14.890	3.713	.765	.602
McU (mm)	183	9.692	2.955	.765	.602
McL (mm)	183	10.894	3.272	.865	.442
NasoA (mm^2)	183	349.640	114.030	1.305	.066
OroA (mm^2)	183	625.884	196.213	1.210	.107
TotalA (mm^2)	183	975.523	282.029	1.164	.133

*Normal distribution was rejected when $p< 0.05$.

Table 28 Normality test of each variable in part I, gender= female

	N	Normal Parameters		Kolmogorov-Smirnov Z	Asymp. Sig. (2-tailed)
		Mean	SD		
AnsPnsU (°)	235	129.814	5.723	.448	.988
SNHy (°)	235	57.279	3.251	.693	.723
SNV (°)	235	51.294	3.418	.557	.916
NSHy (°)	235	89.253	3.739	.477	.977
NSV (°)	235	97.036	3.774	.945	.334
MpMeHy (°)	235	16.984	7.362	1.175	.126
MpMeV (°)	235	17.745	5.665	.681	.742
SperHy (mm)	235	16.427	5.338	.496	.967
SperV (mm)	235	3.513	5.018	.643	.802
HyFH (mm)	235	77.785	6.774	.771	.592
VFH (mm)	235	76.666	7.638	.690	.727
PnsU (mm)	235	30.779	3.401	.833	.492
SPT (mm)	235	8.549	1.244	.844	.475
VT (mm)	235	65.250	6.460	.757	.615
Hvt (mm)	235	32.110	3.871	.681	.742
PnsUpw (mm)	235	23.309	3.587	.963	.312
UMpw (mm)	235	9.732	2.576	1.173	.128
VLpw (mm)	235	14.558	2.730	.768	.597
McU (mm)	235	10.042	2.744	.683	.739
McL (mm)	235	10.317	2.988	1.152	.141
NasoA (mm^2)	235	328.767	84.066	.682	.741
OroA (mm^2)	235	574.576	143.393	1.035	.234
TotalA (mm^2)	235	903.343	195.873	.968	.306

*Normal distribution was rejected when $p< 0.05$.

Table 29 Normality test of each variable in part I, skeletal age= pre-pubertal

	N	Normal Parameters		Kolmogorov-Smirnov Z	Asymp. Sig. (2-tailed)
		Mean	SD		
AnsPnsU (°)	112	129.982	5.922	.517	.952
SNHy (°)	112	56.609	3.720	.637	.811
SNV (°)	112	49.980	3.601	.476	.977
NSHy (°)	112	88.940	4.285	.634	.816
NSV (°)	112	97.066	4.077	.415	.995
MpMeHy (°)	112	17.209	7.654	.838	.483
MpMeV (°)	112	16.046	5.296	.695	.720
SperHy (mm)	112	16.124	5.859	.703	.707
SperV (mm)	112	3.130	5.224	.633	.818
HyFH (mm)	112	72.570	6.118	.471	.980
VFH (mm)	112	69.675	5.865	.922	.363
PnsU (mm)	112	28.969	2.838	.754	.620
SPT (mm)	112	8.213	1.058	.757	.616
VT (mm)	112	60.369	5.472	.700	.711
Hvt (mm)	112	28.715	3.168	.592	.874
PnsUpw (mm)	112	20.914	3.695	1.214	.105
UMpw (mm)	112	9.758	2.942	.724	.671
VLpw (mm)	112	13.142	2.853	.653	.787
McU (mm)	112	8.304	2.499	.388	.998
McL (mm)	112	10.727	2.961	.654	.786
NasoA (mm^2)	112	264.425	65.113	.598	.867
OroA (mm^2)	112	500.610	124.843	.579	.891
TotalA (mm^2)	112	765.035	159.729	.726	.668

*Normal distribution was rejected when p< 0.05.

Table 30 Normality test of each variable in part I, skeletal age= pubertal

	N	Normal Parameters		Kolmogorov-Smirnov Z	Asymp. Sig. (2-tailed)
		Mean	SD		
AnsPnsU (˚)	167	129.085	5.674	.468	.981
SNHy (˚)	167	58.162	2.989	.609	.852
SNV (˚)	167	51.698	3.067	.695	.720
NSHy (˚)	167	88.722	3.644	.514	.954
NSV (˚)	167	96.897	3.748	.536	.936
MpMeHy (˚)	167	18.051	7.186	1.021	.248
MpMeV (˚)	167	18.132	5.630	.605	.858
SperHy (mm)	167	18.065	5.174	.939	.341
SperV (mm)	167	4.239	4.862	.697	.716
HyFH (mm)	167	80.320	6.346	.956	.320
VFH (mm)	167	78.728	6.856	.782	.573
PnsU (mm)	167	30.955	3.476	.659	.778
SPT (mm)	167	8.946	1.357	.641	.806
VT (mm)	167	66.707	6.145	.475	.978
Hvt (mm)	167	33.163	3.587	.479	.976
PnsUpw (mm)	167	23.101	3.509	.720	.678
UMpw (mm)	167	9.790	2.365	1.091	.185
VLpw (mm)	167	14.280	2.837	.670	.760
McU (mm)	167	9.635	2.624	.631	.821
McL (mm)	167	10.489	2.902	1.242	.091
NasoA (mm^2)	167	325.195	74.260	1.022	.248
OroA (mm^2)	167	586.560	143.569	1.050	.220
TotalA (mm^2)	167	911.755	185.373	.881	.420

*Normal distribution was rejected when $p < 0.05$.

Table 31 Normality test of each variable in part I, skeletal age= post-pubertal

	N	Normal Parameters		Kolmogorov-Smirnov Z	Asymp. Sig. (2-tailed)
		Mean	SD		
AnsPnsU (°)	139	128.293	6.691	.763	.606
SNHy (°)	139	58.888	3.817	.755	.619
SNV (°)	139	52.957	3.621	.497	.966
NSHy (°)	139	88.929	3.938	.458	.985
NSV (°)	139	96.662	3.856	.655	.785
MpMeHy (°)	139	18.559	8.495	1.066	.206
MpMeV (°)	139	19.438	6.334	.715	.686
SperHy (mm)	139	18.428	6.645	.541	.932
SperV (mm)	139	4.461	5.807	.745	.635
HyFH (mm)	139	86.059	8.402	1.295	.070
VFH (mm)	139	85.523	8.101	.675	.752
PnsU (mm)	139	32.590	3.184	.745	.635
SPT (mm)	139	9.229	1.386	.611	.849
VT (mm)	139	69.757	5.721	.571	.901
Hvt (mm)	139	34.680	3.572	.363	.999
PnsUpw (mm)	139	25.156	2.961	.631	.821
UMpw (mm)	139	10.286	3.090	.686	.734
VLpw (mm)	139	16.471	3.054	.865	.442
McU (mm)	139	11.472	2.536	.820	.513
McL (mm)	139	10.539	3.506	.845	.474
NasoA (mm^2)	139	412.383	96.169	.896	.398
OroA (mm^2)	139	687.324	185.423	.969	.305
TotalA (mm^2)	139	1099.708	246.088	.979	.294

*Normal distribution was rejected when $p < 0.05$.

Table 32 Normality test of each variable in part I, skeletal Class I

	N	Normal Parameters		Kolmogorov-Smirnov Z	Asymp. Sig. (2-tailed)
		Mean	SD		
AnsPnsU (°)	180	129.784	5.491	.727	.665
SNHy (°)	180	57.494	3.250	.665	.769
SNV (°)	180	51.275	3.218	.410	.996
NSHy (°)	180	89.548	3.450	.420	.994
NSV (°)	180	97.442	3.458	.455	.986
MpMeHy (°)	180	19.178	7.623	.895	.400
MpMeV (°)	180	18.644	5.765	.718	.680
SperHy (mm)	180	16.624	5.609	.665	.768
SperV (mm)	180	3.173	4.912	.554	.919
HyFH (mm)	180	80.892	8.275	.937	.344
VFH (mm)	180	79.061	8.686	.523	.948
PnsU (mm)	180	31.348	3.544	.958	.318
SPT (mm)	180	8.859	1.350	.565	.908
VT (mm)	180	66.982	6.530	.728	.665
Hvt (mm)	180	32.449	4.140	.421	.994
PnsUpw (mm)	180	23.022	3.853	.808	.532
UMpw (mm)	180	9.698	2.683	.759	.613
VLpw (mm)	180	14.685	2.741	1.036	.234
McU (mm)	180	9.661	2.562	.788	.564
McL (mm)	180	10.257	3.062	.974	.299
NasoA (mm^2)	180	325.781	85.232	.807	.533
OroA (mm^2)	180	590.712	144.519	1.291	.071
TotalA (mm^2)	180	916.492	194.663	.896	.398

*Normal distribution was rejected when $p < 0.05$.

Table 33 Normality test of each variable in part I, skeletal Class II

	N	Normal Parameters		Kolmogorov-Smirnov Z	Asymp. Sig. (2-tailed)
		Mean	SD		
AnsPnsU (°)	108	131.473	5.843	.690	.728
SNHy (°)	108	56.917	3.566	.660	.776
SNV (°)	108	50.676	3.787	.820	.512
NSHy (°)	108	90.083	4.082	.436	.991
NSV (°)	108	98.043	4.211	.580	.889
MpMeHy (°)	108	18.630	8.168	.864	.444
MpMeV (°)	108	18.248	6.542	.621	.835
SperHy (mm)	108	15.935	5.399	.690	.728
SperV (mm)	108	2.715	5.274	.651	.791
HyFH (mm)	108	79.492	8.937	1.032	.238
VFH (mm)	108	77.643	9.729	.890	.406
PnsU (mm)	108	31.547	3.129	.624	.831
SPT (mm)	108	8.846	1.307	1.021	.248
VT (mm)	108	66.378	7.156	.759	.612
Hvt (mm)	108	32.008	3.924	.471	.979
PnsUpw (mm)	108	23.485	3.680	.900	.392
UMpw (mm)	108	9.358	2.741	.788	.564
VLpw (mm)	108	14.330	3.311	.671	.759
McU (mm)	108	9.140	2.868	.810	.528
McL (mm)	108	9.856	2.876	.444	.989
NasoA (mm^2)	108	334.002	98.850	.658	.780
OroA (mm^2)	108	553.019	177.299	.968	.305
TotalA (mm^2)	108	887.020	249.251	.543	.930

*Normal distribution was rejected when $p < 0.05$.

