การประเมินภาวะหยุดหายใจขณะนอนหลับแบบอุดกั้นโดยใช้ค่าการวัดจากซีบีซีทีและแบบสอบถามการนอนหลับในประชากรไทยกลุ่มหนึ่ง

นายพงศธร กังวานสุรกิจ

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชารังสีวิทยาช่องปากและใบหน้า ภาควิชารังสีวิทยา
คณะทันตแพทยศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2555

EVALUATION FOR OBSTRUCTIVE SLEEP APNEA USING CBCT PARAMETERS AND SLEEP QUESTIONNAIRE IN A GROUP OF THAI POPULATION

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Oral and Maxillofacial Radiology
Department of Radiology
Faculty of Dentistry
Chulalongkorn University
Academic Year 2012

Thesis Title EVALUATION FOR OBSTRUCTIVE SLEEP APNEA USING CBCT PARAMETERS AND SLEEP QUESTIONNAIRE IN A GROUP OF THAI POPULATION

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Field of Study Oral and Maxillofacial Radiology

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พงศธร กังวานสุรกิจ : การประเมินภาวะหยุดหายใจขณะนอนหลับแบบอุดกั้นโดยใช้ค่าการวัดจากซีบีซีทีและแบบสอบถามการนอนหลับในประชากรไทยกลุ่มหนึ่ง (EVALUATION FOR OBSTRUCTIVE SLEEP APNEA USING CBCT PARAMETERS AND SLEEP QUESTIONNAIRE IN A GROUP OF THAI POPULATION) อ. ที่ปรึกษาวิทยานิพนธ์หลัก : รศ.ทพญ.ดร. ภฑิตา ภูริเดช, 85 หน้า.

วัตถุประสงค์ : เพื่อเปรียบเทียบค่าการวัดจากซีบีซีทีที่ถ่ายภาพผู้ป่วยในท่านั่งของทางเดินหายใจส่วนบนระหว่างผู้ป่วยภาวะหยุดหายใจขณะนอนหลับแบบอุดกั้นและผู้ป่วยนอนกรนพร้อมกับศึกษาความสัมพันธ์ของค่าการวัดจากซีบีซีทีร่วมกับแบบสอบถามการนอนหลับ

วิธีการ : กลุ่มตัวอย่าง 45 คนประกอบด้วยผู้ป่วยนอนกรน 14 คน (เอเอชไอ < 5 ครั้ง/ชั่วโมง) และผู้ป่วยภาวะหยุดหายใจขณะนอนหลับแบบอุดกั้น 31 คน (เอเอชไอ ≥ 15 ครั้ง/ชั่วโมง) ข้อมูลของทางเดินหายใจได้จากการถ่ายซีบีซีทีในท่านั่ง (3ดี แอกคิวโตโม 170, เจ โมริตะ) ด้วยขนาดภาพ 140x100 มิลลิเมตร พร้อมกันนั้นผู้ป่วยจะต้องตอบแบบสอบถามการนอนหลับสต๊อป-แบง ข้อมูลจากซีบีซีทีถูกนำมาศึกษาด้วยโปรแกรม อินวิโว 5.1และทำการวัดซ้ำภายหลัง 1 สัปดาห์ ข้อมูลทั้งหมดนำไปวิเคราะห์ทางสถิติด้วยโปรแกรมเอสพีเอสเอสสำหรับวินโดว์ เวอร์ชัน 17.0

ผลการทดลอง : จากการศึกษาพบว่ามีความแตกต่างของค่าการวัดจากซีบีซีทีอย่างมีนัยสำคัญทางสถิติระหว่างกลุ่มผู้ป่วยภาวะหยุดหายใจขณะนอนหลับแบบอุดกั้นและผู้ป่วยนอนกรนได้แก่ ปริมาตร พื้นที่หน้าตัดส่วนที่เล็กที่สุด พื้นที่หน้าตัดเฉลี่ย ความกว้างในแนวหน้าหลังและด้านข้าง ความสม่ำเสมอของทางเดินหายใจและความยาวเพดานอ่อน สำหรับแบบสอบถามการนอนหลับพบว่าผู้ป่วยภาวะหยุดหายใจขณะนอนหลับแบบอุดกั้นอายุมากกว่า เป็นเพศชาย กรนดังและสังเกตพบการหยุดหายใจ

สรุปผลการทดลอง : ปริมาตร พื้นที่หน้าตัดส่วนที่เล็กที่สุด พื้นที่หน้าตัดเฉลี่ย ความกว้างในแนวหน้าหลังและด้านข้าง ความสม่ำเสมอของทางเดินหายใจและความยาวเพดานอ่อนมีความแตกต่างอย่างมีนัยสำคัญทางสถิติระหว่างกลุ่มผู้ป่วยภาวะหยุดหายใจขณะนอนหลับแบบอุดกั้นและผู้ป่วยนอนกรนซึ่งสามารถนำไปสร้างแบบจำลองสำหรับทำนายโรคในประชากรไทยกลุ่มหนึ่งได้

ภาควิชา รังสีวิทยา ลายมือชื่อนิสิต .
สาขาวิชา รังสีวิทยาช่องปากและใบหน้า ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก .
ปีการศึกษา 2555 .

5475815332 : MAJOR ORAL AND MAXILLOFACIAL RADIOLOGY

KEYWORDS: CONE BEAM COMPUTED TOMOGRAPHY / CBCT / OBSTRUCTIVE SLEEP APNEA / OSA / QUESTIONNAIRE

PONGSATORN KANGVANSURAKIT : EVALUATION FOR OBSTRUCTIVE SLEEP APNEA USING CBCT PARAMETERS AND SLEEP QUESTIONNAIRE IN A GROUP OF THAI POPULATION. ADVISOR : ASSOC. PROF. PATITA BHURIDEJ, Ph.D., 85 pp.

Objectives : To compare parameters of upper airway dimension from upright CBCT between obstructive sleep apnea (OSA) and habitual snorers as well as to investigate the relationship of CBCT values combined with STOP-BANG questionnaire.

Methods : Forty five samples, consisting of 14 habitual snorers (AHI $<$ 5 events/hour) and 31 consecutive OSA patients (AHI $\geq$ 15 events/hour), were recruited for this study. Volumetric data from an upright CBCT unit (3D Accuitomo 170, J.Morita) with 140x100 mm field of view were obtained; meanwhile, STOP-BANG questionnaire were completed. Upper airway dimensions from CBCT data were measured using InVivo 5.1 software by one investigator twice within 1-week interval. All data were then statistically analyzed using the SPSS software for Windows version 17.0.

Results : There were statistically significant differences among habitual snorers and OSA subjects in terms of CBCT parameters including volume, minimum cross-sectional area, average cross-sectional area, anteroposterior and lateral dimensions, and uniformity of the airway and soft palate length. For the STOP-BANG questionnaire, OSA subjects were observed to be older, being male, having more loudly snoring, and having observed apnea.

Conclusions : Volume, minimum cross-sectional area, average cross-sectional area, anteroposterior and lateral dimensions, and uniformity of the airway and soft palate length were statistically significantly different between habitual snorers and OSA subjects. These parameters could be of use to develop a prediction model in a group of Thai population.

Department : Radiology	Student's Signature :
Field of Study : Oral & Maxillofacial Radiology	Advisor's Signature :
Academic Year : 2012	

ACKNOWLEDGEMENTS

This thesis has been completed with helpful supports from so many people. First of all, I would like to thank Associate Professor Patita Bhuridej, my thesis advisor, for her advices and dedication. Second, I would like to thank Dr. Onanong Silkosessak for her supports and suggestions in CBCT imaging and Dr. Naricha Chirakalwasan for her supports and suggestions in the field of sleep medicine. Third, I would like to express my gratitude to the thesis committee for their helpful guidance. Moreover, I would like to thank the Department of Radiology, Faculty of Dentistry, Chulalongkorn University and the Excellence Center for Sleep Disorders, King Chulalongkorn Memorial Hospital for their supports throughout research progression. And to the Medical Intensive Care Co., Ltd. for their portable sleep test product, Stardust II, used in this research.

Last but not least, I would like to give my special thanks to my family and friends who support me to succeed with my work.

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CHAPTER I

INTRODUCTION

Background and Rationale

Sleep is an important restorative part of humans' lives. During sleep, mechanisms and functions of the body system are different from awakened stage such as decrease in awareness, decrease in muscle tone, muscle atonia, minimal psychologic activity, and decrease in pulse rate, respiratory rate and blood pressure which allow the body to be restful. Normally, an adult need approximately 7-8 hours of sleep each night. Anyway, sleep may be disrupted by many reasons such as sleep environment and effects from last sleep, but one of all these which is gaining much more attention is sleep disorders, especially obstructive sleep apnea (OSA).

Sleep apnea is a condition which affects overall health status. It causes the patients interruptions to their restful sleep by means of arousal. As a result, the patients can experience significantly lessened efficiency in their daily activities for both learning and working due to excessive daytime sleepiness. It substantially increases accidents while driving or working with machines [1]. Furthermore, previous study showed that OSA is associated with significant impairment of procedural and verbal declarative memory [2]. Moreover, OSA is proven to increase risk or be related to several diseases such as hypertension [3], coronary artery disease [4], arrhythmia [5], congestive heart failure [6], cerebrovascular disease [7], and depression [8].

Beside history taking and clinical examination, diagnostic tool accepted as gold standard for sleep apnea is polysomnography. Though it can certainly diagnose OSA, there are several drawbacks such as procedural discomfort, high cost, and limited availability. Therefore, it is reasonable to develop the diagnostic tool for sleep apnea screening with high statistical correlation with polysomnography which can lead to early treatment.

To develop a diagnostic tool as a prediction model, one must begin with other available means which can be helpful in predicting the occurrence of OSA, but not in definitely diagnosis OSA such as radiographic examination and sleep questionnaire.

Combining both methods might offer effective screening channels. Sleep questionnaire is a widely used screening tool for OSA with varying forms available. Among these questionnaire, Berlin questionnaire is the one gaining popularity due to its specificity [9]. However, since it is a Likert-type or rating scale question which, on the other hand, has main drawback in its less user-friendliness due to memory recall problem. The subsequently developed questionnaires such as STOP (Snoring, Tiredness, Observed apnea, high blood Pressure) and STOP-BANG (STOP including Body mass index (BMI), Age, Neck circumference and Gender) questionnaire provide more sensitivity and comfortable answering manner because of yes-or-no type response [10].

For radiographic examination, there are many techniques available for OSA assessment but the one well-researched and closely related to the field of dentistry is lateral cephalometric radiograph. Though it is usually utilized for maxillofacial orthodontic or orthognathic assessment, there are several studies about its various usages to reveal a variety of soft and hard tissue abnormalities and indicate risk factors or to follow up treatment outcome in upper airway passage for OSA [11, 12, 13]. Anyway, several drawbacks exist including inconsistent result for severity prediction [14, 15, 16, 17], different data from actual sleeping information due to upright instead of supine positioning [18], and its major drawback of only two-dimensional information offer. Therefore, it can assess the upper airway only in anteroposterior dimension, while many studies point out that OSA patients have narrower lateral dimension of upper airway as well [19, 20, 21, 22, 23]. As a result, this implies that three-dimensional information is necessary, so computed tomography (CT) may take its part. However, there is a problem that CT used in medical field or multislice CT (MSCT) scans. The patient receive relatively much higher X-ray dosage compared to conventional radiography, and this problem make medical CT an improper screening modality. Regarding this hindrance, cone beam CT (CBCT) or dental CT might be a promising solution, as it can also provide three-dimensional information with lower radiation usage [24].

Nowadays, recently developed CBCT machine such as 3D Accuitomo 170 (J.Morita) scans with just 54 microSievert [25] for medium field of view, even lower than 170.7 microSievert used for full mouth intraoral radiographic examination with F-speed film [26].

There was a study developing a prediction model for OSA previously in 2010, Enciso R et al [19] developed prediction model for OSA in US population using CBCT parameters and Berlin questionnaire. Their study concluded that age > 57 years, male gender, high risk from Berlin questionnaire, and lateral dimension of upper airway < 17 mm are significant risk factors for OSA occurrence. Anyway, their result may not be applicable for Thai population whose morphology and anatomy are different, thus, study for prediction model for Thai population must be initiated and continued.

Research Question

Do CBCT parameters of upper airway and STOP-BANG questionnaire correlate with obstructive sleep apnea in Thai population?

Objectives

1. To study correlation between CBCT parameters of upper airway combined with STOP-BANG questionnaire and obstructive sleep apnea in a group of Thai population
2. To develop a prediction model for obstructive sleep apnea in a group of Thai population

Research Hypotheses

CBCT parameters of upper airway correlate with obstructive sleep apnea

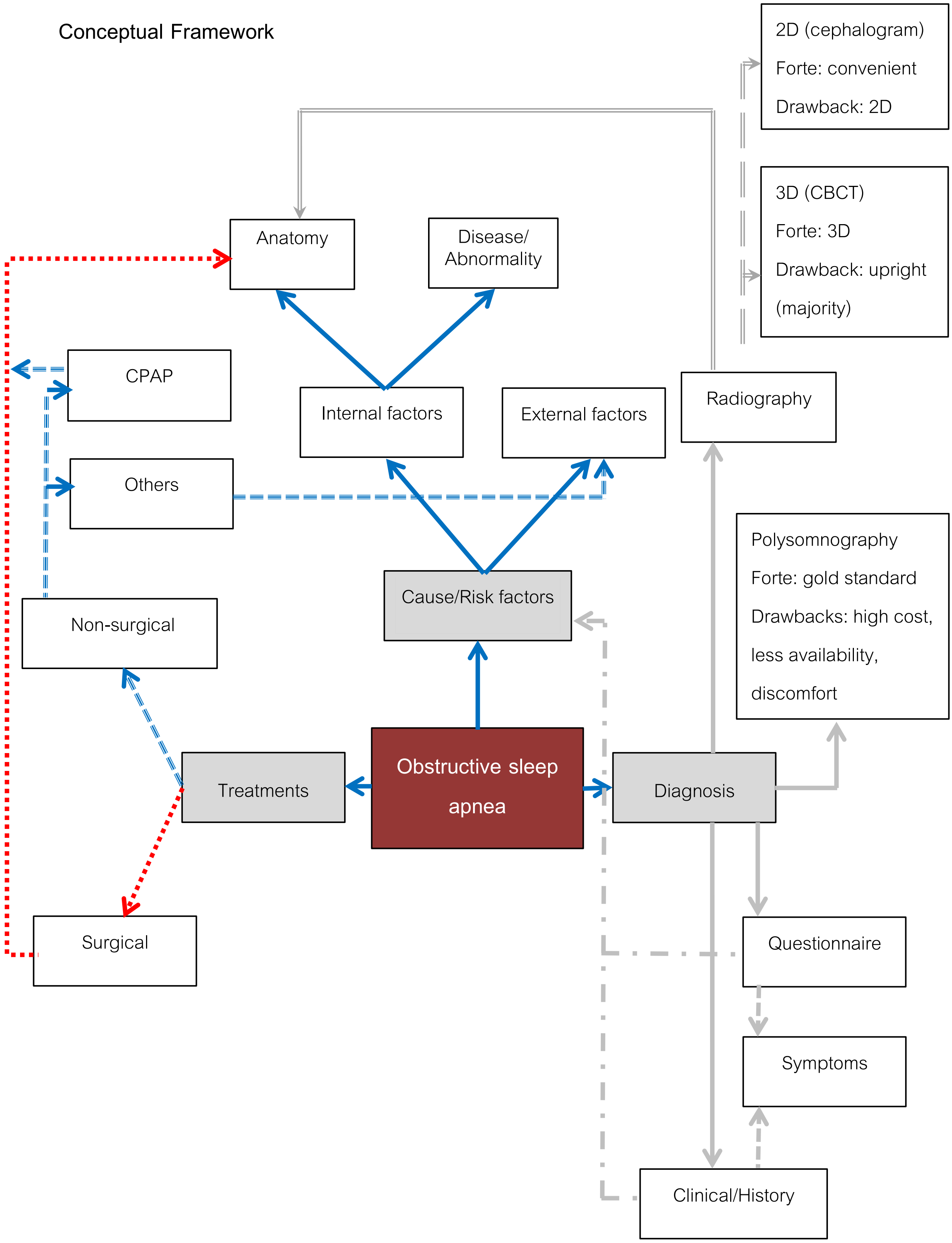
Expected Benefits and Applications

The prediction model developed in this study will provide benefits to whom suspected to be OSA patient as a preliminary diagnostic tool for screening and thus leading to early treatment.