Table 34 Normality test of each variable in part I, skeletal Class II

	N	Normal Parameters		Kolmogorov-Smirnov Z	Asymp. Sig. (2-tailed)
		Mean	SD		
AnsPnsU (°)	130	126.060	6.003	.635	.815
SNHy (°)	130	59.560	3.543	.447	.988
SNV (°)	130	53.000	3.530	.957	.319
NSHy (°)	130	86.856	3.637	.427	.993
NSV (°)	130	95.085	3.500	.713	.690
MpMeHy (°)	130	15.827	7.207	1.371	.047
MpMeV (°)	130	16.925	5.477	.830	.496
SperHy (mm)	130	20.544	5.825	.498	.965
SperV (mm)	130	6.262	5.185	.751	.626
HyFH (mm)	130	79.674	9.192	1.066	.206
VFH (mm)	130	78.635	9.840	.858	.454
PnsU (mm)	130	29.956	3.544	.737	.649
SPT (mm)	130	8.820	1.399	.624	.831
VT (mm)	130	64.400	6.859	.533	.938
Hvt (mm)	130	32.902	4.477	.435	.992
PnsUpw (mm)	130	23.204	3.700	.619	.838
UMpw (mm)	130	10.778	2.786	.977	.296
VLpw (mm)	130	15.039	3.648	.523	.947
McU (mm)	130	10.827	2.953	.563	.909
McL (mm)	130	11.594	3.174	1.223	.101
NasoA (mm^2)	130	357.936	112.714	1.321	.061
OroA (mm^2)	130	642.368	186.843	1.229	.098
TotalA (mm^2)	130	1000.305	274.143	1.358	.050

*Normal distribution was rejected when $p< 0.05$.

Table 35 Intraclass Correlation Coefficients (ICC) of variables measured from lateral cephalometric radiographs

Variables	Intraclass Correlation	95% Confidence Interval		F Test	
		Lower Bound	Upper Bound	Value	Sig
SNA	0.991	.978	.996	225.649	<0.01**
SNB	0.991	.977	.996	212.633	<0.01**
ANB	0.994	.985	.998	331.856	<0.01**
AnsPnsU	0.872	.706	.947	14.658	<0.01**
MpMeV	0.989	.973	.996	183.981	<0.01**
MpMeHy	0.991	.976	.996	212.397	<0.01**
NSV	0.967	.920	.987	60.327	<0.01**
NSHy	0.995	.986	.998	371.263	<0.01**
SNV	0.978	.945	.991	89.970	<0.01**
SNHy	0.994	.985	.998	323.513	<0.01**
TotalA	0.990	.976	.996	205.662	<0.01**
OroA	0.993	.982	.997	271.852	<0.01**
NasoA	0.970	.925	.988	64.780	<0.01**
McL	0.994	.986	.998	351.551	<0.01**
McU	0.991	.978	.996	224.018	<0.01**
VLpw	0.925	.820	.969	25.531	<0.01**
Umpw	0.947	.871	.979	36.771	<0.01**
PnsUpw	0.958	.896	.983	46.294	<0.01**
VFH	0.994	.985	.998	334.612	<0.01**
SperV	0.841	.642	.934	11.576	<0.01**
Hvt	0.925	.820	.969	25.533	<0.01**
VT	0.923	.817	.969	25.092	<0.01**
SPT	0.913	.794	.965	22.010	<0.01**
PnsU	0.854	.667	.939	12.654	<0.01**
HyFH	0.998	.994	.999	868.594	<0.01**
SperHy	0.957	.894	.983	45.157	<0.01**
Mean	0.959				

**ICC was accepted at p< 0.01.

Table 36 Intraclass Correlation Coefficients (ICC) of variables measured from reconstructed lateral cephalometric radiographs and CBCT scans

Variables	Intraclass Correlation	95% Confidence Interval		F Test	
		Lower Bound	Upper Bound	Value	Sig
recon_PnsUpw	0.983	.958	.993	115.810	<0.01**
recon_Umpw	0.921	.817	.967	24.438	<0.01**
recon_VLpw	0.953	.888	.981	41.697	<0.01**
recon_McU	0.970	.928	.988	66.439	<0.01**
recon_McL	0.995	.988	.998	425.032	<0.01**
recon_NasoA	0.913	.797	.964	21.867	<0.01**
recon_OroA	0.989	.974	.996	183.580	<0.01**
recon_TotalA	0.975	.939	.990	78.752	<0.01**
Mean	0.959				
TotalVol	0.971	.928	.988	67.825	<0.01**

**ICC was accepted at p< 0.01.

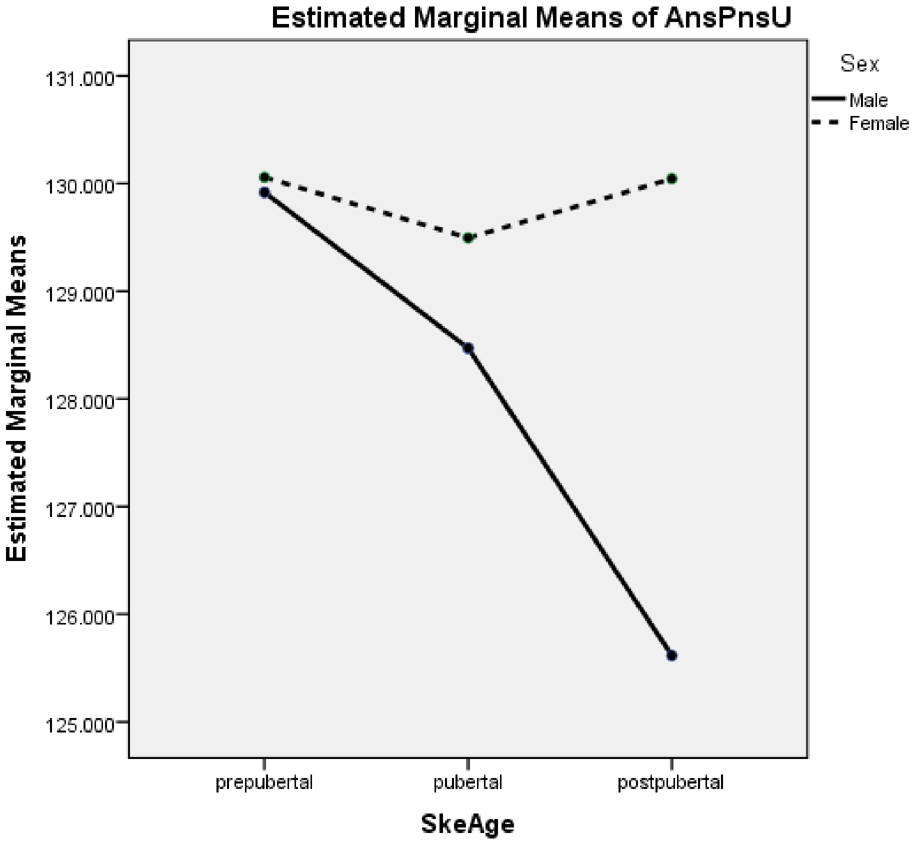

Figure 17 Interaction of skeletal ages and sexes on soft palate angulation (ANS-PNS-U)

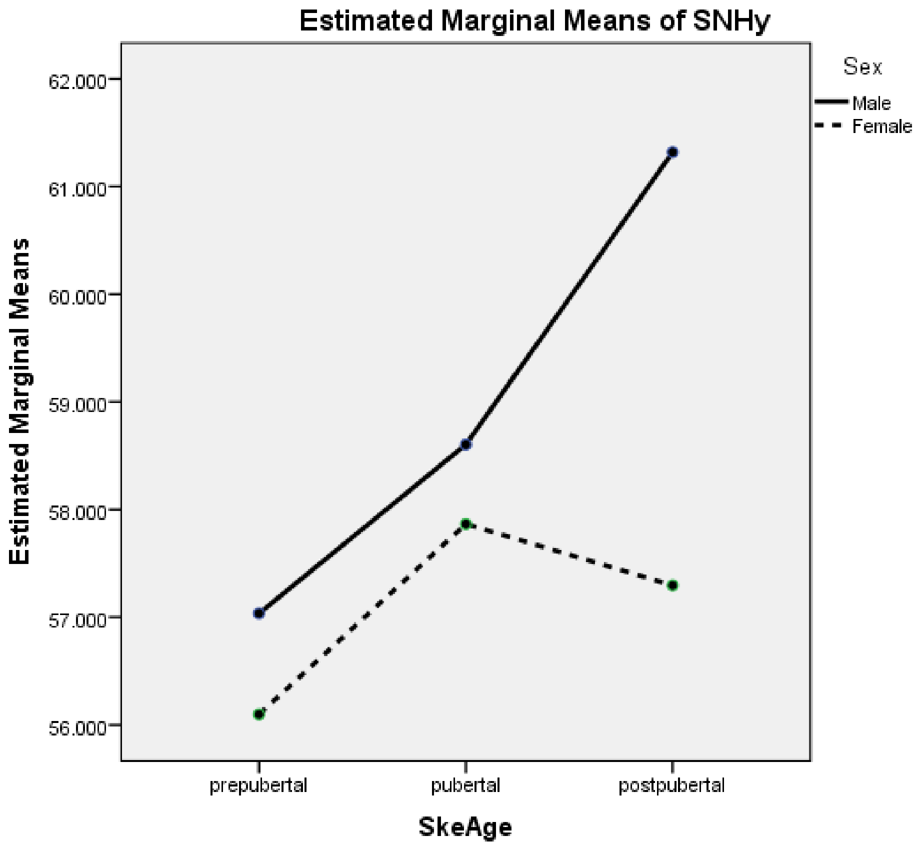

Figure 18 Interaction of skeletal ages and sexes on horizontal hyoid position (angle) in relation to Sella-Nasion (SN) plane (SNHy)

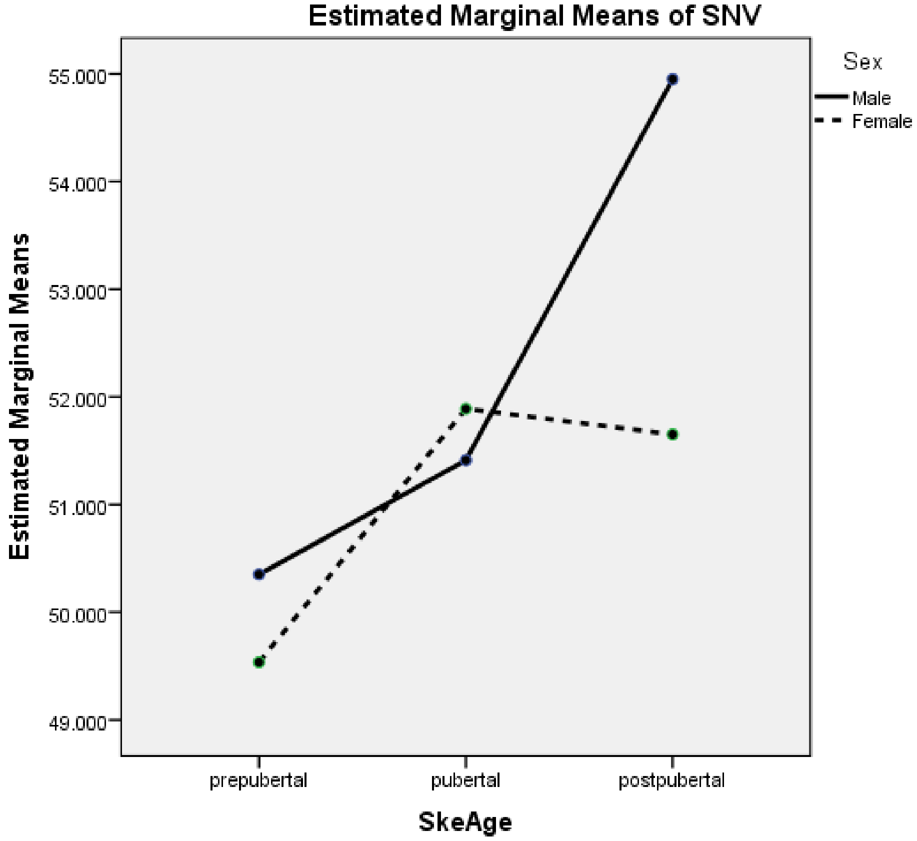

Figure 19 Interaction of skeletal ages and sexes on horizontal tongue position (angle) in relation to Sella-Nasion (SN) plane (SNV)