Research design

Prospective analytical research

Conceptual Framework



List of abbreviations

OSA	=	obstructive sleep apnea
CBCT	=	cone beam computed tomography
AHI	=	apnea-hypopnea index
RERA	=	respiratory effort-related arousal
RDI	=	respiratory disturbance index
MPR	=	multiplanar reconstruction
PAS	=	pharyngeal airway space
NL	=	nasal level
ANS	=	anterior nasal spine
PNS	=	posterior nasal spine
B	=	B point
Go	=	gonion
MpH	=	mandibular plane to hyoid distance

CHAPTER II

LITERATURE REVIEW

Literature Review

Obstructive sleep apnea

Sleep has been defined as “a reversible physiologic and behavioral state that manifests as decreased awareness and reaction to external stimuli” [27] or “a reversible behavioral state of perceptual disengagement from and unresponsiveness to the environment” [28]. In other word, it can be said that sleep is a complex amalgam of physiologic and behavioral processes.

Sleep can be classified as 2 separated states according to their physiologic parameters, rapid and non-rapid eye movement sleep (REM and NREM sleep), which occurs almost equally in infants, but 20-25% and 75-80% of sleep in adults. These two states can be identified by means of electroencephalogram (EEG), electromyogram (EMG), and electrooculogram (EOG).

Rapid eye movement state of sleep is the state with decrease in muscle tone, or even atonia. In this state, there are erratic cardiac and respiratory patterns. Electroencephalogram of this state shows asynchronous and paradoxical patterns as presented by episodic bursts of rapid eye movement which is a characteristic of this state. Besides, this is the state of sleep associated with dream. Considering a decrease in muscle tone, especially the tongue which will locate posteriorly, an airway obstruction can easily occur. This makes rapid eye movement sleep a state with high probability for OSA occurrence.

Non-rapid eye movement sleep is the state with synchronous electroencephalogram. It can be divided into 3 stages (NREM 1, NREM 2, and NREM 3) which are parallel a depth of sleep continuum, with arousal thresholds generally lowest in NREM 1 stage and highest in NREM 3 stage. NREM 1 stage is considered a transitional stage to sleep. This stage is also marked by a decrease in awareness and in muscle tone. A common sign of severely disrupted sleep is an increase in the amount and percentage of this stage [28].

NREM 2 stage is considered as a true onset of sleep, but it should be aware that to exactly identify the onset of sleep is difficult if a single parameter is used. This stage is also presented by a further decrease in awareness and in muscle tone. Furthermore, a more intense stimulus is required to produce arousal.

NREM 3 stage is considered as a deep sleep, in other word, the most restful stage. Electroencephalogram of NREM 3 stage shows high-voltage slow wave, thus this stage is also called slow wave sleep (SWS) or delta sleep. With increasing age, deep sleep progressively occupies less.

Sleep can be affected by several causes, but the one disrupting it is sleep disorders. Sleep disorders can be categorized as insomnia, sleep related breathing disorders, hypersomnias of central origin, circadian rhythm disorders, and parasomnias. Obstructive sleep apnea which causes excessive sleepiness is classified as one of a group of sleep related breathing disorders according to International Classification of Sleep Disorders (ICSD) second edition by American Academy of Sleep Medicine.

Obstructive sleep apnea study should begin with terminologies and definitions. The term apnea is defined as a period of at least 10 seconds during which airflow is absent by nose or mouth [27]. Apnea can be categorized into 3 types by means of their origin as follows.

1. Obstructive apnea: an apnea with inspiratory effort as chest and abdominal movement can be observed

2. Central apnea: an apnea without inspiratory effort which is usually a result of pathology in the central nervous system
3. Mixed apnea: an apnea with no inspiratory effort at first (central) then follow by an inspiratory effort later (obstructive)

Another related term is hypopnea which is a 30% decrease in airflow from baseline for more than 10 seconds [27]. Attention should be paid to hypopnea as well as apnea because both can cause sleep disruption. Therefore, both events were counted altogether averagely in an hour and defined as apnea-hypopnea index (AHI) which is used to assess sleep apnea.

However, not only apnea and hypopnea event can interrupt the patient's sleep, inspiratory effort can do even so and arousal may occur. Thus, these arousals which occur because at least 10 seconds of airway obstruction without obvious evidence of apnea or hypopnea while respiratory muscles increase their activity, so called respiratory effort-related arousal (RERA), are used with AHI to assess OSA. The combination of apnea, hypopnea, and RERAs events per hour of sleep is called respiratory disturbance index (RDI).

Pathophysiology of OSA begins with inspiration. Diaphragm and thoracic muscle work together to create a negative pressure inside the thoracic cavity so that air can flow into the lung. When air moves through the upper airway, it encounters resistance due to the airway itself, and in OSA patients, this resistance increases. As a result, inspiratory effort occurs by increasing activity of respiratory muscles thus producing negative inspiratory pressure. This negative pressure narrows the upper airway until it collapses. Clinically, this translates to progressive vibration causing snoring and collapse of upper airway soft tissue causing obstruction of airflow or, in other word, OSA.

Here is a list for risk factors for OSA.

1. Large neck: neck circumference > 17 inches (43.2 cm) in male and > 16 inches (40.6 cm) in female [29]
2. Abnormal nasal structure: deviated septum, polyps, prominent nasal turbinate
3. Macroglossia (scalloping tongue or tongue ridging can be observed) or posteriorly displaced tongue
4. Low-lying soft palate or enlarged uvula
5. Enlarged tonsil or enlarged adenoids (important cause for pediatric OSA)
6. Narrow airway (often in lateral dimension)
7. Abnormal facial skeleton: midface hypoplasia, retrognathia, micrognathia, mandibular hypoplasia
8. Genetic diseases affecting facial skeleton: Down's syndrome
9. Obesity [30]
10. Endocrine disorders [31, 32] or neurologic disorders
11. Smoking: causing swelling of upper airway soft tissue thus increasing risk for obstruction
12. Alcohol: inhibiting activity of upper airway muscles thus collapse occurs more easily
13. Drugs: muscle relaxants, sedative-hypnotics; benzodiazepines, barbiturates (decreasing tone of upper airway dilator muscle)
14. Familial history of having OSA patient in family
15. End stage renal disease: increasing chance for OSA occurrence by 10 times [33]
16. Congestive heart failure: having 47-76% incidence for OSA [34]

17. Hypertension: 83% of patients with drug-resistant hypertension having AHI $\geq$ 10 events/hour [35]

There are many symptoms usually found in OSA patients as follows.

1. Excessive daytime somnolence: the patients feel sleepy and need a rest or nap, even though they adequately slept last night, due to arousal caused by OSA
2. Morning headache: this could be migraine, tension headache, cluster headache or nonspecific headache [36]
3. Nocturia: normally, sleep continues throughout the night, but in OSA patients, upper airway obstruction increases negative intrathoracic pressure thus increasing venous return, resulting in right atrial distension and atrial natriuretic peptide releasing, following by natriuresis and diuresis at last [37]
4. Nocturnal choking
5. Witnessed apnea and other symptoms such as insomnia and restless sleep

According to International Classification of Sleep Disorders (ICSD) second edition by American Academy of Sleep Medicine, patients will be diagnosed as OSA patient in case that they meet criteria A, B and D or C and D as follows.

A. Consisting of at least 1 of followings
   i. Unintentional sleep episodes during wakefulness, daytime sleepiness, unrefreshing sleep, fatique, or insomnia
   ii. Waking with breath holding, gasping, or insomnia
   iii. Their sleep partner reporting their loud snoring, breathing interruptions, or both during sleep
B. Polysomnography reveals
   i. Apnea, hypopnea or RERAs at least 5 events/hour
   ii. Inspiratory effort occurring during these events

C. Polysomnography reveals

    i. Apnea, hypopnea or RERAs at least 15 events/hour

    ii. Inspiratory effort occurring during these events

D. These symptoms cannot be explained by any other causes

The criteria B and C obviously indicate that polysomnography is accepted as a gold standard in OSA diagnosis. Besides, it can be used to classify severity of OSA into mild (RDI = 5-15 events/hour), moderate (RDI = 15-30 events/hour), and severe (RDI > 30 events/hour).

Polysomnography must be done in sleep laboratory throughout the night with many electrodes on the patient's body and under observation of sleep technician. This is for assessment of several parameters as follows.

1. Electroencephalogram (EEG), electromyogram (EMG), and electrooculogram (EOG) are done to determine the depth of sleep and separate sleep from wakefulness.
2. Nasal and oral airflow and respiratory effort (thoracic and abdominal movement) are recorded to determine whether there is any apneic event and that event is central or obstructive in origin.
3. Blood oxygen saturation is measured to assess severity of decrease in blood oxygen during apnea.
4. Electrocardiogram (EKG) is used to reveal arrhythmia which may occur during apnea.

Indications for polysomnography are listed as follows.

1. Patients with sign and symptoms pointing to OSA and diagnosis confirmation needed

2. Patients with risk factors for OSA and complications suspected to be caused by OSA
3. Patients suspected to have OSA with incompatible history and clinical examination result
4. To diagnose patients suspected to have sleep disorder
5. For continuous positive airway pressure (CPAP) titration or treatment follow up

However, from diagnostic criteria for OSA and indications for polysomnography, symptoms and risk factors appear obviously to have an important role in diagnosis. Therefore, history taking and clinical examination can come up with useful information, but it should be bear in mind that such information may not be compatible with result from polysomnography. Anyway, in daily practice, screening should be done before thorough examination by physician. One easy-in-practical and effective method to gather these informations is questionnaire. Nowadays, questionnaires used to screen for OSA in patients older than 18 years of age are Berlin questionnaire, Wisconsin questionnaire, STOP and STOP-BANG questionnaire. Although the most popular one widely used is Berlin questionnaire, STOP and STOP-BANG questionnaire might be better in the aspect of feasibility of use for they consist of yes-or-no type questions. Furthermore, these latter two are more reliable in developing process while all questionnaire are good in aspect of generalizability. Besides, for predicting moderate to severe OSA, STOP-BANG questionnaire has highest sensitivity while Berlin questionnaire has highest specificity.

To date, there are several radiographic examination used for OSA assessment but one technique widely used is lateral cephalogram. Anyway, this technique has several drawbacks as mentioned previously. One important drawback is that it provides only two-dimensional information. Therefore, lateral dimension of airway cannot be assessed. From this point, CT increases its role more and more in airway assessment. As mentioned before, medical CT scans the patient with high dosage of radiation thus it does not suit for this situation. Magnetic resonance imaging (MRI) can be used to provide three-dimensional information as well but with lower image quality. Besides, the cost is high and availability is limited. CBCT comes up with the solution for this problem since it provides information equivalent to medical CT with much lower X-radiation dosage [24].

Cone beam computed tomography and obstructive sleep apnea

As aforementioned, lateral cephalometry which can be used to assess the upper airway and related structures for management of OSA has several drawbacks. One of these drawbacks is being two-dimensional imaging which limits its advantage in three-dimensional structures assessment itself. As a result, today's trend grows toward the development and utilization of advanced imaging such as CBCT which, despite the lower radiation dose comopared to medical CT, can explicitly define border between soft tissue and air.

However, CBCT also has its limitation. Majority of CBCT machines were designed for upright position scanning while there is a change in dimension of the oropharyngeal airway from supine, which is used in medical CT scanning, to upright position [38, 39]. Moreover, OSA events occur during sleep with supine position. Therefore, major limitation of CBCT is that its scanning position does not reflect the natural sleep posture. Anyway, there is only supine position scanning CBCT, the NewTOM 3G, available commercially. As a consequence, though the supine position scanning yields more benefits obviously, it is considerable whether more diagnostic accuracy obtained using supine position is so important and essential that usage of CBCT should be abandoned, and thus further studies are needed.

For accuracy and reliability of CBCT, compared with lateral cephalogram, CBCT can exhibit more variety in volumetric data of the airway and is accepted as effective tool for accurate airway assessment [40]. When used to determine volume and minimum area of the airway, it yields accurate and reliable results. Anyway, if the airway needs to be assessed completely, all linear, area, and volumetric measurements should be included altogether.

The DICOM viewers also play an important role in effectiveness of CBCT in airway assessment. When comparing 3 softwares including Dolphin3D, InVivo Dental, and OnDemand 3D in volumetric measurements, the result showed low accuracy for all softwares but high correlation with each other. This suggested that low accuracy was probably due to systematic errors [41].

Although CBCT has its major advantage of being three-dimensional, it can also be used two-dimensionally. Compared to cephalogram, CBCT can yield midsagittal image which is the true single plane midline image. Besides, two-dimensional image from CBCT is presented with no magnification, so this image can be measured as the same size as the real structure resulting in more reliable data.

For three-dimensional evaluation using CBCT, the study using supine CBCT showed that parameters which can be used to screen OSA patients were anteroposterior dimension and minimum cross-sectional area of the oropharyngeal airway. These two parameters are smaller in OSA patients [42].

Interesting parameters that could be of use to differentiate OSA patients from normal ones are minimum cross-sectional area, anteroposterior and lateral dimension of oropharyngeal airway. OSA patients have smaller and laterally narrower airway compared to normal. Moreover, there was a study in OSA patients showed that patients with high body mass index (BMI), or in other word, obese patients with high risk for OSA, have more spherical airway due to laterally narrowing of the airway [43].

The prediction model for OSA had been studied previously. In that study [19], the prediction model was developed from CBCT data and Berlin questionnaire and concluded that age > 57 years, male gender, high risk from Berlin questionnaire, and lateral dimension of upper airway < 17 mm are the significant risk factors for OSA. Moreover, the study also showed that minimum cross-sectional area, lateral dimension, and uniformity of airway are significantly different between OSA patients and snorers.

CHAPTER III

RESEARCH METHODOLOGY

Population

Thai population aged 25-70 years old with habitual snoring

Sample Size

Since this study included statistical comparison of the means of parameters between OSA patients and habitual snorers, sample size calculation from pilot study is demonstrated as follows.

Sample size estimation formula of each group for testing mean of two independent populations

$$n = \frac{2\sigma^2 (Z_{1-\alpha/2} + Z_{1-\beta})^2}{(\mu_1 - \mu_2)^2}$$

From pilot study which there was 10 samples in control group and 13 samples in case group, mean and standard deviation of significant parameters, recorded for the calculation of sample size, are shown in the table 1. α and β were set at 0.05 and 0.15 respectively.