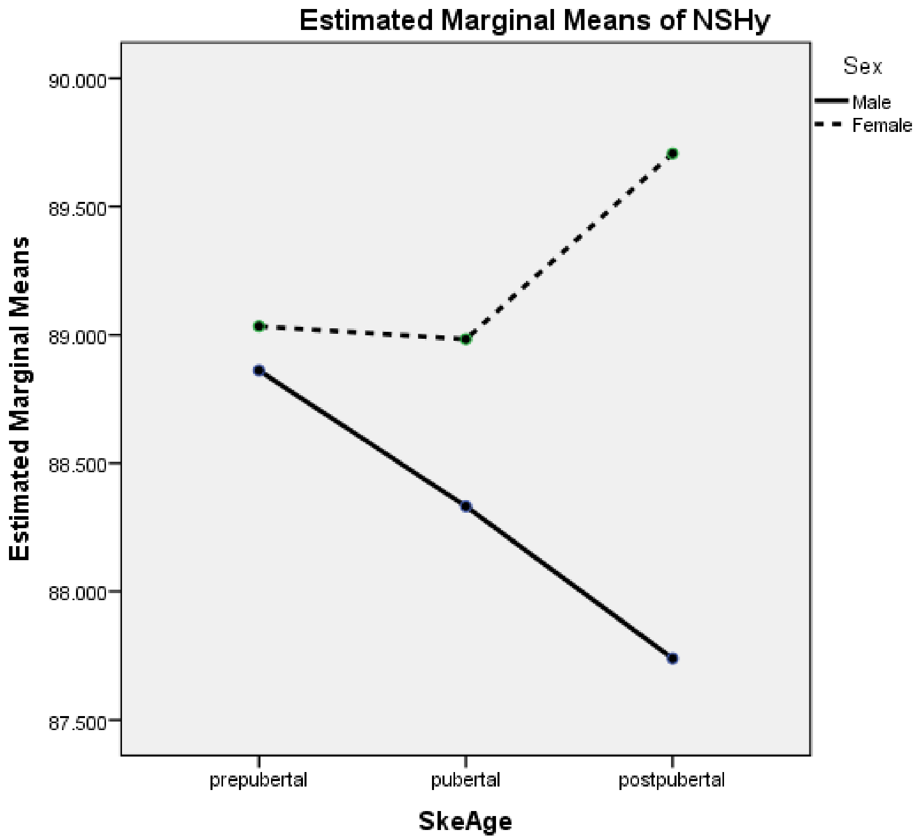

Figure 20 Interaction of skeletal ages and sexes on horizontal hyoid position (angle) in relation to Sella-Nasion (SN) plane (NSHy)

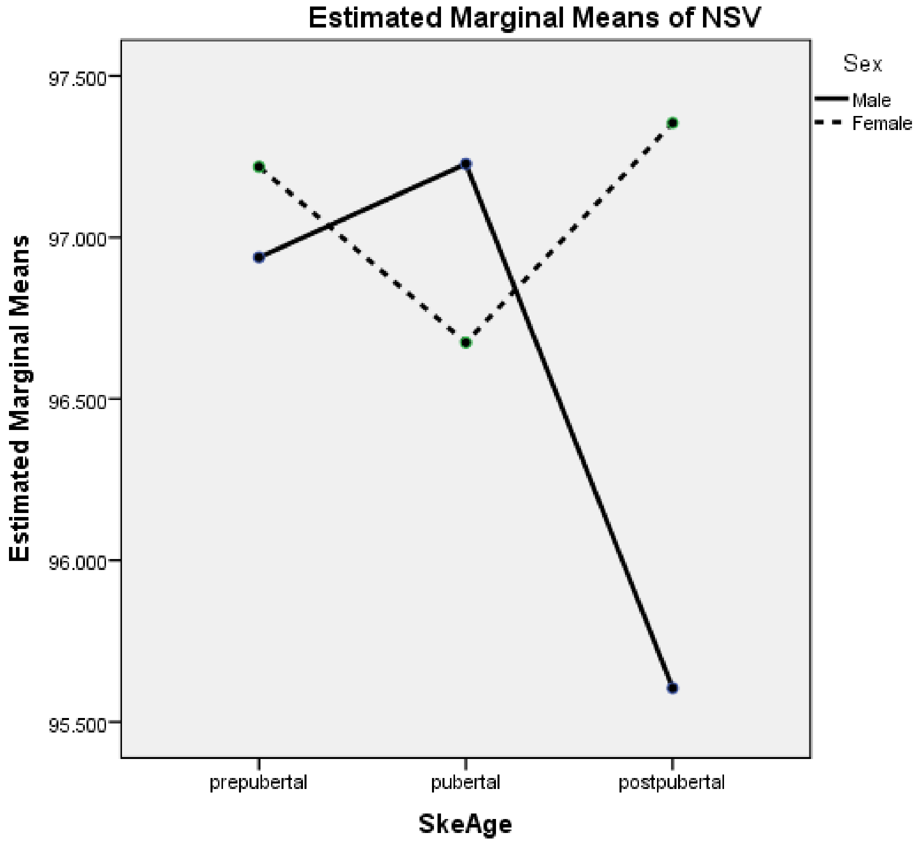

Figure 21 Interaction of skeletal ages and sexes on horizontal tongue position (angle) in relation to Sella-Nasion (SN) plane (NSV)

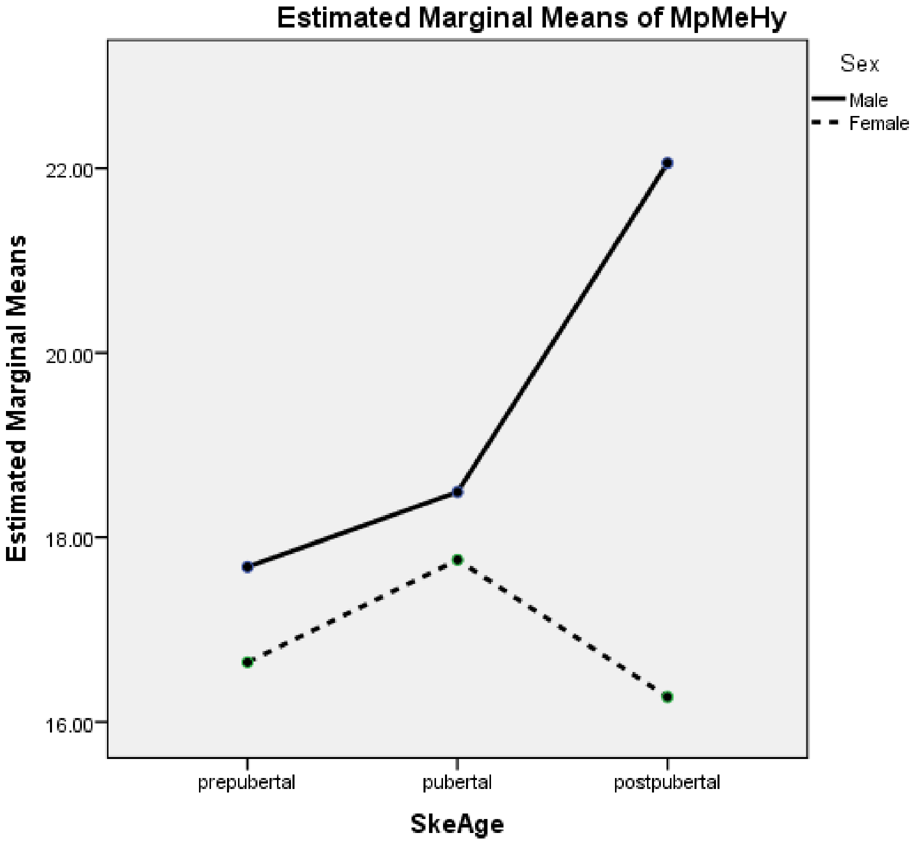

Figure 22 Interaction of skeletal ages and sexes on vertical hyoid position (angle) in relation to mandibular plane (MP-Me-Hy)

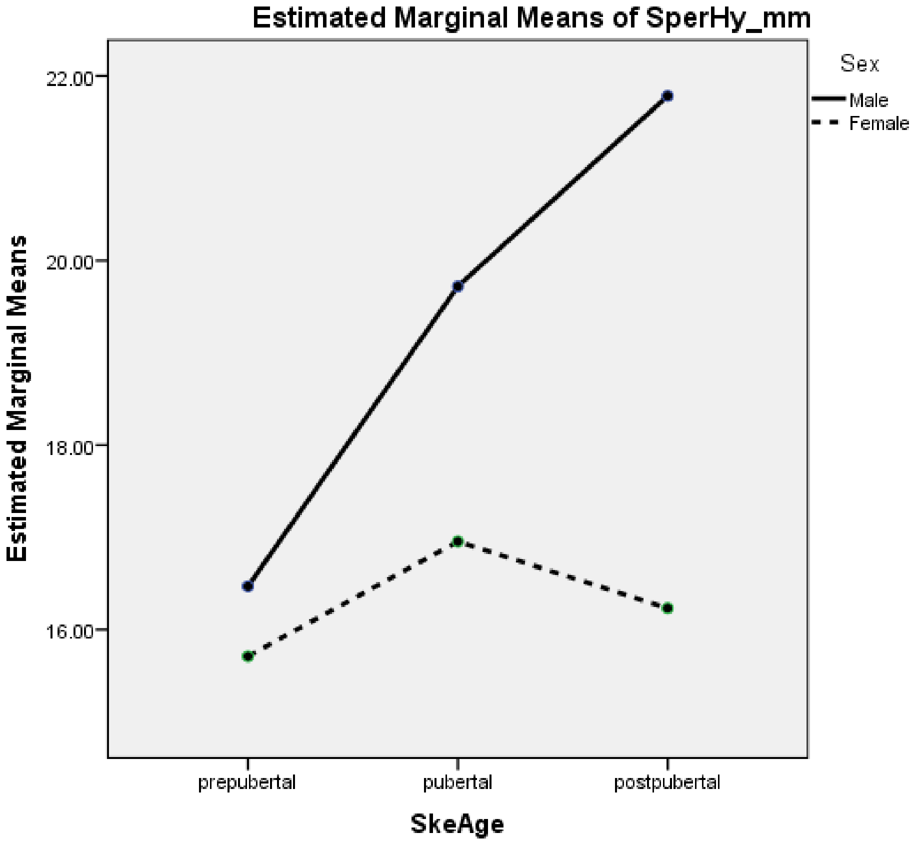

Figure 23 Interaction of skeletal ages and sexes on horizontal hyoid position (distance) in relation to S perpendicular to Frankfort horizontal (FH) plane (S per-Hy)

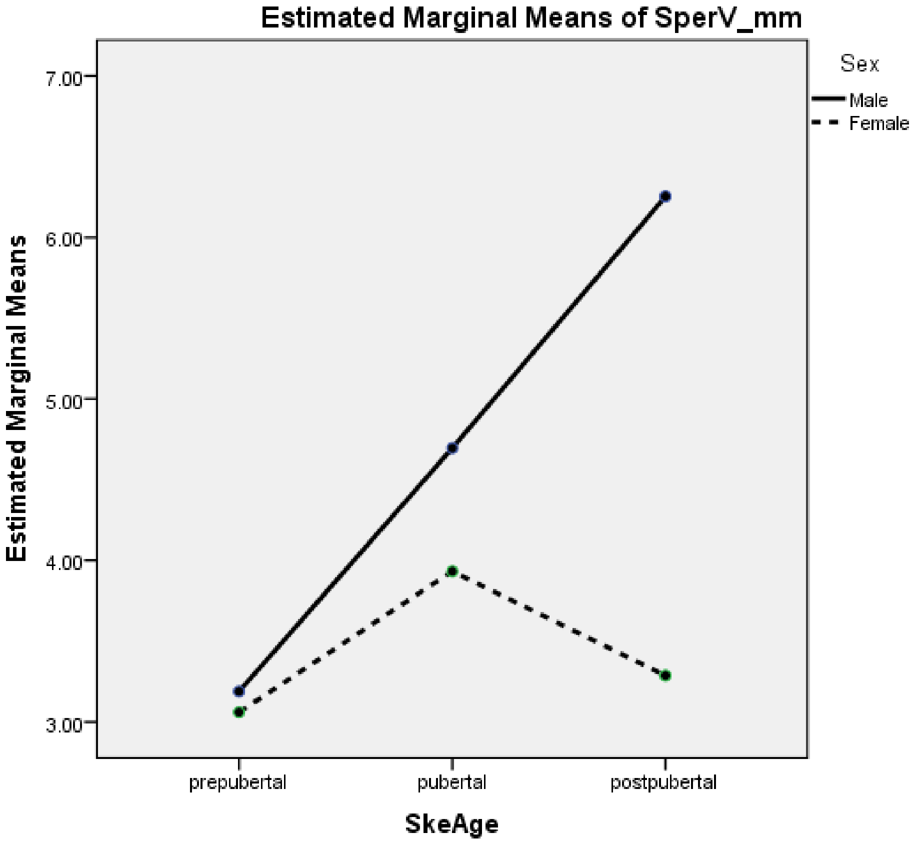

Figure 24 Interaction of skeletal ages and sexes on horizontal tongue position (distance) in relation to S perpendicular to Frankfort horizontal (FH) plane (S per-V)

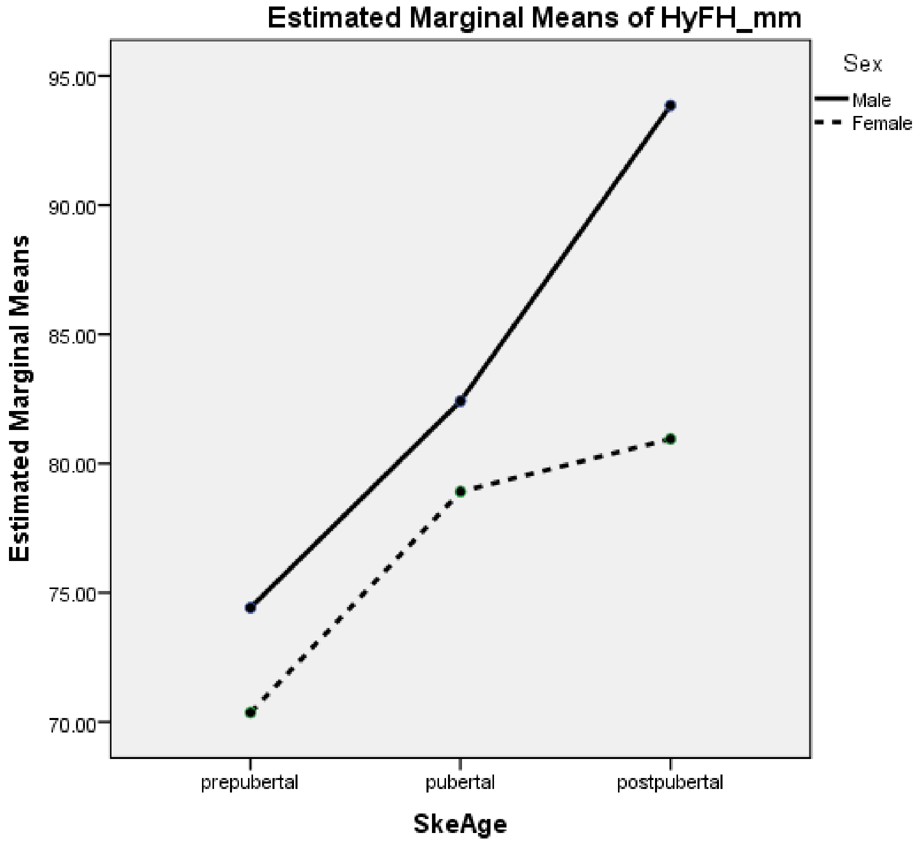

Figure 25 Interaction of skeletal ages and sexes on vertical hyoid position (distance) in relation to Frankfort horizontal (FH) plane (HyFH)

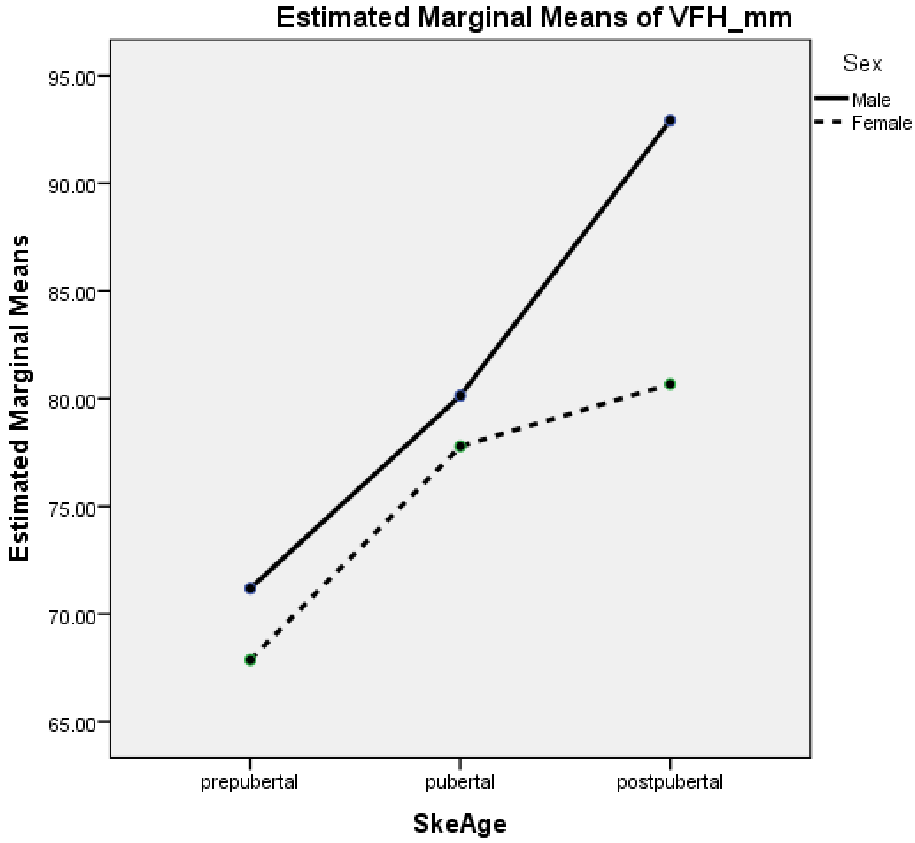

Figure 26 Interaction of skeletal ages and sexes on vertical tongue position (distance) in relation to Frankfort horizontal (FH) plane (VFH)

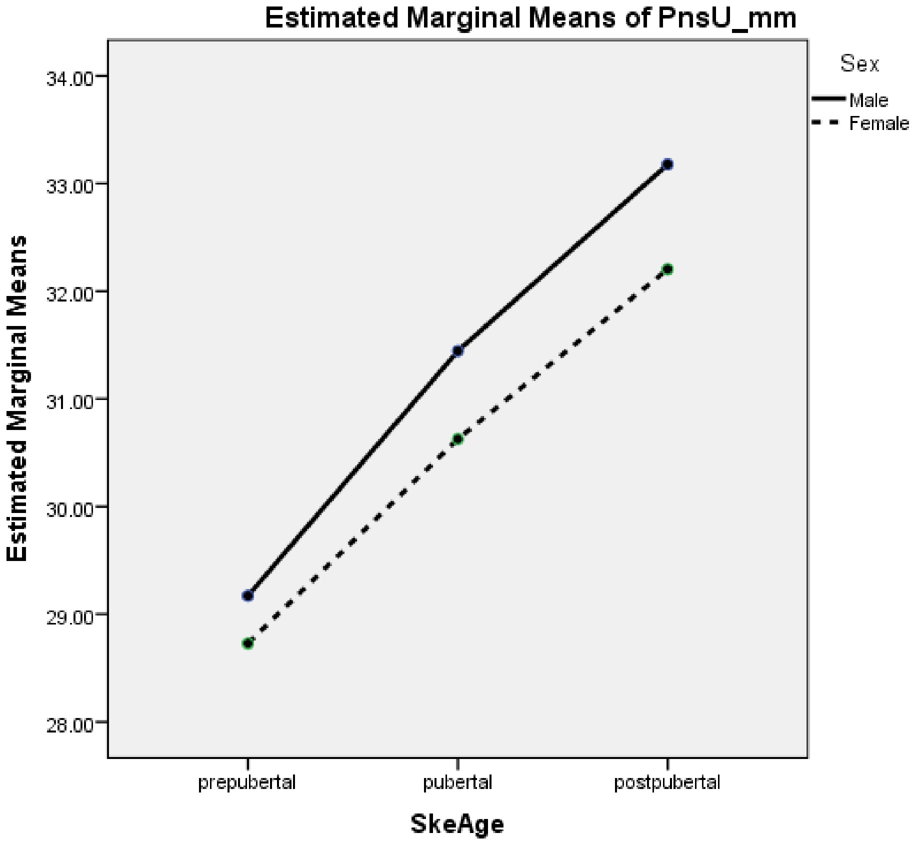

Figure 27 Interaction of skeletal ages and sexes on soft palate length (PNS-U)