Table 1 Sample size calculation

Parameter	μ_1	σ_1	μ_2	σ_2	Sample size
Minimum cross-sectional area	104.66	89.72	197.59	92.30	34.31
Average cross-sectional area	182.26	94.55	287.21	127.46	39.36
Anteroposterior dimension	7.09	3.74	10.85	3.45	33.26
Lateral dimension	18.20	8.27	26.17	7.94	37.37
MpH	15.41	4.41	9.72	5.26	25.48
Soft palate length (2D)	35.40	6.15	30.45	2.01	34.22

Data in the table is calculated that the minimal total sample size is 40 which is the highest value, thus sample size is set at 45 to assure statistical power of the test.

Sample

This study involved 45 patients consisting of 14 habitual snorers referred to Department of Radiology, Faculty of Dentistry, Chulalongkorn University for CBCT examination, with AHI < 5 events/hour as control group and 31 OSA patients from Excellence Center for Sleep disorders, King Chulalongkorn Memorial Hospital, Thai red cross society with AHI ≥ 15 events/hour. The subjects were enrolled between March 2012 and January 2013 through telephone calls. AHI of control subjects were assessed by 1-night baseline ambulatory sleep test using Stardust II portable diagnostic system (Philips Respironics, Merrysville, PA, USA) shown in figure 1 and 2, while AHI of OSA subjects were assessed by full night baseline polysomnography performed at Excellence Center for Sleep disorders.

1. Inclusion criteria

    1.1 Control group

1.1.1 The patients were informed about the research information and agreed to participate.

1.1.2 The patients were habitual snorers.

1.1.3 The patient's AHI < 5 events/hour.

1.2 Case group

1.2.1 The patients were informed about the research information and agreed to participate.

1.2.2 The patients were OSA patients with AHI $\geq$ 15 events/hour.

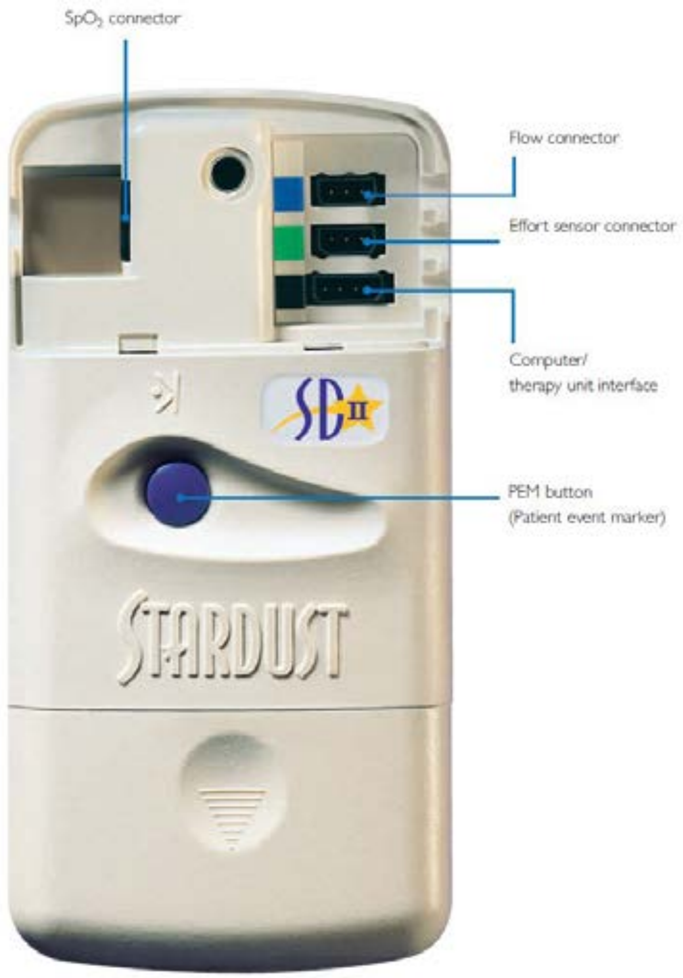
2. Exclusion criteria

2.1 The patients had been treated surgically in oropharyngeal region such as uvulopalatopharyngoplasty (UPPP) or had gone under surgery which affects facial skeletal structures such as orthognathic surgery.

2.2 The patients cannot be examined by CBCT, for example, who cannot sit still even for a short period of time.

Figure 1 Stardust II portable diagnostic system (Philips Respironics, Merrysville, PA, USA): its accessories

Figure 2 Stardust II portable diagnostic system (Philips Respironics, Merrysville, PA, USA): the device



Methodology

CBCT scan

All subjects sit in upright position within one CBCT machine (3D Accuitomo 170, J.Morita, Kyoto, Japan), shown in figure 3, for a full round scan with Frankfort horizontal plane parallel to the floor while awake. Scanning parameter included a medium field of view (140x100 mm) focusing on upper airway, a 0.25 mm resolution, 80 kVp, 5 mA and 17.5 sec. Volumetric data was then exported in DICOM format, and was imported into InVivo 5.1 software (Anatomage, CA) for upper airway analysis.

Figure 3 3D Accuitomo 170 (J.Morita, Kyoto, Japan), the upright CBCT used in this study

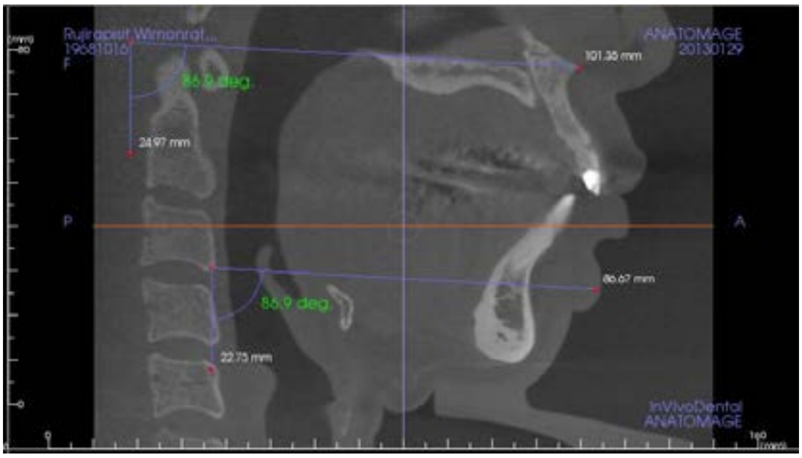
Questionnaire

Case and control subjects were interviewed to acquire raw data for STOP-BANG sleep questionnaire by an operator. The questionnaire consists of 8 questions regarding symptoms and conditions believed to be associated with OSA including snoring, tiredness, observed apnea, history of high blood pressure, body mass index (BMI), age, neck circumference and gender as shown in appendix A.

Measurement

One blinded investigator measured all CT data with repetition of randomly selected 10 cases after 1 week interval for reliability analysis. The region of interest was defined in midsagittal plane. The upper border was marked by intersection of anterior nasal spine to posterior nasal spine (ANS-PNS) plane to posterior pharyngeal wall, while the lower border was set paralleled to the upper plane at the level of most antero-inferior point of the second cervical vertebrae as shown in figure 4.

Figure 4 Region of interest of the upper airway in this study



CBCT parameters were measured using InVivo 5.1 software (Anatomage, CA) following these steps below.

1. Using "Section" mode (in other word, MPR)
    1.1 The airway length (mm) was measured perpendicularly to upper and lower borders while the length of soft palate were measured from PNS to uvula tip as shown in figure 5 and 6.

Figure 5 Airway length measurement

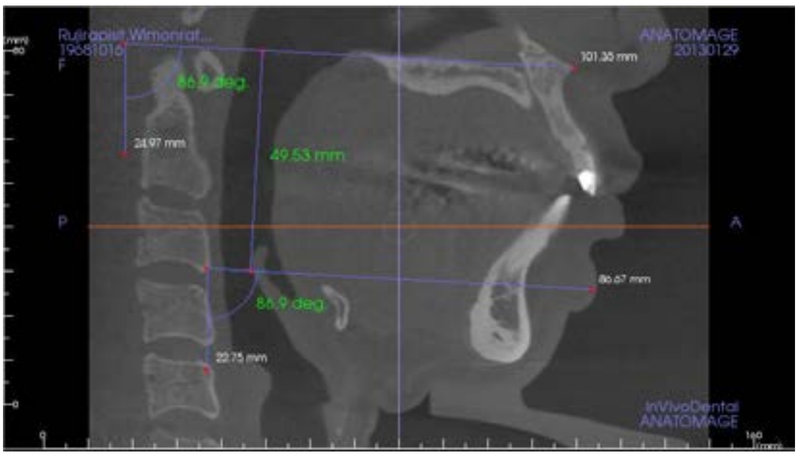
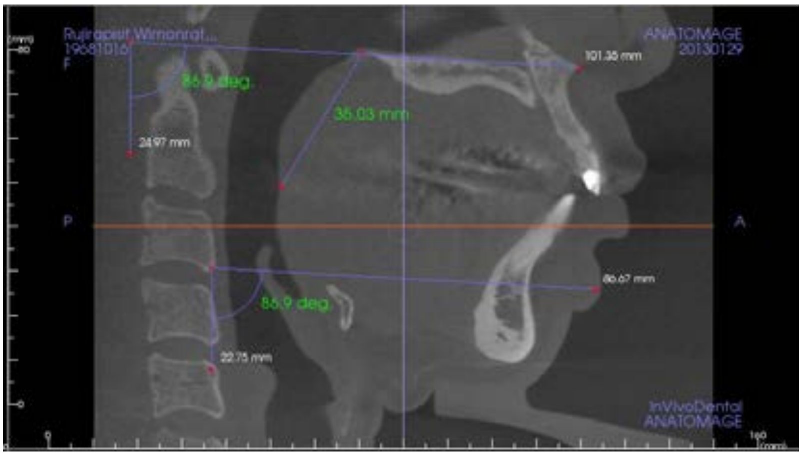
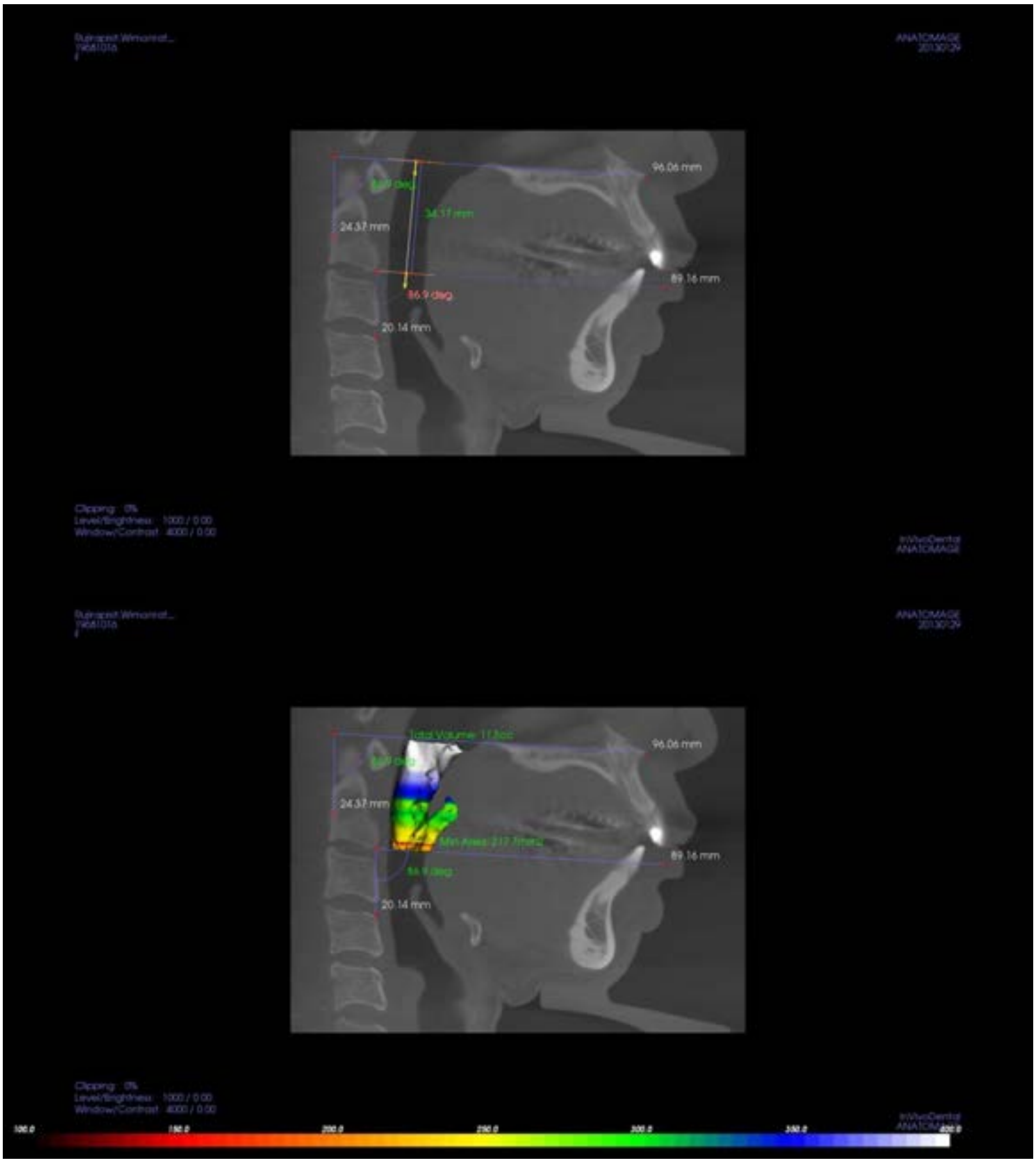


Figure 6 Soft palate length measurement



2. Using "Volume Render" mode
    2.1 The airway volume (cc) and minimum cross-sectional area (mm^2) were automatically calculated perpendicularly to upper and lower borders.

Figure 7 Airway volume and minimum cross-sectional area calculated by InVivo 5.1 software



2.2 The average area (mm^2) and airway uniformity (minimum area divided by average area) was computed by the investigator.

2.3 Anteroposterior and lateral dimensions of airway's minimum area were measured as shown in figure 8 and 9.

Figure 8 Anteroposterior dimension measurement

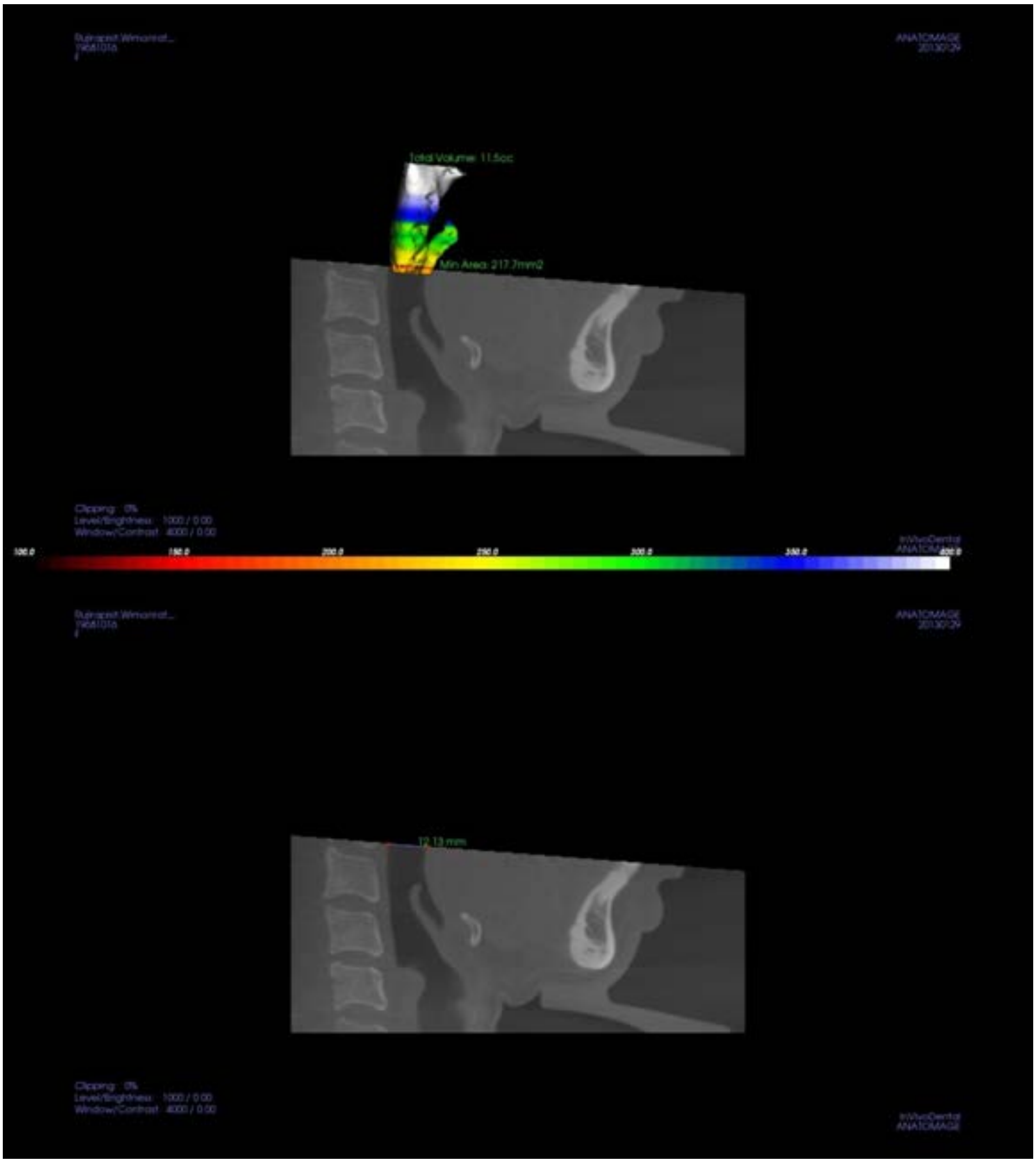
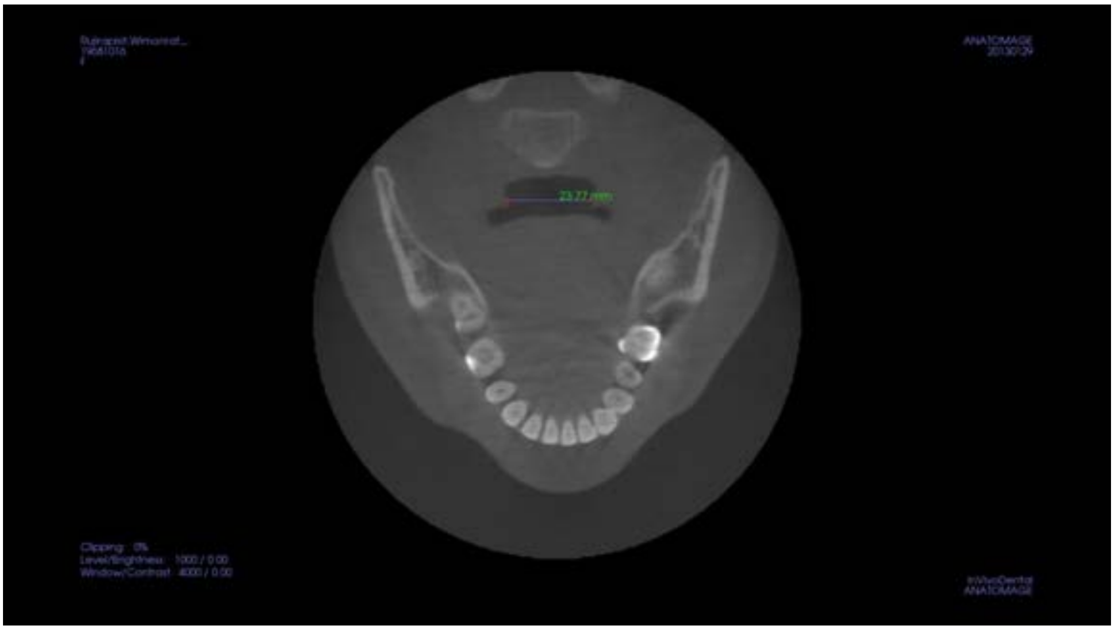
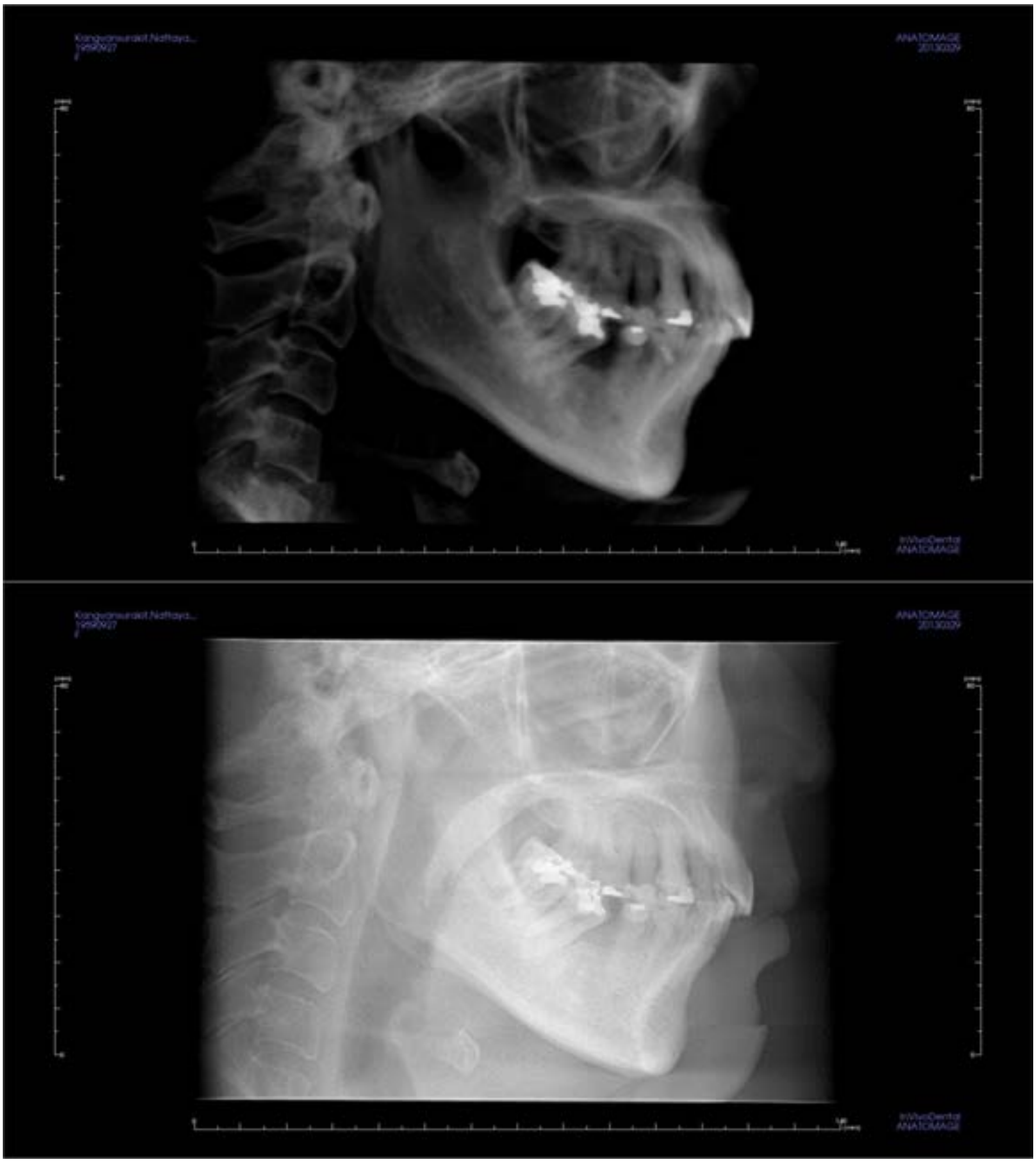


Figure 9 Lateral dimension measurement



3. Using “Super Ceph” mode, ray-sum cephalogram was reconstructed to mimic conventional 2D radiograph based on superimposing external auditory meati as shown in figure 10.

Figure 10 Lateral cephalogram reconstruction



3.1 Airway length and soft palate length were again measured using the same criteria as for three-dimensional assessment as shown in figure 11 and 12.

Figure 11 Airway length measurement in 2D

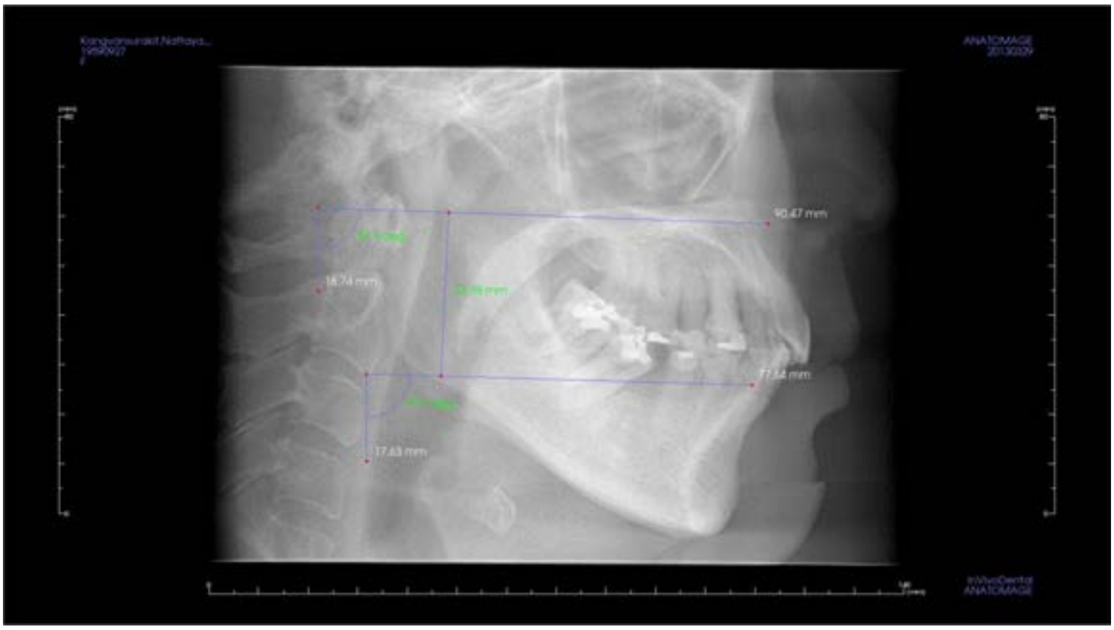
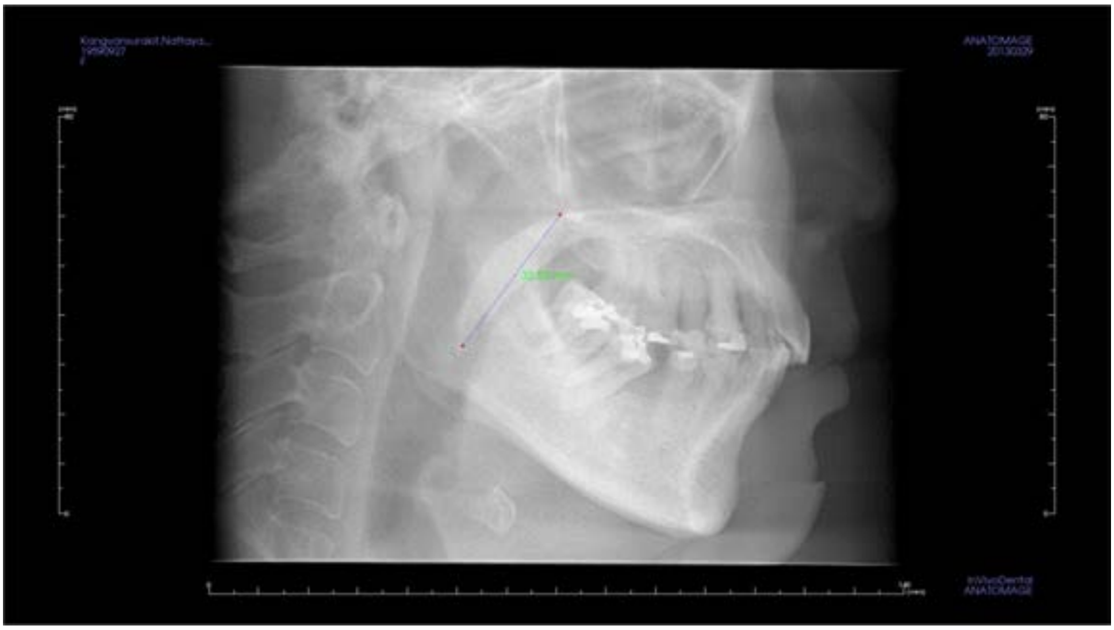


Figure 12 Soft palate length measurement in 2D



3.2 Pharyngeal airway space at nasal level (PAS-NL) along the plane drawn through ANS and PNS, and at the level of tongue base (PAS-BGo) along the plane drawn through B point and gonion.