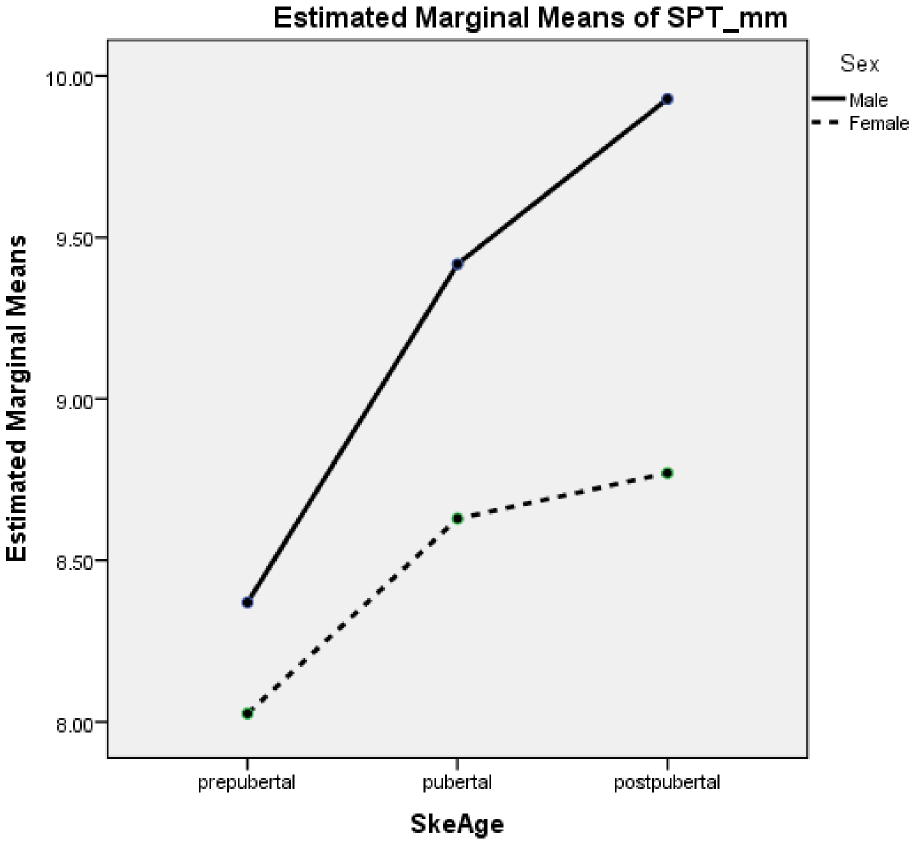

Figure 28 Interaction of skeletal ages and sexes on soft palate thickness (SPT)

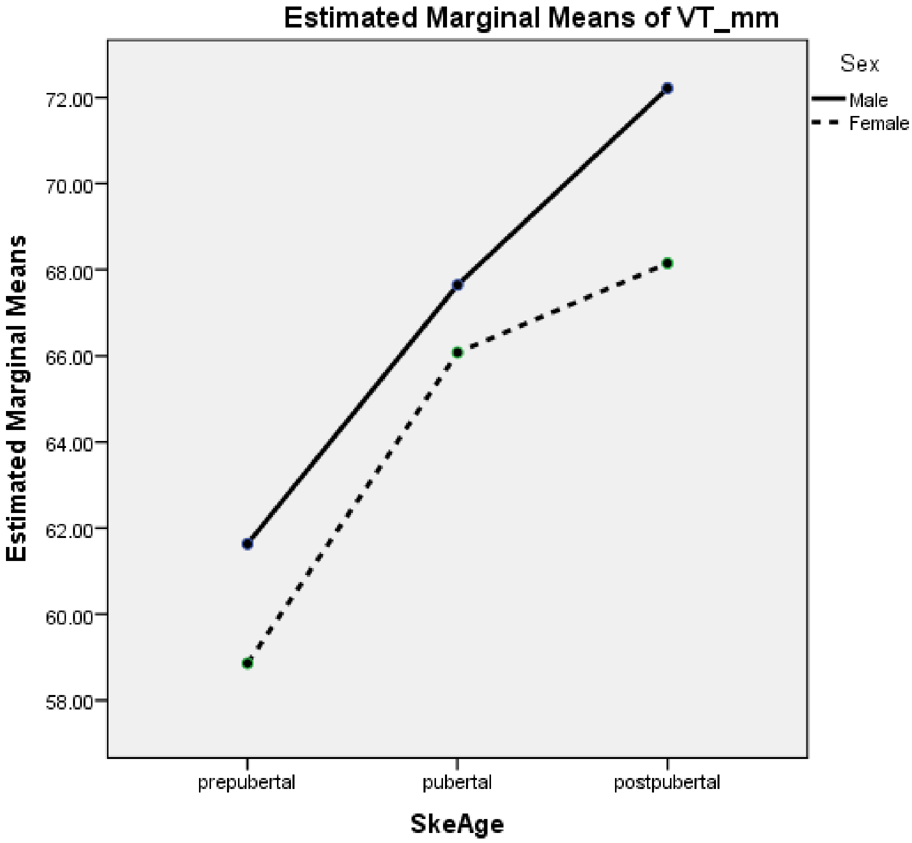

Figure 29 Interaction of skeletal ages and sexes on tongue length (VT)

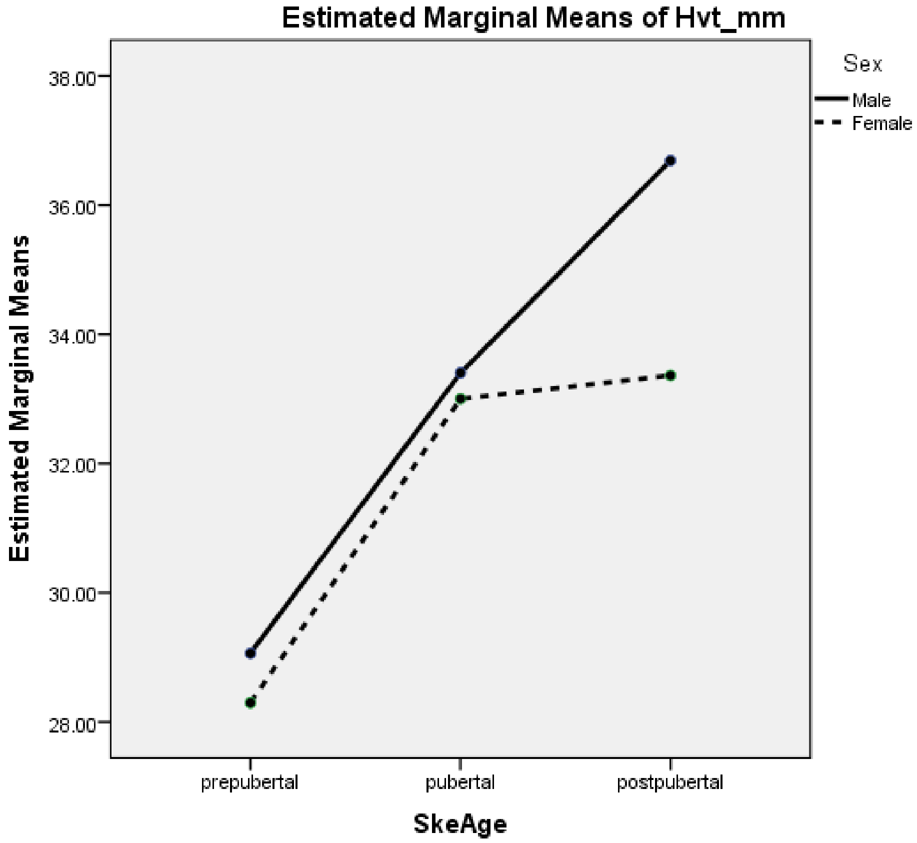

Figure 30 Interaction of skeletal ages and sexes on tongue thickness (H-VT)

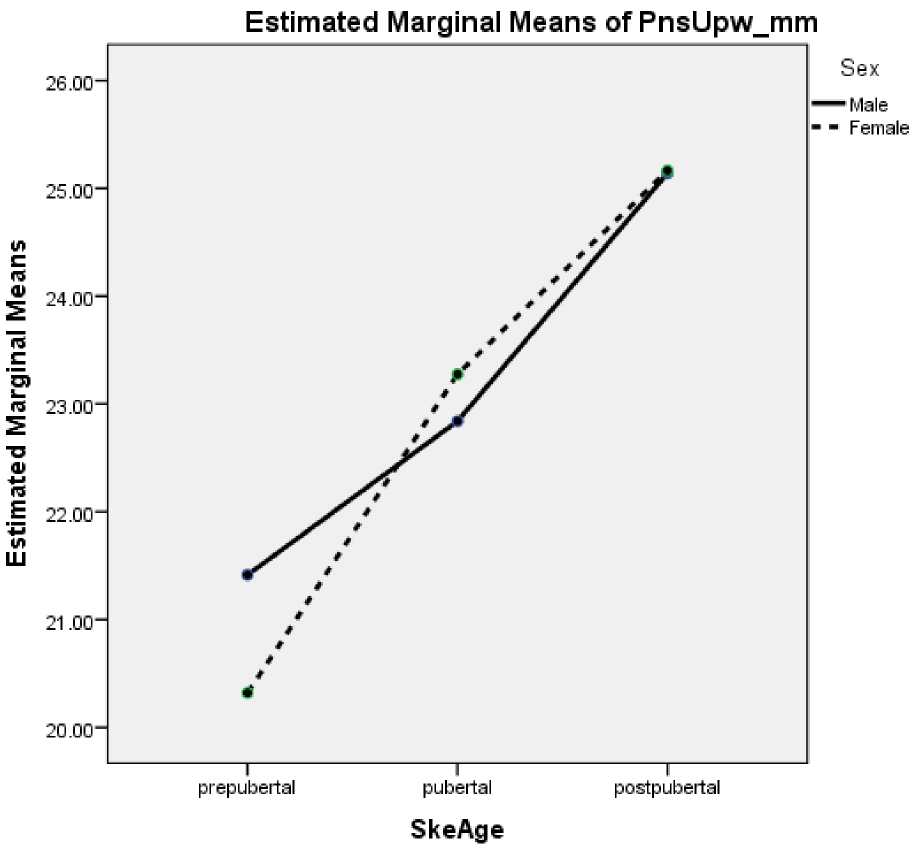

Figure 31 Interaction of skeletal ages and sexes on airway width at the level of palate (PNS-UPW)