Figure 13 PAS-NL measurement

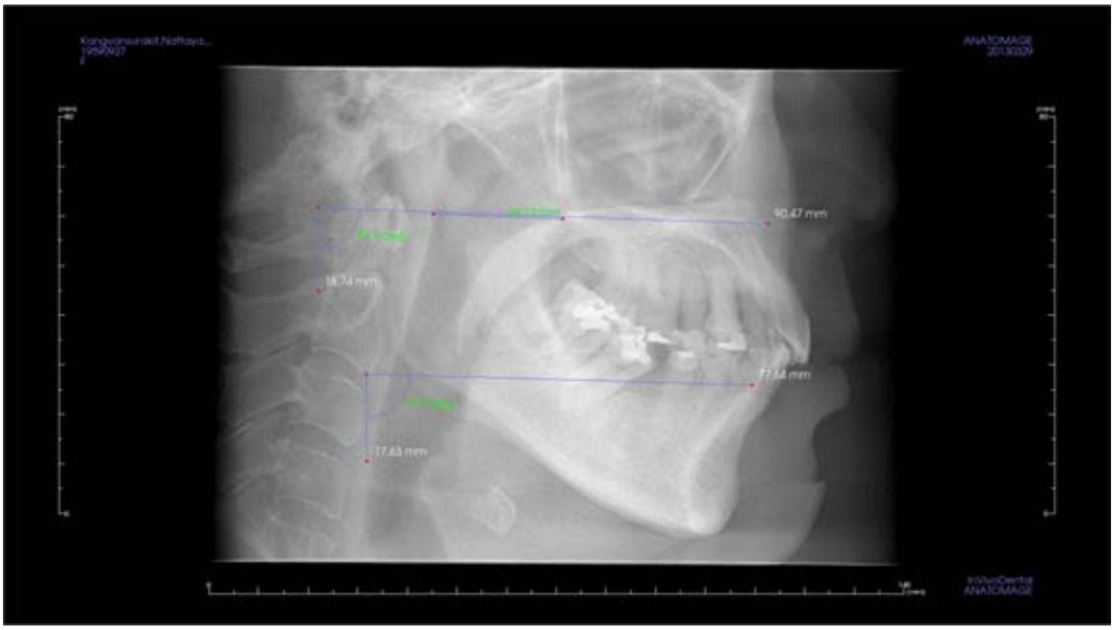
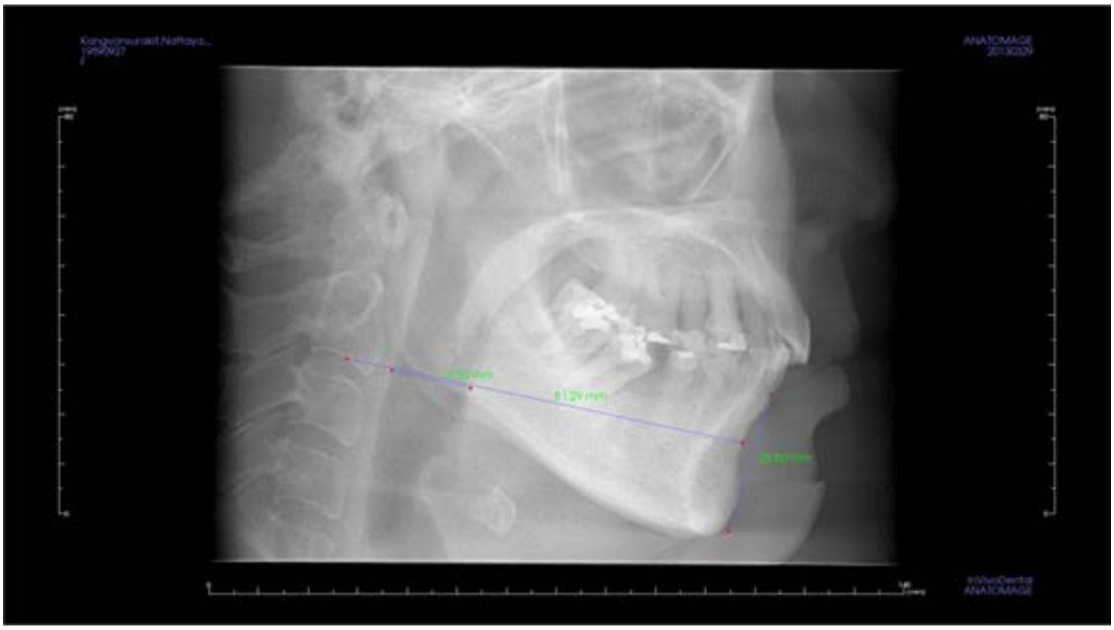
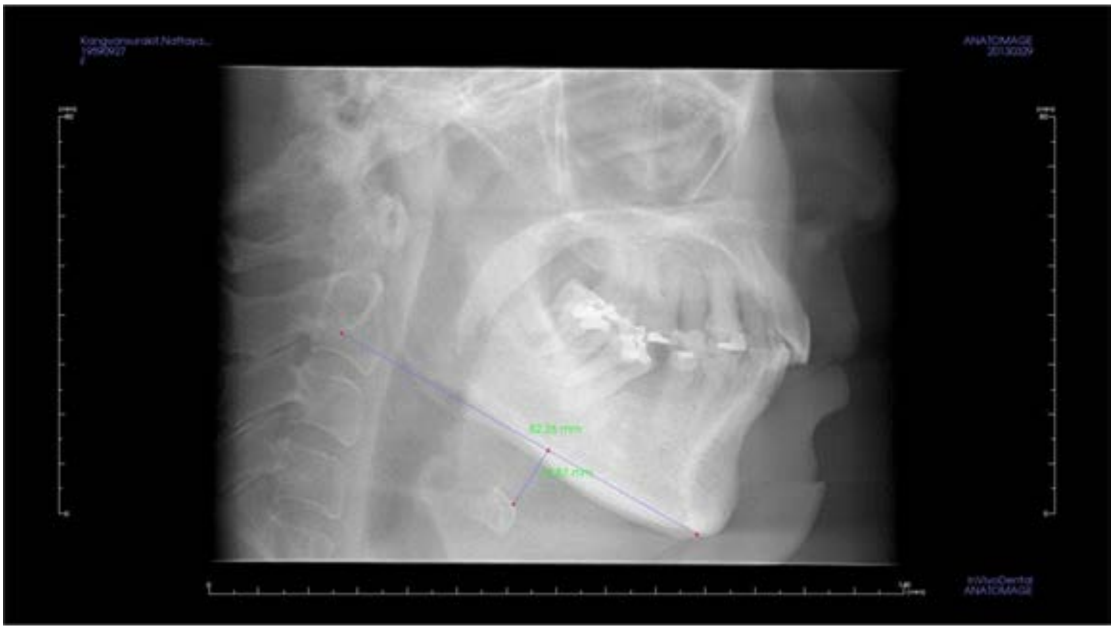


Figure 14 PAS-BGo measurement



3.3 Distance between hyoid bone to mandibular plane (MpH) was also measured from the most anterosuperior point of hyoid bone to mandibular plane perpendicularly as shown in figure 15.

Figure 15 MpH measurement



Statistical Analysis

All statistical analysis were performed using SPSS 17.0 software following these steps below.

1. The intraclass correlation was used for intra-observer reliability assessment.
2. Descriptive statistics were obtained for gender, age, neck circumference, BMI, and AHI with Chi-square analysis for gender and Wilcoxon rank sum test for others.
3. Kolmogorov-Smirnov test was used to check for normality of all parameters.
4. The independent *t* test (parametric statistics) and the Wilcoxon rank sum test (non-parametric statistics) were used to compare CBCT parameters between case and control subjects with 95% confident level.
5. For factors from STOP-BANG questionnaire, Chi-square test was used to compare the difference between groups with 95% confident level.

6. CBCT parameters and factors from STOP-BANG questionnaire were analyzed using multiple linear regression as follows.
    6.1 All CBCT parameters and STOP-BANG factors were analyzed using stepwise multiple linear regression with ≤ 0.050 significant level to enter and ≥ 0.100 significant level to remove from the model.
    6.2 Predictors (CBCT parameters) from analysis 6.1 were analyzed using enter multiple linear regression with ≤ 0.050 significant level to enter the model. BMI, age, and gender were controlled by being forced to enter the analysis.
    6.3 Each predictor (CBCT parameter) from analysis 6.1 were analyzed using enter multiple linear regression with ≤ 0.050 significant level to enter the model. BMI, age, and gender were controlled by being forced to enter the analysis.
    6.4 Predictors (CBCT parameters) from analysis 6.1 1 were analyzed using enter multiple linear regression with ≤ 0.050 significant level to enter the model, but instead of BMI, age, and gender, STOP-BANG score were controlled by being forced to enter the analysis.
    6.5 All models from multiple linear regression analysis were tested for multicollinearity of their predictors using collinearity statistics (Eigenvalue and VIF)

CHAPTER IV

RESULTSDescriptive statistics

This study included 45 subjects consisting of 14 control and 31 OSA subjects, whose demographic data were shown in table 2 with Chi-square analysis for gender and Wilcoxon rank sum test for others.

Table 2 Demographic data for study's subjects

Variable	Case (n = 31) Mean ± SD	Control (n = 14) Mean ± SD	p-value
Gender	22M : 9F	5M : 9F	0.025
Age (year)	50.48 ± 9.52	36.28 ± 12.57	0.001
Neck circumference (cm)	37.10 ± 3.34	31.75 ± 4.04	< 0.001
BMI (kg/m^2)	27.36 ± 4.87	21.72 ± 3.29	< 0.001
AHI (events/hour)	38.28 ± 24.15	2.60 ± 1.42	< 0.001

CBCT parameters

From table 3, the results of the independent *t* test (for parameters with normal distribution including airway length, PAS-NL, PAS-BGo and airway length in 2D) and the Wilcoxon rank sum test (for other parameters without normal distribution) are presented for case and control comparisons. There were statistically significant differences between volume ($p = 0.001$), minimum cross-sectional area ($p < 0.001$), average cross-sectional area ($p < 0.001$), anteroposterior width ($p < 0.001$), lateral width ($p = 0.001$), uniformity ($p = 0.009$), PAS-BGo ($p = 0.012$), MpH ($p = 0.002$), and soft palate length in 2D ($p < 0.001$), while remaining parameters did not show statistically significant differences ($p > 0.05$).

Table 3 Comparison of radiographic parameters between case and control group

Parameter	Case (n=31) Mean ± SD	Control (n=14) Mean ± SD	p-value
Volume (cc)	6.27 ± 4.04	11.11 ± 4.75	0.001
Minimum cross-sectional area (mm^2)	88.22 ± 76.51	196.10 ± 79.36	<0.001
Average cross-sectional area (mm^2)	159.43 ± 91.38	286.03 ± 109.70	<0.001
Anteroposterior dimension (mm)	6.24 ± 3.24	10.48 ± 2.97	<0.001
Lateral dimension (mm)	16.80 ± 7.90	26.14 ± 6.79	0.001
Airway length (mm)	38.85 ± 4.82	38.75 ± 4.50	0.944
Uniformity	0.49 ± 0.21	0.66 ± 0.13	0.009
Soft palate length (mm)	41.25 ± 6.95	35.21 ± 3.94	0.001
PAS-NL (mm)	19.80 ± 4.66	21.88 ± 3.35	0.140
PAS-BGo (mm)	9.72 ± 3.22	12.37 ± 2.99	0.012
MpH (mm)	16.33 ± 5.17	9.86 ± 4.66	0.002
Soft palate length in 2D (mm)	38.22 ± 5.63	31.91 ± 3.15	<0.001
Airway length in 2D (mm)	37.88 ± 5.12	38.08 ± 4.56	0.901

STOP-BANG questionnaire

From table 4, the Chi-square test was performed for each factor from the questionnaire, in case of less than 5 expected count, the Fisher's exact test was utilized. Factors with statistically significance between case and control groups were snoring ($p = 0.002$), observed apnea ($p = 0.009$), age ($p = 0.023$), and gender ($p = 0.025$). The other factors showed no statistically significant differences ($p > 0.05$).

Table 4 Comparison of STOP-BANG questionnaire between case and control group

STOP-BANG	Case (n = 31)	Control (n = 14)	p-value
S : Snoring	25Y : 6N	4Y : 10N	0.002
T : Tiredness	18Y : 13N	4Y : 10N	0.067
O : Observed apnea	12Y : 19N	0Y : 14N	0.009
P : High blood Pressure	14Y : 17N	2Y : 12N	0.090
B : Body mass index	4Y : 27N	0Y : 14N	0.294
A : Age	18Y : 13N	3Y : 11N	0.023
N : Neck circumference	4Y : 27N	1Y : 13N	1.000
G : Gender	22Y : 9N	5Y : 9N	0.025

Intra-observer reliability results

Using the intraclass correlation coefficient (ICC), all 10 subjects showed highly reproducible measurements with ICC in range of 0.911-0.999. All details are demonstrated in table 5.

Table 5 Intra-observer reliability results

Parameter	Intraclass Correlation Coefficient (ICC)
Volume	0.999
Minimum cross-sectional area	0.987
Anteroposterior dimension	0.972
Lateral dimension	0.994
Airway length	0.975
Soft palate length	0.996
PAS-NL	0.911
PAS-BGo	0.973
MpH	0.999
Soft palate length (2D)	0.967
Airway length (2D)	0.964

Prediction model

All CBCT parameters and STOP-BANG factors were analyzed by stepwise multiple linear regression with $\leq$ 0.050 significant level to enter and $\geq$ 0.100 significant level to remove from the model. As a result, the prediction model for AHI was formulated as

$$AHI = 1.842(MpH) - 1.074(\text{lateral dimension})$$

The p-value of each predictor in the model was < 0.001 and 0.001 respectively as they appear in the model above. The R square of the model equaled 0.563 and adjusted R square equaled 0.538 with p-value < 0.001 for F-test. The collinearity statistics of this model were within accepted limits (Eigenvalue closes to 1 and VIF < 10).

Nevertheless, this result was not yet controlled for BMI, age, and gender which can be confounding factors in this study. This problem was solved by second analysis of MpH, lateral dimension, BMI, age, and gender using multiple linear regression with enter method. The STOP-BANG factors from questionnaire, BMI, age, and gender, enter in the analysis with value of "1" if the answer was "yes" (BMI > 35 kg/m^2, age > 50 or male gender) and value of "0" if the answer was "no" (BMI $\leq$ 35 kg/m^2, age $\leq$ 50 or female gender). As a result, the prediction model for AHI was formulated as

$$AHI = -1.023(\text{lateral dimension}) + 1.407(MpH) + 17.905(BMI)$$

The p-value of each predictor in the model was 0.002, 0.011, and 0.050 respectively as they appear in the model above. The R square of the model equaled 0.619 and adjusted R square equaled 0.558 with p-value < 0.001 for F-test. The collinearity statistics of this model were within accepted limits (Eigenvalue closes to 1 and VIF < 10).

Next, the third analysis was done using multiple linear regression with enter method in the same way as the second, but instead of using both parameters (MpH and lateral dimension), only 3D parameter, lateral dimension, was used to formulate the model. As a result, the prediction model for AHI was formulated as

$$AHI = 42.182 – 1.469(\text{lateral dimension}) + 39.530(BMI) + 12.807(\text{gender})$$

The p-value of each predictor in the model was < 0.001, < 0.001, and 0.036 respectively as they appear in the model above. The R square of the model equaled 0.551 and adjusted R square equaled 0.506 with p-value < 0.001 for F-test. The collinearity statistics of this model were within accepted limits (Eigenvalue closes to 1 and VIF < 10).

Then the fourth analysis was done as same as the third, except for the parameter used which was changed to 2D parameter, MpH. As a result, the prediction model for AHI was formulated as

$$AHI = 1.800(MpH) + 21.295(BMI)$$

The p-value of each predictor in the model was 0.004 and 0.043 respectively as they appear in the model above. The R square of the model equaled 0.471 and adjusted R square equaled 0.405 with p-value < 0.001 for F-test. The collinearity statistics of this model were within accepted limits (Eigenvalue closes to 1 and VIF < 10).

Last, the fifth analysis was done using multiple linear regression with enter method. Both parameters (MpH and lateral dimension) entered in the analysis while STOP-BANG score obtained from “yes” answer from the questionnaire as (in range of 0 to 8) was used to control confounding effect instead of BMI, age, and gender. As a result, the prediction model for AHI was formulated as

$$AHI = 1.710(MpH) – 1.018(lateral\ dimension)$$

The p-value of each predictor in the model was 0.004 and 0.005 respectively as they appear in the model above. The R square of the model equaled 0.565 and adjusted R square equaled 0.526 with p-value < 0.001 for F-test. The collinearity statistics of this model were within accepted limits (Eigenvalue closes to 1 and VIF < 10).