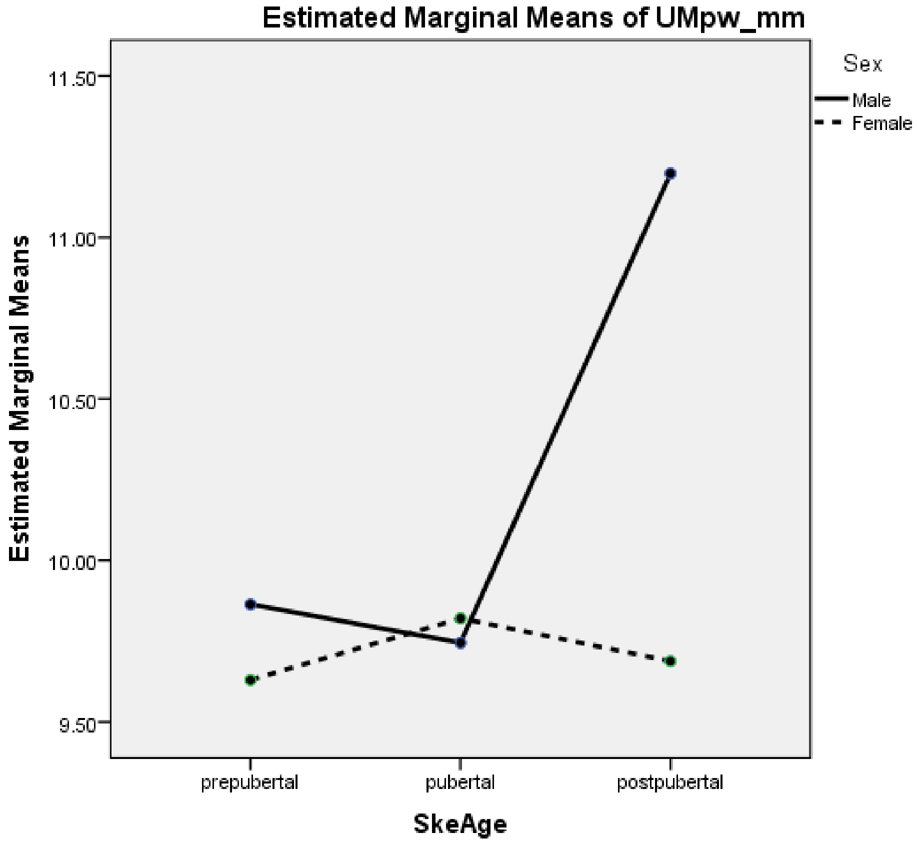

Figure 32 Interaction of skeletal ages and sexes on airway width at the level of uvula tip (U-MPW)

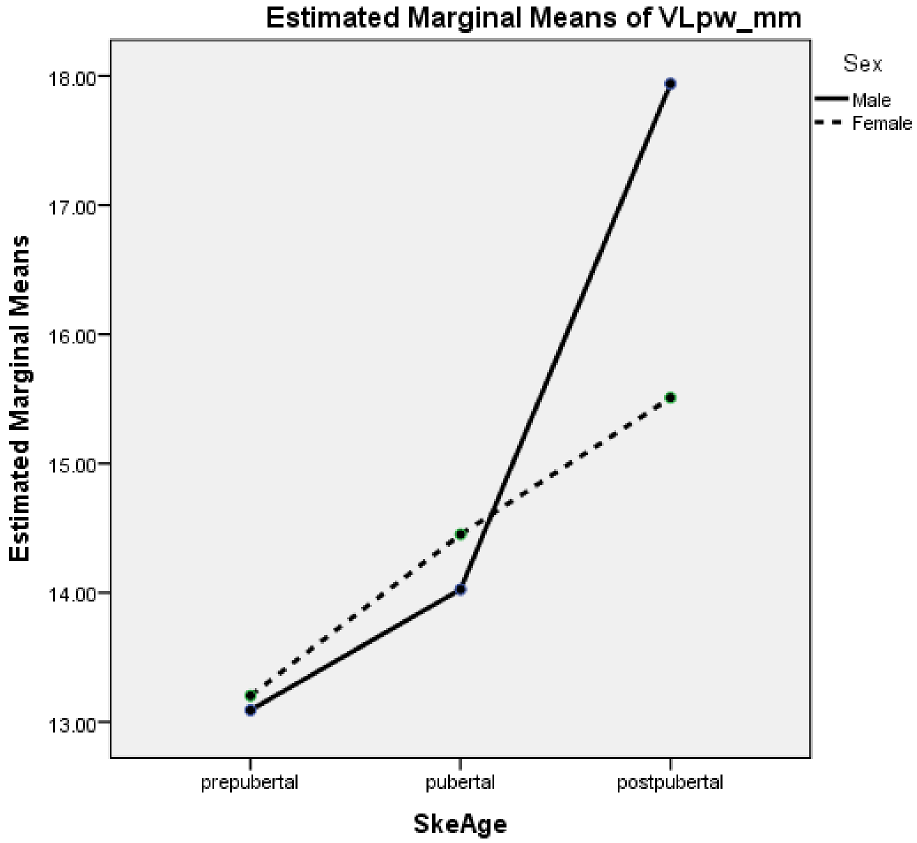

Figure 33 Interaction of skeletal ages and sexes on airway width at the level of tongue base (V-LPW)

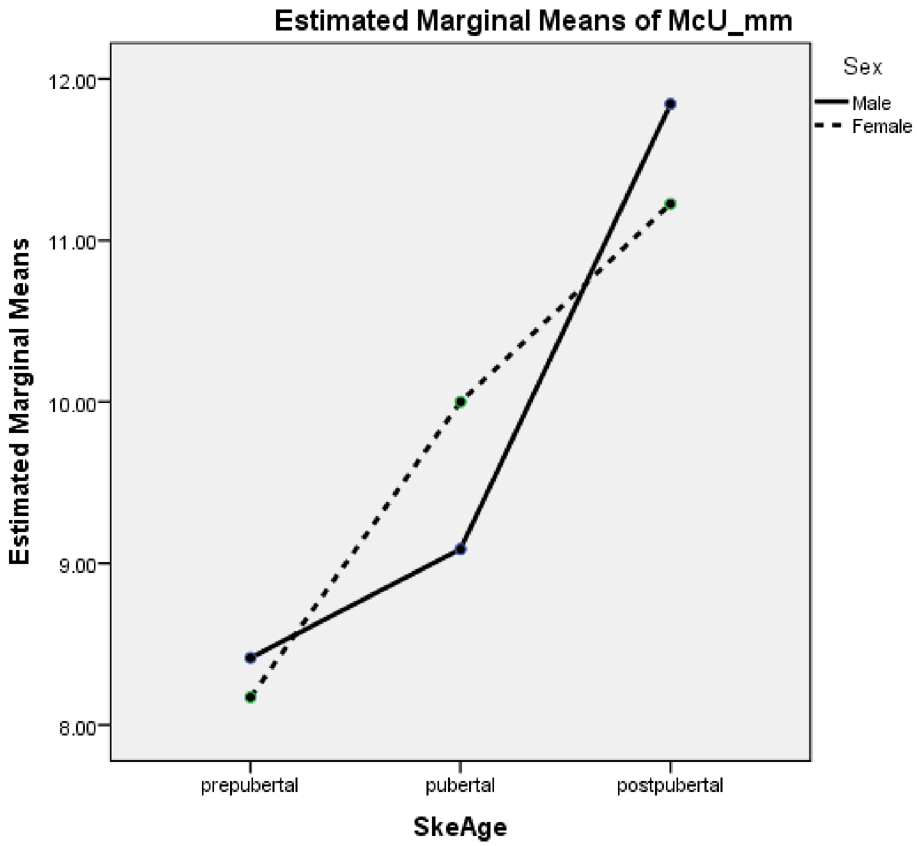

Figure 34 Interaction of skeletal ages and sexes on McNamara's upper pharynx dimension (McU)

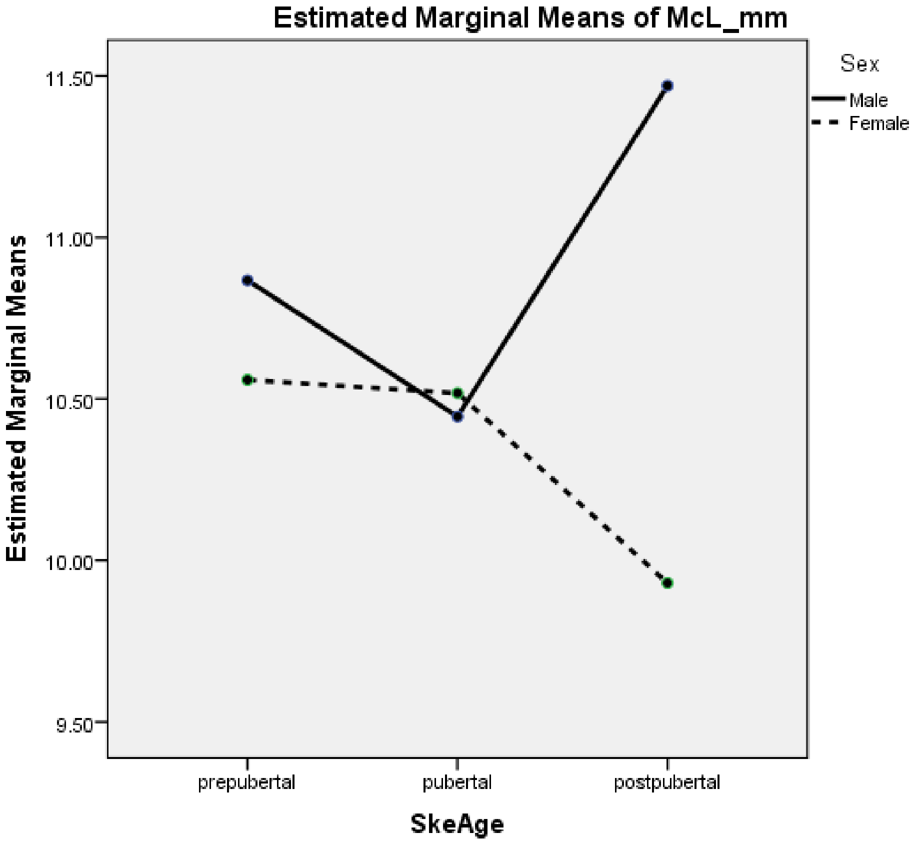

Figure 35 Interaction of skeletal ages and sexes on McNamara's lower pharynx dimension (McL)