From these 5 prediction models for AHI, the second model with both 2D and 3D parameter, which controlled for BMI, age, and gender, yielded higher R square and adjusted R square compared to others. All data of the prediction models were presented in table 6.

Table 6 Results of multiple linear regression analysis of all prediction models

Model	R^2	Adjusted R^2	Predictor	Coefficient	p-value	Eigenvalue	VIF
1	0.563	0.538	MpH	1.842	< 0.001	0.172	1.069
			Lateral dimension	-1.074	0.001	0.037	1.069
2	0.619	0.558	Lateral dimension	-1.023	0.002	0.096	1.090
			MpH	1.407	0.011	0.034	1.774
			BMI	17.905	0.050	0.951	1.130
3	0.551	0.506	Constant	42.182	< 0.001	3.198	
			Lateral dimension	-1.469	< 0.001	0.058	1.077
			BMI	39.530	< 0.001	0.968	1.098
			Gender	12.807	0.036	0.344	1.128
4	0.471	0.405	MpH	1.800	0.004	0.058	1.690
			BMI	21.295	0.043	0.949	1.116
5	0.565	0.526	MpH	1.710	0.004	0.321	1.842
			Lateral dimension	-1.018	0.005	0.054	1.339

CHAPTER V

DISCUSSION AND CONCLUSION

Discussion

This study was conducted with limited period of time, while appropriate subjects according to our inclusion criteria are somewhat difficult to recruit, resulting in rather small sample size and possible some selection bias for subject enrollment as shown by a large gap between mean age between case and control groups. Given older age is an important risk factor for OSA development, thus matching the age of case and control subjects was nearly impossible with small sample size.

Regarding control group, which are healthy subjects undergoing CBCT examinations for general treatment purposes and have some snoring problem but no real needs for the sleep test, may felt overwhelmed with the sleep test device. Despite the fact that this portable device is much more compact and is already deprived of all electrodes and wires, it still bothers the conventional resting time. As a result, some individuals refused to continue with the project. Moreover, the discomfort due to nasal flow checker or tightness of the chest belt, measuring the air flow and chest movement indicating the attempt to breathe or arousal troubled the subjects and caused less than 6 hours of sleep. Another popular problem with the device was loosened oxygen saturation monitor at the finger-tip, which came out during the night causing missing data and repeating tests. Finally, some of these clinical snorers are actually not a snorer or mild OSA populations, but a more severe OSA group, which got excluded from the study.

Concerning test group, which are OSA patient already underwent polysomnography, despite their good heart, may have more crucial obligations than additional CBCT scan. For example, severe overweight patient might felt too much to overcome for another trip for not yet warrant modality, while elderly might requiring accompany support proved to be too complicated. In addition, some subjects already got other more aggressive treatment, which might affect the dimension of upper airway and was excluded as well.

In general, questionnaires are considered a quick and easy media to get information from the subjects. To do so effectively and to get correct response, the questionnaire must be clearly understood by the subjects and also user friendly. This is the reason why STOP-BANG questionnaire was chosen over Berlin questionnaire for this study. Even though, unlike Berlin questionnaire that was verified for its usage in Thai language [44], the Thai-versioned of STOP-BANG questionnaire is not proven suitable for Thai population yet. Therefore, there might be issues regarding confusion or ambiguous of the questions. However, this glitch was dealt by operator interviewing the subject, then filling the form instead of direct self-answering by participants.

Since, the majority of countless commercially available CBCT present as upright patient positioning, which also bring up similar draw back to lateral cephalometric examination of not truly replicating the collapse during the sleep. To our knowledge, only 2 scanners from QR srl - Verona, Italy offer supine positioning, and using those machines is not only impossible in Thailand. This study settles on scanner from J. Morita, Japan with its high quality image and low exposure dose [25] in mind. In addition, considering previous results of positioning effect to airway structure [18, 38, 39] that the dimension of upper airway is less favor for OSA in upright position. Using this upright setting, it should offer a less sensitive, but more specific prediction model.

This study targeted the investigation to the upper airway, especially the oropharynx, since, from previous systematic review, the most common site of obstruction detected was at the level of the oropharynx with considerable variability in the techniques [45]. Nevertheless, minor differences can be seen in measuring technique. Enciso [19] used a reference plane parallel to the Frankfort plane passing through the most distal point of the bony hard palate and the same plane through the most anterior-inferior point of the second cervical vertebrae, which means the large field of view (FOV) covering from inferior border of the orbital cavity to approximate level of hyoid bone, covering both nasopharynx and oropharynx. Considered the unclear risk or benefit for low dose radiation, this study opt for the smaller FOV as a medium filed and used the plane going through ANS and PNS as reference plane passing through hard palate and C2 instead.

For CBCT parameters, volume, minimum cross-sectional area, average cross-sectional area, anteroposterior and lateral dimension, and uniformity of the upper airway were significantly different between OSA patients and habitual snorers in this study. This finding is concurred with smaller airway cross-sections in studies conducted by Ogawa, et al in 2007 [42] and Enciso, et al in 2010 [19]. However, their results show no significant difference for volume and average cross-sectional area parameter. Since, airway average cross-section indicates overall airway dimension and hence overall airway resistance. Combined with significantly less airway uniformity in this study, it implies small cross-sections' ability to obstruct airway as much as overall large airway with some narrowing points. As for volume, the reason for significant difference in this study might be because of a large gap in AHI of case and control group which reflects their severity. Anyway, some authors found that total airway volume of the oropharyngeal airway showed significant group difference between OSA and gender-matched controls [46]. For anteroposterior dimension, the result from our study is also consistent with the study of Ogawa and colleagues [42] but inconsistent with Enciso's group [19]. This might owe to the larger sample size of the latter study or the characters of Thai ethnic group. For the last significant parameter, reduced lateral airway width was corresponded to several studies using both CBCT [19] and magnetic resonance imaging [21, 22, 23]; despite the fact that this study use upright position. This parameter is accepted as a significant predictor for OSA, which may be explained by the increased lateral pharyngeal wall thickness. However, there was a study suggesting that the shape of the pharyngeal lumen is more dependent on BMI than the presence of OSA [43].

In 2D measurements, other two significant cephalometric parameters are the length of soft palate and the position of the hyoid bone. This study revealed similar result: longer uvula and more inferiorly positioned hyoid bone in OSA patients as previously reported [47, 48]. There was also previous study which marked increase in soft palate length in cephalogram leads to reduction of the airway and increased contact between soft palate and tongue thus leading to collapse of the airway [49]. As for hyoid position, there was a study pointing out that it was inferiorly placed in OSA patients with cervical vertebra as reference point [50]. Besides, another study also reported inferiorly positioned hyoid bone by means of sella-hyoid distance measurement in more severe OSA [51]. From previously mentioned study, it appears that there are many superior anatomical structures suitable as reference points for determining hyoid position, anyway, this study used mandibular plane as a reference because CBCT images were used instead of lateral cephalogram thus larger field of view means higher radiation dose to the patient. However, some authors explained that inferiorly placed hyoid bone apparently gives the tongue a more upright position with more of the tongue tissue narrowing the airway [49]. Furthermore, this study's result indicates a significantly reduced width in anteroposterior dimension for only 3D, but not in 2D mode except for PAS-BGo which locates retrogrossally. This reflects that retrogrossal oropharyngeal airway might be a better predictor for OSA than retropalatal airway at the nasopharyngeal-oropharyngeal connection as PAS-NL.

According to STOP-BANG questionnaire, our study showed OSA subjects with observation of being older, being male, having more snoring, and having observed apnea when compared to habitual snorers. Even though, the result was not unexpected but the findings suggested that the presence of apnea observed during sleep, loudness of snoring, being male and older age > 50 can be of use as predictors for Thai OSA. However, Shigeta, et al [52] found that anteroposterior and lateral dimension, and airway cross-sectional area were not statistically different in their control and OSA patients after adjusting gender, age, and BMI. This might refer that significantly differences in CBCT dimensional parameters in this study might be confounded by these factors.

Although it is generally known that OSA occurs in supine position, or in other word, natural sleep posture, this study used an upright CBCT to examine the patients despite the fact that there were evidences showing a reduction in airway dimension due to a change in position from upright to supine [38, 39]. Nevertheless, the statistically significant differences in CBCT parameters in this study do support that upright CBCT generally available can be used in upper airway assessment for OSA.

For prediction model, predictors entering the model included both 2D and 3D parameters with relatively high R square. This might refer that these parameters are essential for OSA assessment and the prediction model can be used for AHI estimation quite well. Compared to study of Enciso et al [19], lateral dimension of airway was also one of the predictors as in this study thus emphasizing the forte of 3D information acquired by CBCT. However, generalizability of this prediction model must be continued on further study.

Conclusion

The main purpose of this study was to compare parameters of upper airway dimension from upright CBCT for a group of Thai population, and to study relationship of CBCT values combined with STOP-BANG questionnaire between habitual snorers and OSA subjects. Statistically significant differences were found among habitual snorers and OSA subjects in terms of CBCT parameters and positivity of STOP-BANG questionnaire. For CBCT parameters, major parameters related to Thai OSA subjects are volume, minimum cross-sectional area, average cross-sectional area, anteroposterior and lateral dimensions, and uniformity of the upper airway and soft palate length. For the sleep questionnaire, significantly different factors for Thai groups include history of snoring, presence of observed apnea, being male, and age > 50. This study also formulated a prediction model from CBCT parameters and STOP-BANG questionnaire, however, further study on its effectiveness should be conducted.

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APPENDICES

Appendix A

STOP-BANG Questionnaire

1. **S**noring: คุณกรนดัง (ดังกว่าเสียงพูดหรือดังขนาดที่สามารถได้ยินผ่านประตูที่ปิด) หรือไม่

☐ ใช่ ☐ ไม่ใช่

2. **T**ired: คุณรู้สึกเหนื่อย เพลีย หรือง่วงนอนตอนกลางวันหรือไม่

☐ ใช่ ☐ ไม่ใช่

3. **O**bserved: เคยมีใครเห็นว่าคุณหยุดหายใจตอนนอนหลับหรือไม่

☐ ใช่ ☐ ไม่ใช่

4. Blood **P**ressure: คุณมีโรคความดันโลหิตสูงหรือกำลังได้รับการรักษาโรคความดันโลหิตสูงหรือไม่

☐ ใช่ ☐ ไม่ใช่

5. **B**MI: ดัชนีมวลกายมากกว่า 35 kg/m^2

☐ ใช่ ☐ ไม่ใช่

6. **A**ge: อายุมากกว่า 50 ปี

☐ ใช่ ☐ ไม่ใช่

7. **N**eck circumference: ขนาดคอใหญ่กว่า 40 cm (วัดที่ระดับ thyroid cartilage จุดที่ protrude ที่สุดตรงคอ)

☐ ใช่ ☐ ไม่ใช่

8. **G**ender: เพศชายหรือไม่

☐ ใช่ ☐ ไม่ใช่

คะแนน ________

☐ **High risk of OSA**: ตอบว่าใช่ตั้งแต่ 3 ข้อขึ้นไป

☐ **Low risk of OSA**: ตอบว่าใช่น้อยกว่า 3 ข้อ

Appendix B

Research data

Table 7 shows STOP-BANG questionnaire data

Table 8 shows CBCT parameters data (1^{st} measurement)

Table 9 shows CBCT parameters data (2^{nd} measurement)

Table 7 STOP-BANG questionnaire data

ID	STOP-BANG									
	S	T	O	P	B	A	N	G	Total	Risk
1	0	0	0	0	0	0	0	0	0	0
2	1	1	0	1	1	0	0	0	4	1
3	1	0	0	0	0	0	0	1	2	0
4	0	1	0	0	0	0	0	0	1	0
5	0	1	0	0	0	0	0	1	2	0
6	1	1	1	1	0	1	1	1	7	1
7	1	1	0	1	0	1	0	1	5	1
8	1	0	1	1	0	1	0	0	4	1
9	0	0	0	0	0	1	0	1	2	0
10	1	0	0	1	0	0	0	1	3	1
11	0	1	1	0	0	1	0	1	4	1
12	1	1	1	1	1	0	1	0	6	1
13	1	1	0	1	0	1	0	1	5	1
14	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	1	1	0
16	0	0	0	0	0	0	0	0	0	0
17	1	1	0	1	0	1	0	1	5	1
18	0	0	0	0	0	1	0	0	1	0
19	1	0	0	1	0	0	1	1	4	1
20	0	0	0	0	0	0	0	0	0	0
21	1	1	0	0	0	0	0	0	2	0
22	1	0	0	1	1	1	0	0	4	1
23	1	1	0	1	0	1	0	0	4	1
24	1	1	1	0	0	1	0	0	4	1
25	0	1	0	0	0	1	0	1	3	1
26	1	1	0	0	0	1	0	1	4	1
27	1	1	0	0	0	1	0	0	3	1
28	1	0	1	0	0	1	0	1	4	1
29	1	0	0	0	0	1	0	1	3	1
30	1	1	1	1	0	1	0	1	6	1

Table 7 STOP-BANG questionnaire data (continued)

ID	STOP-BANG									
	S	T	O	P	B	A	N	G	Total	Risk
31	1	1	1	0	0	1	0	1	5	1
32	1	0	0	0	0	0	0	1	2	0
33	1	1	1	0	0	0	0	1	4	1
34	0	1	0	1	0	0	0	1	3	1
35	1	0	1	0	0	0	0	1	3	1
36	1	0	0	0	0	1	0	1	3	1
37	1	1	0	1	0	0	0	0	3	1
38	1	0	0	0	0	1	0	1	3	1
39	0	0	0	1	0	0	0	1	2	0
40	0	0	0	0	0	0	0	0	0	0
41	1	1	1	1	1	0	1	1	7	1
42	1	1	1	0	0	0	0	1	4	1
43	0	0	0	0	0	1	0	0	1	0
44	0	0	0	0	0	0	0	0	0	0
45	1	0	0	0	0	0	1	1	3	1

Table 8 CBCT parameters data (1st measurement)