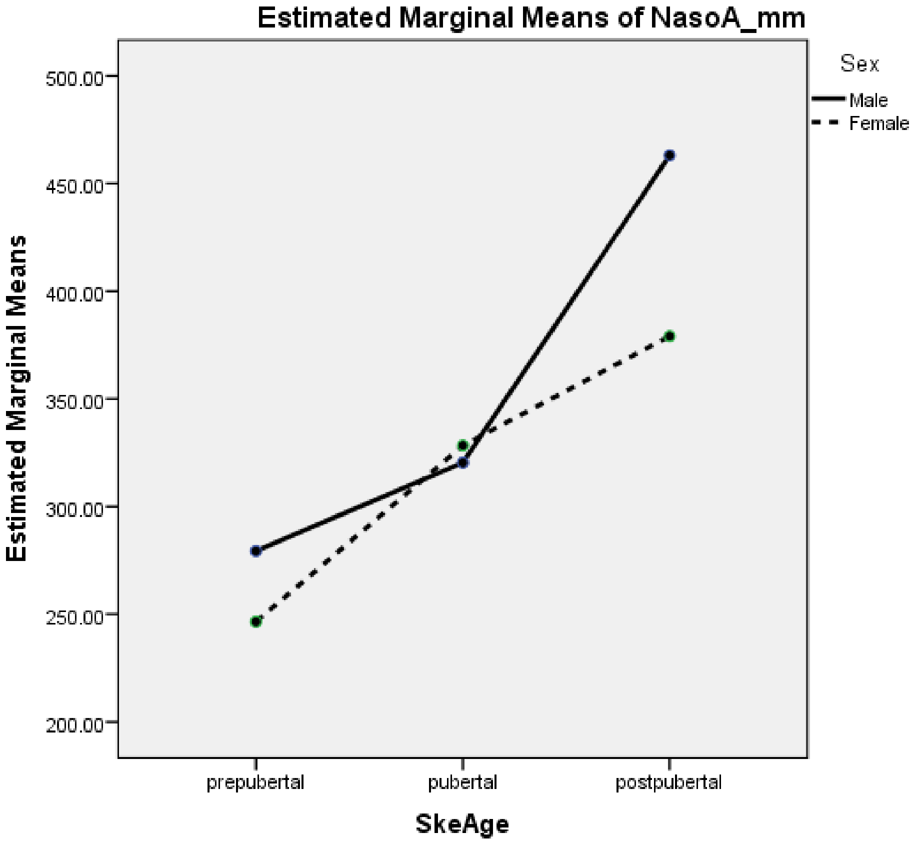

Figure 36 Interaction of skeletal ages and sexes on nasopharyngeal area (NasoA)

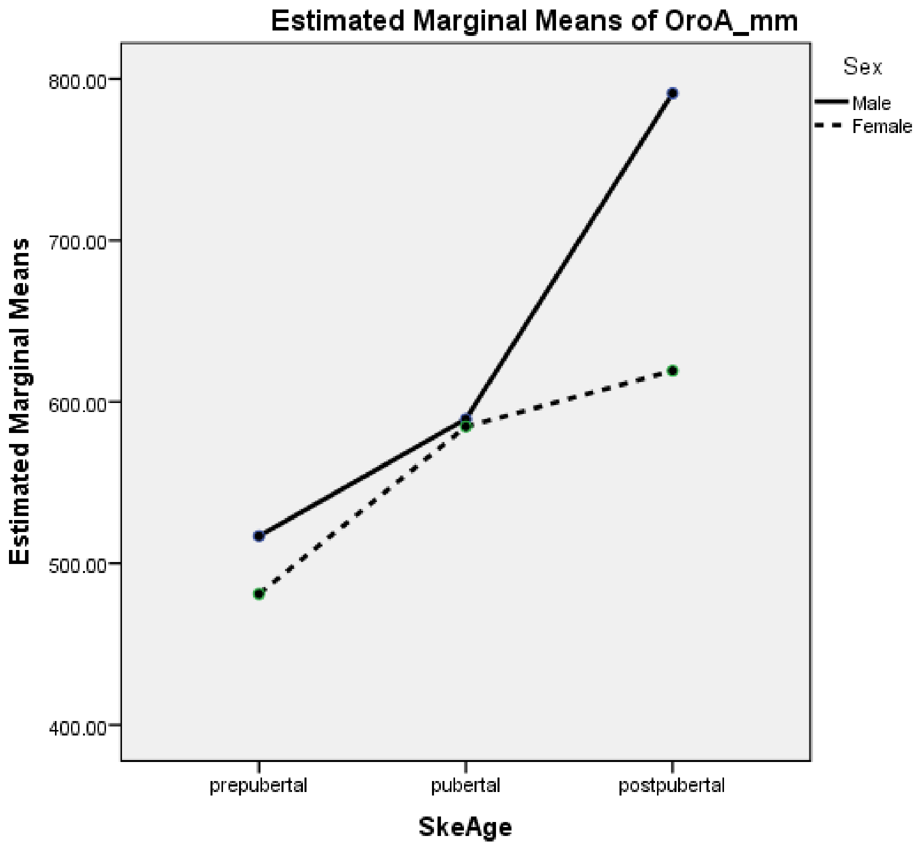

Figure 37 Interaction of skeletal ages and sexes on oropharyngeal area (OroA)

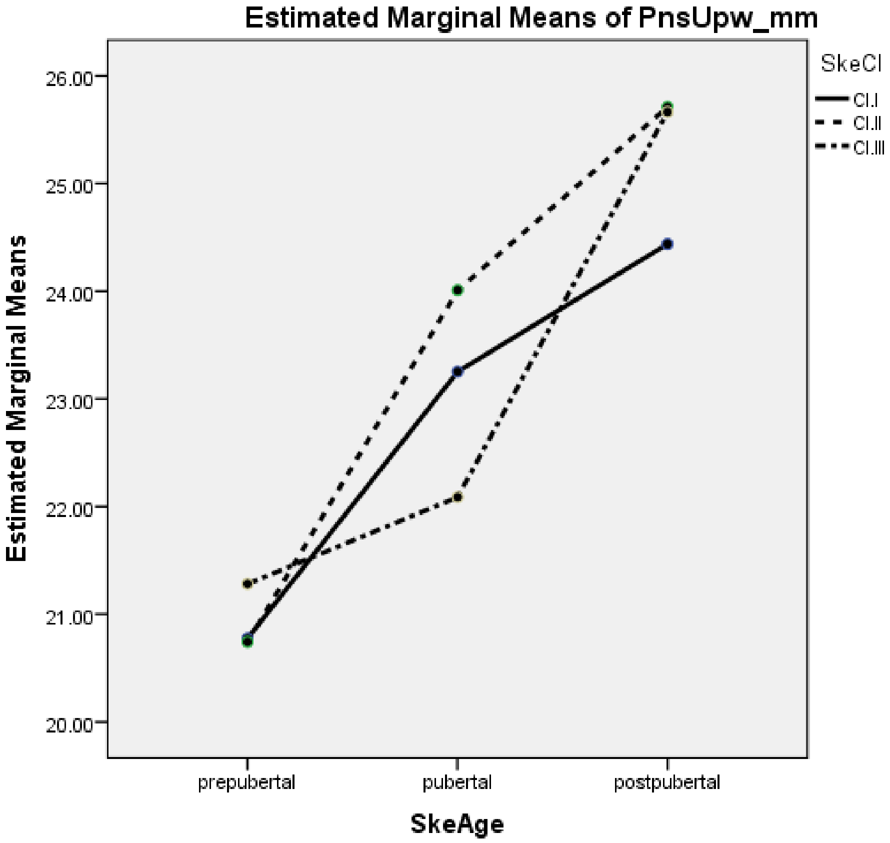

Figure 38 Interaction of skeletal ages and sagittal skeletal patterns on airway width at the level of palate (PNS-UPW)

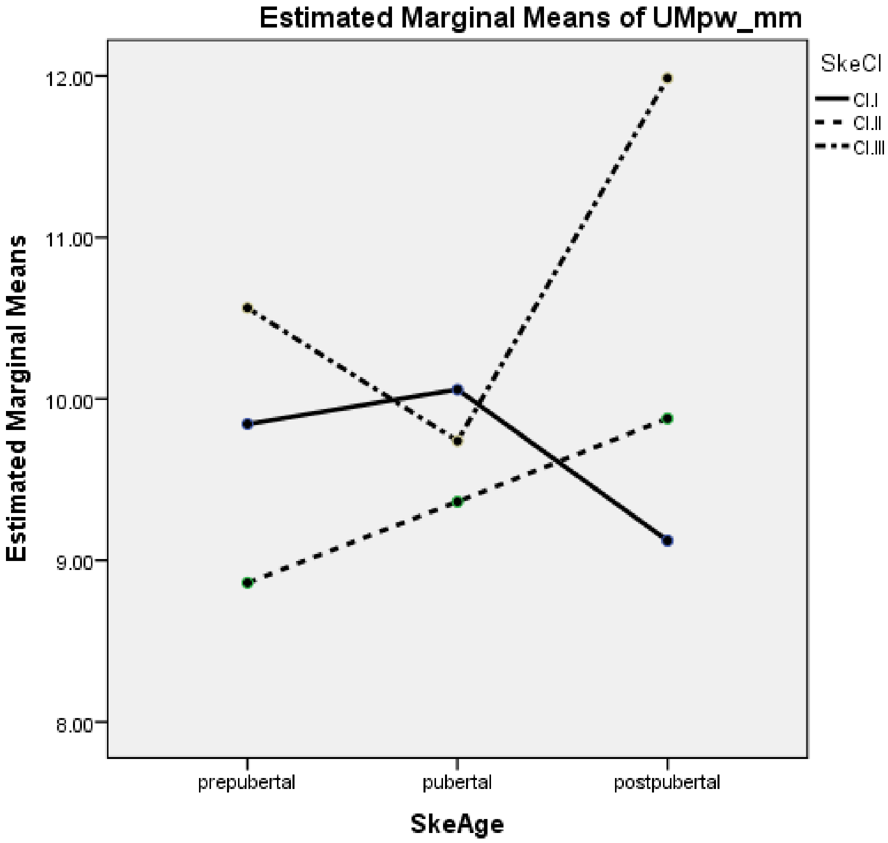

Figure 39 Interaction of skeletal ages and sagittal skeletal patterns on airway width at the level of uvula tip (U-MPW)

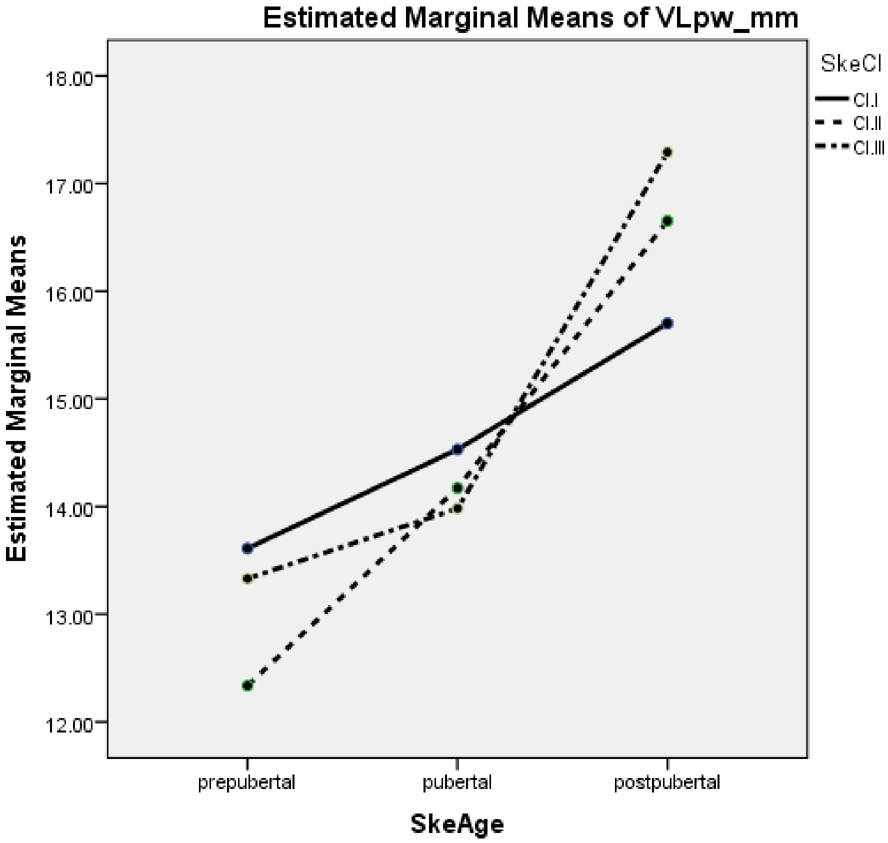

Figure 40 Interaction of skeletal ages and sagittal skeletal patterns on airway width at the level of tongue base (V-LPW)

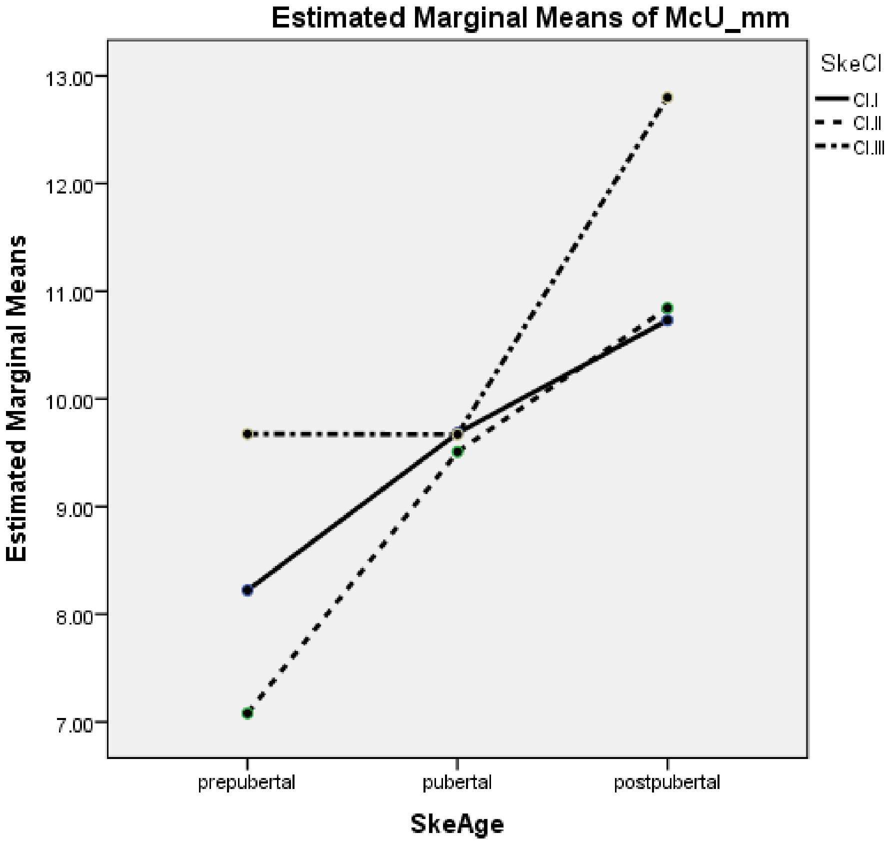

Figure 41 Interaction of skeletal ages and sagittal skeletal patterns on McNamara’s upper pharynx dimension (McU)

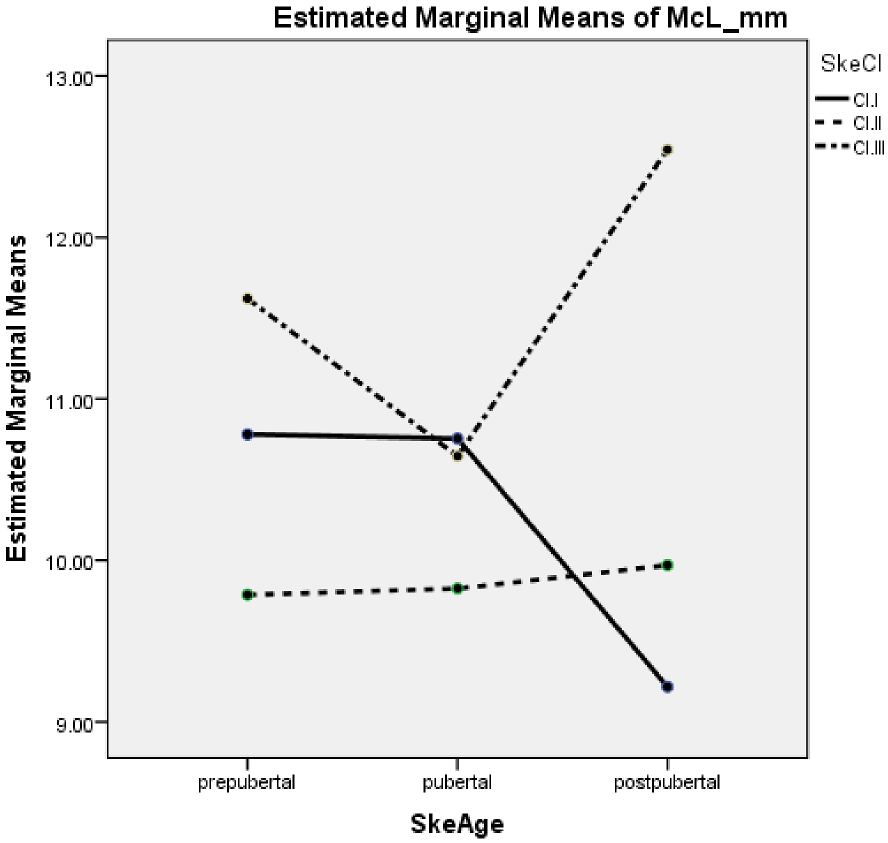

Figure 42 Interaction of skeletal ages and sagittal skeletal patterns on McNamara’s lower pharynx dimension (McL)

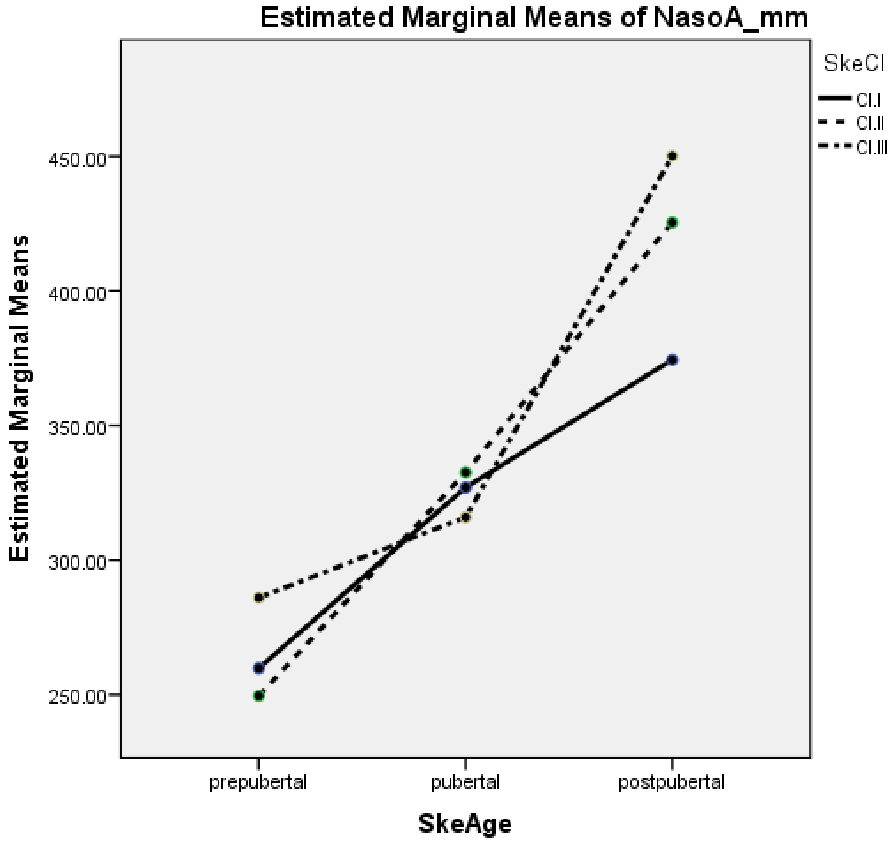

Figure 43 Interaction of skeletal ages and sagittal skeletal patterns on nasopharyngeal area (NasoA)

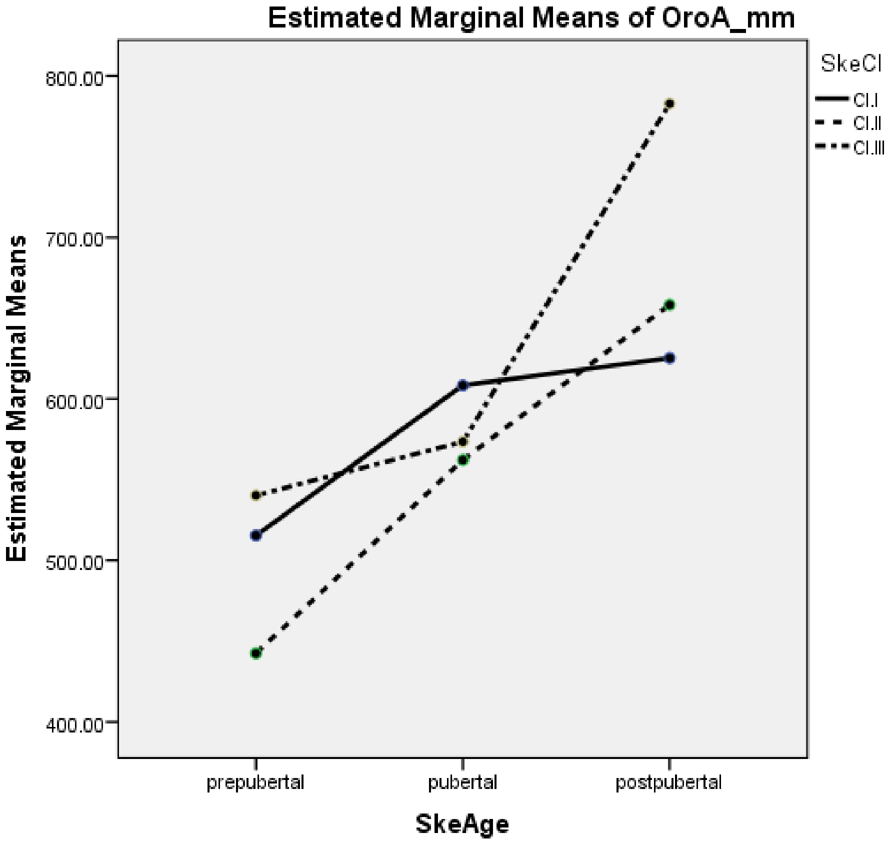

Figure 44 Interaction of skeletal ages and sagittal skeletal patterns on oropharyngeal area (OroA)

VITA

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