ID	CBCT													AHI	Gr
	Vol	Min Area	Avg Area	AP	Lat	Length	Uniform	SPL	PAS-NL	PAS-Bgo	MPH	SPLC	Length C		
1	8.2	166	240.6103	11.71	24.02	34.08	0.689912	34	21.56	10.8	0.93	30.73	30.41	2.4	0
2	8.6	202.2	254.3626	11.77	24.37	33.81	0.794928	31.63	24.26	15.75	12.94	31.25	31.51	17.8	1
3	3.6	12.9	106.2574	4.84	4.05	33.88	0.121403	36.32	14.81	10.96	999	32.91	35.88	62.7	1
4	15.3	288.8	336.3377	12.29	27.39	45.49	0.858661	35.93	25.28	15.47	999	28.07	44.7	1.4	0
5	19.8	310.4	480	13.92	31.06	41.25	0.646667	28.56	22.99	17.81	16.23	29.36	40.73	1.6	0
6	5.6	13.4	108.4011	1.95	4.18	51.66	0.123615	62.78	19.63	9.54	999	50.95	49.75	81.7	1
7	6.6	127.2	194.5181	9.54	21.35	33.93	0.653924	39.72	23.76	11.48	21.57	39.89	33.58	37	1
8	20.1	312.9	421.6488	14.73	31.82	47.67	0.742087	37.56	20.88	14.94	999	30.89	49.99	17.4	1
9	9.3	160.7	212.0867	6.65	28.81	43.85	0.757709	41.85	22.09	10.1	8.57	36.77	37.47	21.4	1
10	8.3	168.9	264.163	8.06	21.77	31.42	0.639378	34.06	18.77	13.03	14.37	28.07	27.43	23.8	1
11	4.4	37.4	112.0448	4.27	12.51	39.27	0.333795	34.53	16.1	13.82	21.1	33.57	38.77	48.2	1
12	2.4	6.4	60.71338	2.07	16.36	39.53	0.105413	36.53	6.8	9.73	999	38.47	36.46	116.1	1
13	6	111.8	151.4387	10.47	18.15	39.62	0.738253	39.42	21.88	11.97	17.07	38.79	40.88	30.6	1
14	11	222.3	309.0756	16.53	28.4	35.59	0.719242	31.42	23.37	15.81	7.04	28.67	35.65	1.7	0
15	11.6	193.5	272.3005	9.47	34.24	42.6	0.710612	35.8	18.44	11.7	11.09	33.49	41.89	2.8	0
16	11.7	249.7	337.4676	11.08	32.93	34.67	0.739923	33.98	21.6	12.44	11.6	29.06	34.69	4.4	0
17	7.8	140.3	188.3148	7.08	28.82	41.42	0.745029	35.34	18.91	9.63	15.94	30.43	36.78	4.3	0
18	9.3	95.6	211.6523	6.24	19.96	43.94	0.451684	35.15	23.66	5.88	999	30.23	38.52	15	1
19	2.9	18.8	69.87952	4.05	11.89	41.5	0.269034	41.38	12.93	7.83	13.34	34.29	43.03	2.4	0
20	18.6	282.5	464.3035	11	30.62	40.06	0.608438	30.92	22.27	12.18	7.15	30.62	37.3	5	0
21	7.1	103.6	173.7641	11.39	12.34	40.86	0.596211	32.93	22.23	11.31	4.2	29.78	39.38	2.5	0
22	4.9	61.7	135.9978	6.06	19.96	36.03	0.453684	36.39	15.64	10.78	15.23	29.78	34.38	37	1
23	4.7	49.5	136.0347	5.47	13.3	34.55	0.363878	34.85	26.35	11.38	12.43	38.66	38.38	25.2	1
24	2.6	19	67.84969	1.81	11.89	38.32	0.280031	38.21	10.83	2.52	17.38	36.1	37.74	36.5	1
25	6.1	86.4	151.3648	4.87	24.98	40.3	0.570807	38.07	23.58	5.64	11.46	37.65	38.09	19	1
26	5.3	19.7	123.2845	1.41	16.92	42.99	0.159793	53.63	20.5	8.8	25.45	49.24	44.99	17.5	1
27	3.6	68.7	105.2016	6.7	14.12	34.22	0.653032	36.39	19.89	12.64	13.16	35.45	34.12	38.1	1
28	3.8	38.1	95.79027	1.86	14.93	39.67	0.397744	47.19	20.6	4.4	19.29	42.07	38.77	63.1	1
29	15.4	246.3	372.9717	9.69	26.63	41.29	0.660372	44.95	29.12	12.93	15.69	40.4	37.22	46.6	1
30	7.1	37.8	181.4465	2.85	14.7	39.13	0.208326	51.3	24.27	6.67	999	46.09	39.08	28.5	1

Table 8 CBCT parameters data (1st measurement) (continued)

ID	CBCT													AHI	Gr
	Vol	Min Area	Avg Area	AP	Lat	Length	Uniform	SPL	PAS-NL	PAS-Bgo	MPH	SPLC	Length C		
31	5.7	101.6	165.5052	5.85	18.53	34.44	0.613878	45.67	20.75	5.86	23.77	42.65	32.1	30.4	1
32	2.5	25.8	55.38325	7.26	9.07	45.14	0.465845	35.09	15.66	7.23	23.88	32.29	42.77	76.6	1
33	8	192.4	236.7564	9.47	33.65	33.79	0.81265	40.91	21.3	12.1	23.93	39.57	34.83	31.9	1
34	3.8	42.9	100.9028	5.07	7.86	37.66	0.425162	38.07	22.54	9.42	9.32	40.68	37.47	23.9	1
35	13.2	155.7	304.2176	10.49	22.56	43.39	0.511805	45.14	23.15	9.71	6.51	39.37	40.9	18.2	1
36	2.6	43.3	75.4498	5.1	12.9	34.46	0.573892	48.39	22.1	5.78	15.73	45.35	36.37	21.7	1
37	6.2	77.1	162.0915	6.13	11.69	38.25	0.475657	37.12	16.53	8.7	14.72	39.1	35.69	16.2	1
38	15.8	246.9	365.4024	9.48	29.43	43.24	0.675693	41.02	25.02	12.52	14.32	39.07	43.68	4.2	0
39	7.2	128.6	169.2923	7.08	21.96	42.53	0.759633	36.61	19.14	13.35	14.82	35.88	42.85	24.2	1
40	8.8	156.3	228.3935	9.53	25.19	38.53	0.684345	41.76	21.71	11.64	5.83	35.43	40.1	2.3	0
41	2.7	34.1	78.17024	8.16	5.1	34.54	0.436227	47	15.99	10.57	20.2	38.16	34.73	78	1
42	3.2	37	76.24494	3.85	11.09	41.97	0.485278	48.99	20.32	7.37	13.29	45.67	44.39	26.9	1
43	8.8	201.6	266.1827	10.68	27.6	33.06	0.757375	34.1	25.02	16.03	11.47	33.59	32.4	0	0
44	8.2	164.7	272.4252	8.46	21.96	30.1	0.60457	35.73	24.99	7.98	9.05	34.16	32.38	1.4	0
45	1.7	19.6	51.17399	3.57	5.57	33.22	0.383007	45.2	12.76	8.23	999	38.86	29.2	55.5	1

Table 9 CBCT parameters data (2nd measurement)

ID	CBCT												
	Vol	Min Area	Avg Area	AP	Lat	Length	SPL	Uniform	PAS-NL	PAS-BGo	MPH	SPLC	Length C
1	8.4	111.7	255.2416	12.09	23.57	32.91	34.41	0.437625	21.91	10.62	1.48	31.02	33.73
2	8.5	201.3	240.4526	12.92	22.96	35.35	31.34	0.837171	24.37	16.93	13.01	30.86	30.39
3	3.7	12.9	101.3976	4.44	4.23	36.49	35.41	0.127222	15.51	9.32	999	34.03	33.8
4	14.8	290.8	332.5095	12.69	26.86	44.51	35.42	0.874561	26.14	15.54	999	32.49	44.42
5	20.5	319.5	485.5519	12.33	33.66	42.22	30.02	0.658014	20.84	17.56	16.45	30.8	42.29
6	5.6	13	107.713	2.94	3.79	51.99	63.88	0.120691	20.28	9.22	999	51.4	49.94
7	6.6	127.6	212.6974	7.92	21.04	31.03	41.21	0.599913	25.31	11.8	22.14	37.8	36.12
8	19.9	311.9	428.8793	16.13	32.83	46.4	38.2	0.727244	21.47	15.6	999	31.56	47.72
9	9.1	158.4	214.4204	6.47	27.6	42.44	41.61	0.738736	25.18	9.82	8.58	37.6	40.95
10	8.1	160.2	266.2722	8.27	22.37	30.42	33.6	0.60164	18.36	12.9	14.69	29.47	27.43

Appendix C

SPSS statistics tables

Intra-observer reliability results

- Intraclass correlation coefficient of volume measurements

Intraclass Correlation Coefficient

	Intraclass Correlation[a]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.999[b]	.995	1.000	1335.507	9	9	.000
Average Measures	.999[c]	.997	1.000	1335.507	9	9	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. Type A intraclass correlation coefficients using an absolute agreement definition.

b. The estimator is the same, whether the interaction effect is present or not.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

- Intraclass correlation coefficient of minimum cross-sectional area measurements

Intraclass Correlation Coefficient

	Intraclass Correlation[a]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.987[b]	.952	.997	155.101	9	9	.000
Average Measures	.994[c]	.976	.998	155.101	9	9	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. Type A intraclass correlation coefficients using an absolute agreement definition.

b. The estimator is the same, whether the interaction effect is present or not.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

- Intraclass correlation coefficient of anteroposterior dimension measurements

Intraclass Correlation Coefficient

	Intraclass Correlation[a]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.972[b]	.890	.993	62.797	9	9	.000
Average Measures	.986[c]	.942	.996	62.797	9	9	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. Type A intraclass correlation coefficients using an absolute agreement definition.

b. The estimator is the same, whether the interaction effect is present or not.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

- Intraclass correlation coefficient of lateral dimension measurements

Intraclass Correlation Coefficient

	Intraclass Correlation[a]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.994[b]	.976	.999	300.673	9	9	.000
Average Measures	.997[c]	.988	.999	300.673	9	9	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. Type A intraclass correlation coefficients using an absolute agreement definition.

b. The estimator is the same, whether the interaction effect is present or not.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

- Intraclass correlation coefficient of airway length measurements

Intraclass Correlation Coefficient

	Intraclass Correlation[a]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.975[b]	.907	.994	74.942	9	9	.000
Average Measures	.987[c]	.951	.997	74.942	9	9	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. Type A intraclass correlation coefficients using an absolute agreement definition.

b. The estimator is the same, whether the interaction effect is present or not.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

- Intraclass correlation coefficient of soft palate length measurements

Intraclass Correlation Coefficient

	Intraclass Correlation[a]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.996[b]	.984	.999	478.479	9	9	.000
Average Measures	.998[c]	.992	.999	478.479	9	9	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. Type A intraclass correlation coefficients using an absolute agreement definition.

b. The estimator is the same, whether the interaction effect is present or not.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

- Intraclass correlation coefficient of PAS-NL measurements

Intraclass Correlation Coefficient

	Intraclass Correlation[a]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.911[b]	.699	.977	22.630	9	9	.000
Average Measures	.953[c]	.823	.988	22.630	9	9	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. Type A intraclass correlation coefficients using an absolute agreement definition.

b. The estimator is the same, whether the interaction effect is present or not.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

- Intraclass correlation coefficient of PAS-BGo measurements

Intraclass Correlation Coefficient

	Intraclass Correlation[a]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.973[b]	.897	.993	67.256	9	9	.000
Average Measures	.987[c]	.946	.997	67.256	9	9	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. Type A intraclass correlation coefficients using an absolute agreement definition.

b. The estimator is the same, whether the interaction effect is present or not.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

- Intraclass correlation coefficient of MpH measurements

Intraclass Correlation Coefficient

	Intraclass Correlation[a]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.999[b]	.965	1.000	3582.949	5	5	.000
Average Measures	.999[c]	.982	1.000	3582.949	5	5	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. Type A intraclass correlation coefficients using an absolute agreement definition.

b. The estimator is the same, whether the interaction effect is present or not.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

- Intraclass correlation coefficient of soft palate length (2D) measurements

Intraclass Correlation Coefficient

	Intraclass Correlation[a]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.967[b]	.872	.992	68.045	9	9	.000
Average Measures	.983[c]	.932	.996	68.045	9	9	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. Type A intraclass correlation coefficients using an absolute agreement definition.

b. The estimator is the same, whether the interaction effect is present or not.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

- Intraclass correlation coefficient of airway length (2D) measurements

Intraclass Correlation Coefficient

	Intraclass Correlation[a]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	.964[b]	.870	.991	52.956	9	9	.000
Average Measures	.982[c]	.930	.995	52.956	9	9	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. Type A intraclass correlation coefficients using an absolute agreement definition.

b. The estimator is the same, whether the interaction effect is present or not.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

CBCT parameters

- Normal distribution test of all imaging parameters

Test Statistics[a]

		Volume	Minimum cross-sectional area	Average cross-sectional area	Anteroposterior dimension	Lateral dimension	Length	Uniformity	Soft palate length	PAS-NL	PAS-BGo	Mandibular plane to hyoid distance	Soft palate length in Cephalogram	Length in Cephalogram
Most Extreme Differences	Absolute	.606	.631	.606	.631	.599	.217	.574	.592	.399	.399	.526	.671	.242
	Positive	.606	.631	.606	.631	.599	.217	.574	.000	.399	.399	.000	.000	.242
	Negative	-.032	-.032	.000	.000	.000	-.122	-.058	-.592	-.065	.000	-.526	-.671	-.097
Kolmogorov-Smirnov Z		1.882	1.961	1.882	1.961	1.860	.673	1.782	1.839	1.238	1.238	1.526	2.082	.751
Asymp. Sig. (2-tailed)		.002	.001	.002	.001	.002	.756	.003	.002	.093	.093	.019	.000	.625

a. Grouping Variable: Subject group

- Independent *t* test of parametric imaging parameters

Group Statistics

	Subject group	N	Mean	Std. Deviation	Std. Error Mean
Length	control	14	38.7464	4.49964	1.20258
	case	31	38.8539	4.82173	.86601
PAS-NL	control	14	21.8800	3.34715	.89456
	case	31	19.7955	4.66411	.83770
PAS-BGo	control	14	12.3679	2.99304	.79992
	case	31	9.7187	3.21819	.57800
Length in Cephalogram	control	14	38.0800	4.55963	1.21861
	case	31	37.8810	5.12334	.92018

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Length	Equal variances assumed	.018	.895	-.071	43	.944	-.10744	1.52201	-3.17686	2.96198
	Equal variances not assumed			-.073	26.850	.943	-.10744	1.48195	-3.14894	2.93406
PAS-NL	Equal variances assumed	1.892	.176	1.502	43	.140	2.08452	1.38739	-.71343	4.88246
	Equal variances not assumed			1.701	34.350	.098	2.08452	1.22555	-.40518	4.57421
PAS-BGo	Equal variances assumed	.277	.601	2.610	43	.012	2.64915	1.01490	.60241	4.69589
	Equal variances not assumed			2.684	26.937	.012	2.64915	.98690	.62398	4.67432
Length in Cephalogram	Equal variances assumed	.015	.905	.125	43	.901	.19903	1.59704	-3.02170	3.41976
	Equal variances not assumed			.130	28.093	.897	.19903	1.52701	-2.92843	3.32649

- Wilcoxon rank sum test of non-parametric imaging parameters

Ranks

	Subject group	N	Mean Rank	Sum of Ranks
Volume	control	14	32.75	458.50
	case	31	18.60	576.50
	Total	45		
Minimum cross-sectional area	control	14	33.21	465.00
	case	31	18.39	570.00
	Total	45		
Average cross-sectional area	control	14	33.21	465.00
	case	31	18.39	570.00
	Total	45		
Anteroposterior dimension	control	14	33.43	468.00
	case	31	18.29	567.00
	Total	45		
Lateral dimension	control	14	32.79	459.00
	case	31	18.58	576.00
	Total	45		
Uniformity	control	14	30.57	428.00
	case	31	19.58	607.00
	Total	45		
Soft palate length	control	14	13.64	191.00
	case	31	27.23	844.00
	Total	45		
Mandibular plane to hyoid distance	control	13	11.54	150.00
	case	24	23.04	553.00
	Total	37		
Soft palate length in Cephalogram	control	14	12.57	176.00
	case	31	27.71	859.00
	Total	45		

Test Statistics[b]

	Volume	Minimum cross-sectional area	Average cross-sectional area	Anteroposterior dimension	Lateral dimension	Uniformity	Soft palate length	Mandibular plane to hyoid distance	Soft palate length in Cephalogram
Mann-Whitney U	80.500	74.000	74.000	71.000	80.000	111.000	86.000	59.000	71.000
Wilcoxon W	576.500	570.000	570.000	567.000	576.000	607.000	191.000	150.000	176.000
Z	-3.347	-3.506	-3.506	-3.580	-3.359	-2.599	-3.212	-3.086	-3.580
Asymp. Sig. (2-tailed)	.001	.000	.000	.000	.001	.009	.001	.002	.000
Exact Sig. [2*(1-tailed Sig.)]								.001[a]	

a. Not corrected for ties.

b. Grouping Variable: Subject group

STOP-BANG questionnaire

- Chi-square test for snoring

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	11.414[a]	1	.001		
Continuity Correction[b]	9.254	1	.002		
Likelihood Ratio	11.360	1	.001		
Fisher's Exact Test				.002	.001
Linear-by-Linear Association	11.160	1	.001		
N of Valid Cases	45				

a. 1 cells (25.0%) have expected count less than 5. The minimum expected count is 4.98.

b. Computed only for a 2x2 table

- Chi-square test for tiredness

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	3.357[a]	1	.067		
Continuity Correction[b]	2.281	1	.131		
Likelihood Ratio	3.444	1	.063		
Fisher's Exact Test				.108	.065
Linear-by-Linear Association	3.283	1	.070		
N of Valid Cases	45				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.84.

b. Computed only for a 2x2 table

- Chi-square test for observed apnea

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	7.390[a]	1	.007		
Continuity Correction[b]	5.543	1	.019		
Likelihood Ratio	10.812	1	.001		
Fisher's Exact Test				.009	.005
Linear-by-Linear Association	7.226	1	.007		
N of Valid Cases	45				

a. 1 cells (25.0%) have expected count less than 5. The minimum expected count is 3.73.

b. Computed only for a 2x2 table

- Chi-square test for high blood pressure

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	4.012[a]	1	.045		
Continuity Correction[b]	2.778	1	.096		
Likelihood Ratio	4.406	1	.036		
Fisher's Exact Test				.090	.044
Linear-by-Linear Association	3.923	1	.048		
N of Valid Cases	45				

a. 1 cells (25.0%) have expected count less than 5. The minimum expected count is 4.98.

b. Computed only for a 2x2 table

- Chi-square test for body mass index

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	1.983[a]	1	.159		
Continuity Correction[b]	.710	1	.400		
Likelihood Ratio	3.155	1	.076		
Fisher's Exact Test				.294	.211
Linear-by-Linear Association	1.939	1	.164		
N of Valid Cases	45				

a. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 1.24.

b. Computed only for a 2x2 table

- Chi-square test for age

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	5.201[a]	1	.023		
Continuity Correction[b]	3.833	1	.050		
Likelihood Ratio	5.470	1	.019		
Fisher's Exact Test				.028	.024
Linear-by-Linear Association	5.085	1	.024		
N of Valid Cases	45				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.53.

b. Computed only for a 2x2 table

- Chi-square test for neck circumference

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	.324[a]	1	.569		
Continuity Correction[b]	.003	1	.955		
Likelihood Ratio	.348	1	.555		
Fisher's Exact Test				1.000	.500
Linear-by-Linear Association	.317	1	.574		
N of Valid Cases	45				

a. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 1.56.

b. Computed only for a 2x2 table

- Chi-square test for gender

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	4.994[a]	1	.025		
Continuity Correction[b]	3.633	1	.057		
Likelihood Ratio	4.971	1	.026		
Fisher's Exact Test				.047	.029
Linear-by-Linear Association	4.883	1	.027		
N of Valid Cases	45				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 5.60.

b. Computed only for a 2x2 table

Prediction model

- Stepwise multiple linear regression with collinearity statistics, the first analysis

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Mandibular plane to hyoid distance	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
2	Lateral dimension	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: AHI

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.630[a]	.397	.380	16.21071
2	.751[b]	.563	.538	13.99111

a. Predictors: (Constant), Mandibular plane to hyoid distance

b. Predictors: (Constant), Mandibular plane to hyoid distance, Lateral dimension

ANOVA[c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6048.927	1	6048.927	23.018	.000[a]
	Residual	9197.554	35	262.787		
	Total	15246.481	36			
2	Regression	8590.942	2	4295.471	21.944	.000[b]
	Residual	6655.540	34	195.751		
	Total	15246.481	36			

a. Predictors: (Constant), Mandibular plane to hyoid distance

b. Predictors: (Constant), Mandibular plane to hyoid distance, Lateral dimension

c. Dependent Variable: AHI

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	-8.358	7.026		-1.190	.242		
	Mandibular plane to hyoid distance	2.219	.463	.630	4.798	.000	1.000	1.000
2	(Constant)	19.085	9.735		1.960	.058		
	Mandibular plane to hyoid distance	1.842	.413	.523	4.463	.000	.936	1.069
	Lateral dimension	-1.074	.298	-.422	-3.604	.001	.936	1.069

a. Dependent Variable: AHI

Excluded Variables[c]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics		
						Tolerance	VIF	Minimum Tolerance
1	Snoring	.174[a]	1.158	.255	.195	.756	1.324	.756
	Tiredness	-.052[a]	-.363	.719	-.062	.851	1.175	.851
	Observed apnea	.291[a]	2.159	.038	.347	.858	1.165	.858
	High blood pressure	.049[a]	.366	.717	.063	.982	1.018	.982
	BMI	.249[a]	1.964	.058	.319	.989	1.011	.989
	Age	.007[a]	.052	.959	.009	.853	1.172	.853
	Neck circumference	.135[a]	1.025	.313	.173	.987	1.013	.987
	Gender	.038[a]	.244	.809	.042	.731	1.368	.731
	Volume	-.319[a]	-2.444	.020	-.387	.883	1.132	.883
	Minimum cross-sectional area	-.347[a]	-2.676	.011	-.417	.871	1.148	.871
	Average cross-sectional area	-.346[a]	-2.662	.012	-.415	.870	1.149	.870
	Anteroposterior dimension	-.164[a]	-1.119	.271	-.188	.798	1.253	.798
	Lateral dimension	-.422[a]	-3.604	.001	-.526	.936	1.069	.936
	Length	.013[a]	.095	.925	.016	.998	1.002	.998
	Uniformity	-.175[a]	-1.280	.209	-.214	.905	1.105	.905
	Soft palate length	.134[a]	.934	.357	.158	.845	1.184	.845
	PAS-NL	-.129[a]	-.930	.359	-.158	.903	1.108	.903
	PAS-BGo	-.183[a]	-1.381	.176	-.231	.955	1.047	.955
	Soft palate length in Cephalogram	.048[a]	.327	.746	.056	.816	1.225	.816
	Length in Cephalogram	-.069[a]	-.519	.607	-.089	.984	1.016	.984
2	Snoring	-.005[b]	-.033	.974	-.006	.647	1.546	.647

Tiredness	-.200[b]	-1.592	.121	-.267	.777	1.287	.777
Observed apnea	.207[b]	1.701	.098	.284	.820	1.219	.820
High blood pressure	-.070[b]	-.579	.566	-.100	.908	1.101	.865
BMI	.199[b]	1.782	.084	.296	.971	1.029	.919
Age	.023[b]	.188	.852	.033	.852	1.173	.801
Neck circumference	-.009[b]	-.071	.944	-.012	.868	1.152	.822
Gender	.075[b]	.556	.582	.096	.727	1.376	.683
Volume	.031[b]	.162	.872	.028	.367	2.726	.367
Minimum cross-sectional area	.122[b]	.502	.619	.087	.221	4.535	.221
Average cross-sectional area	.005[b]	.024	.981	.004	.321	3.111	.321
Anteroposterior dimension	.125[b]	.819	.418	.141	.557	1.795	.557
Length	.021[b]	.184	.855	.032	.998	1.002	.934
Uniformity	.228[b]	1.410	.168	.238	.477	2.096	.477
Soft palate length	.017[b]	.134	.894	.023	.786	1.273	.786
PAS-NL	.051[b]	.388	.701	.067	.758	1.318	.758
PAS-BGo	.014[b]	.102	.919	.018	.749	1.334	.734
Soft palate length in Cephalogram	-.094[b]	-.711	.482	-.123	.745	1.343	.745
Length in Cephalogram	-.117[b]	-1.016	.317	-.174	.972	1.029	.924

a. Predictors in the Model: (Constant), Mandibular plane to hyoid distance

b. Predictors in the Model: (Constant), Mandibular plane to hyoid distance, Lateral dimension

c. Dependent Variable: AHI

Collinearity Diagnostics[a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions		
				(Constant)	Mandibular plane to hyoid distance	Lateral dimension
1	1	1.925	1.000	.04	.04	
	2	.075	5.076	.96	.96	
2	1	2.791	1.000	.01	.02	.01
	2	.172	4.029	.00	.41	.34
	3	.037	8.741	.99	.58	.65

a. Dependent Variable: AHI

- Enter multiple linear regression with collinearity statistics, the second analysis

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	Mandibular plane to hyoid distance, BMI, Lateral dimension, Age, Gender[a]	.	Enter

a. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.787[a]	.619	.558	13.68113

a. Predictors: (Constant), Mandibular plane to hyoid distance, BMI, Lateral dimension, Age, Gender

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	9444.108	5	1888.822	10.091	.000[a]
	Residual	5802.373	31	187.173		
	Total	15246.481	36			

a. Predictors: (Constant), Mandibular plane to hyoid distance, BMI, Lateral dimension, Age, Gender

b. Dependent Variable: AHI

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	Collinearity Statistics Tolerance	Collinearity Statistics VIF
1	(Constant)	17.551	9.585		1.831	.077		
	BMI	17.905	8.761	.241	2.044	.050	.885	1.130
	Age	2.533	4.945	.062	.512	.612	.833	1.201
	Gender	6.371	5.666	.152	1.124	.269	.670	1.493
	Lateral dimension	-1.023	.294	-.402	-3.473	.002	.917	1.090
	Mandibular plane to hyoid distance	1.407	.520	.399	2.707	.011	.564	1.774

a. Dependent Variable: AHI

Collinearity Diagnostics[a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions (Constant)	BMI	Age	Gender	Lateral dimension	Mandibular plane to hyoid distance
1	1	4.163	1.000	.00	.00	.02	.01	.01	.00
	2	.951	2.092	.00	.81	.01	.01	.00	.00
	3	.448	3.047	.01	.01	.79	.03	.03	.00
	4	.307	3.685	.01	.03	.01	.46	.12	.01
	5	.096	6.580	.04	.15	.15	.43	.25	.43
	6	.034	11.002	.94	.00	.02	.05	.59	.56

a. Dependent Variable: AHI

- Enter multiple linear regression with collinearity statistics, the third analysis

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	Lateral dimension, Age, BMI, Gender[a]	.	Enter

a. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.742[a]	.551	.506	18.29254

a. Predictors: (Constant), Lateral dimension, Age, BMI, Gender

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	16414.395	4	4103.599	12.264	.000[a]
	Residual	13384.677	40	334.617		
	Total	29799.072	44			

a. Predictors: (Constant), Lateral dimension, Age, BMI, Gender

b. Dependent Variable: AHI

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	42.182	9.123		4.624	.000		
	BMI	39.530	10.041	.437	3.937	.000	.911	1.098
	Age	5.858	5.545	.114	1.057	.297	.972	1.029
	Gender	12.807	5.912	.244	2.166	.036	.886	1.128
	Lateral dimension	-1.469	.330	-.490	-4.452	.000	.928	1.077

a. Dependent Variable: AHI

Collinearity Diagnostics[a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions				
				(Constant)	BMI	Age	Gender	Lateral dimension
1	1	3.198	1.000	.01	.01	.03	.02	.01
	2	.968	1.818	.00	.79	.02	.02	.00
	3	.433	2.718	.01	.02	.90	.13	.02
	4	.344	3.051	.01	.08	.02	.56	.16
	5	.058	7.447	.97	.11	.03	.28	.81

a. Dependent Variable: AHI

- Enter multiple linear regression with collinearity statistics, the fourth analysis

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	Lateral dimension, Age, BMI, Gender[a]	.	Enter

a. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.742[a]	.551	.506	18.29254

a. Predictors: (Constant), Lateral dimension, Age, BMI, Gender

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	16414.395	4	4103.599	12.264	.000[a]
	Residual	13384.677	40	334.617		
	Total	29799.072	44			

a. Predictors: (Constant), Lateral dimension, Age, BMI, Gender

b. Dependent Variable: AHI

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	42.182	9.123		4.624	.000		
	BMI	39.530	10.041	.437	3.937	.000	.911	1.098
	Age	5.858	5.545	.114	1.057	.297	.972	1.029
	Gender	12.807	5.912	.244	2.166	.036	.886	1.128
	Lateral dimension	-1.469	.330	-.490	-4.452	.000	.928	1.077

a. Dependent Variable: AHI

Collinearity Diagnostics[a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions				
				(Constant)	BMI	Age	Gender	Lateral dimension
1	1	3.198	1.000	.01	.01	.03	.02	.01
	2	.968	1.818	.00	.79	.02	.02	.00
	3	.433	2.718	.01	.02	.90	.13	.02
	4	.344	3.051	.01	.08	.02	.56	.16
	5	.058	7.447	.97	.11	.03	.28	.81

a. Dependent Variable: AHI

- Enter multiple linear regression with collinearity statistics, the fifth analysis

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	STOP-Bang score, Lateral dimension, Mandibular plane to hyoid distance[a]	.	Enter

a. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.752[a]	.565	.526	14.17191

a. Predictors: (Constant), STOP-Bang score, Lateral dimension, Mandibular plane to hyoid distance

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	8618.657	3	2872.886	14.304	.000[a]
	Residual	6627.824	33	200.843		
	Total	15246.481	36			

a. Predictors: (Constant), STOP-Bang score, Lateral dimension, Mandibular plane to hyoid distance

b. Dependent Variable: AHI

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	Collinearity Statistics Tolerance	Collinearity Statistics VIF
1	(Constant)	17.594	10.646		1.653	.108		
	Mandibular plane to hyoid distance	1.710	.549	.485	3.116	.004	.543	1.842
	Lateral dimension	-1.018	.338	-.400	-3.012	.005	.747	1.339
	STOP-Bang score	.763	2.054	.064	.371	.713	.440	2.274

a. Dependent Variable: AHI

Collinearity Diagnostics[a]

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions (Constant)	Variance Proportions Mandibular plane to hyoid distance	Variance Proportions Lateral dimension	Variance Proportions STOP-Bang score
1	1	3.593	1.000	.00	.01	.01	.01
	2	.321	3.347	.01	.02	.14	.15
	3	.054	8.155	.03	.97	.03	.60
	4	.033	10.502	.96	.01	.82	.25

a. Dependent Variable: AHI

Biography

Mr. Pongsatorn Kangvansurakit was born on 2nd February 1985. He graduated his Doctor of Dental Surgery from Chulalongkorn University in 2008. After graduation, he worked at Sirindhorn College of Public Health Suphanburi as a general practitioner and lecturer for 2 years. In 2011, he started his Master degree at Chulalongkorn University in Department of Radiology and continued ever since.