

**SLEEP POSITIONS ON AIRFLOW RESISTANCE
DURING WAKEFULNESS IN HEALTHY THAI MALES**



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Thesis
Entitled

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SLEEP POSITIONS ON AIRFLOW RESISTANCE DURING WAKEFULNESS IN HEALTHY THAI MALES

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ABSTRACT

There is a remarkable increasing trend of airway obstruction, or sleep apnea syndrome (SAS) among the Thai population. Positional therapy, a non-invasive method is routinely used in mild obstructive sleep apnea (OSA). Therefore, body position seems to play a significant role in the treatment. To examine the effect of position on airflow resistance during wakefulness condition, thirty Thai healthy males, aged between 18-24 years, were recruited in this study. Respiratory parameters including airway pressure, airflow rate and airflow resistance during quiet inspiratory and expiratory phases using transient interruption technique (R_{int}) and peak expiratory flow (PEF) were measured in four randomized positions (reclining 30^0 , supine, left and right side lying).

The result showed that airway pressure, airflow and airflow resistance had significant difference among positions ($p < 0.05$) but no significant difference between two side-lying positions ($p > 0.05$). Inspiratory airflow resistances showed the highest value in supine ($9.878 \pm 1.315 \text{ cmH}_2\text{O/L.s}^{-1}$), and lowest in reclining 30^0 ($7.340 \pm 0.850 \text{ cmH}_2\text{O/L.s}^{-1}$). Either left or right side lying caused no difference in airflow resistance (8.241 ± 1.202 vs. $8.364 \pm 1.341 \text{ cmH}_2\text{O/L.s}^{-1}$ in left vs. right side lying). Expiratory airflow resistance was the lowest in the reclining position ($5.618 \pm 0.623 \text{ cmH}_2\text{O/L.s}^{-1}$); whereas, supine position had the highest resistance ($7.397 \pm 0.996 \text{ cmH}_2\text{O/L.s}^{-1}$). Either left or right side lying caused no difference in airflow resistance (6.255 ± 0.753 vs. $6.241 \pm 0.799 \text{ cmH}_2\text{O/L.s}^{-1}$ in left vs. right side lying). PEF was significantly different among positions ($p < 0.05$) but no significant difference between two side-lying positions was shown ($p > 0.05$).

This study provides beneficial information for positional therapy; sleep positions influence airflow resistance during awake conditions in young males. The airway showed the highest patency in reclining 30^0 and side lying tended to be higher than supine position. Consequently, this simple intervention might be useful in treatment of sleep disorders. It could be used in possible clinical-based and home-based interventions.

KEY WORDS: OBSTRUCTIVE SLEEP APNEA/ SLEEP POSITIONS/
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ทำนองต่อความต้านทานของการไหลเวียนของอากาศในทางเดินหายใจขณะตื่นในชายไทยสุขภาพดี
(SLEEP POSITIONS ON AIRFLOW RESISTANCE DURING WAKEFULNESS IN HEALTHY THAI MALES)

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บทคัดย่อ

อุบัติการณ์การเกิดภาวะหยุดหายใจชั่วคราวขณะนอนหลับในประชากรไทยมีแนวโน้มเพิ่มมากขึ้น การรักษาด้วยการจัดท่าอนึ่งซึ่งเป็นวิธีแพร่หลายที่มักใช้รักษาผู้ป่วยที่มีภาวะอุดกั้นของทางเดินหายใจขณะนอนหลับในระดับที่ไม่รุนแรง ดังนั้นจึงจะเห็นได้ว่าท่าอนึ่งมีบทบาทสำคัญต่อการรักษา ดังนั้นการศึกษานี้มีจุดประสงค์เพื่อศึกษาผลของท่าอนึ่งต่อความต้านทานของการไหลเวียนของอากาศในทางเดินหายใจขณะตื่นในชายไทยสุขภาพดีอายุระหว่าง 18-24 ปีจำนวน 30 คน ตัวแปรในการศึกษาได้แก่ ความดันอากาศ อัตราการไหลของอากาศ ความต้านทานของการไหลเวียนของอากาศทั้งขณะหายใจเข้าและหายใจออกด้วยเทคนิค Transient interruption และอัตราการไหลของอากาศสูงสุดขณะหายใจออก โดยวัดอย่างสุ่มใน 4 ท่าได้แก่ ท่านั่งเอนหลัง 30 องศา ท่าอนึ่งหงาย ท่าอนึ่งตะแคงซ้ายและขวา

ผลการศึกษานี้แสดงว่าความดันอากาศ อัตราการไหลของอากาศ และความต้านทานของการไหลเวียนของอากาศมีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติในแต่ละท่า ($p < 0.05$) ยกเว้นในท่าอนึ่งตะแคงซ้ายและขวา ($p > 0.05$) ความต้านทานของการไหลเวียนของอากาศในขณะหายใจเข้ามีค่าสูงสุดในท่าอนึ่งหงาย ($9.878 \pm 1.315 \text{ cmH}_2\text{O/L.s}^{-1}$) ต่ำสุดในท่าอนึ่งเอนหลัง 30 องศา ($7.340 \pm 0.850 \text{ cmH}_2\text{O/L.s}^{-1}$) และไม่แตกต่างกันในท่าอนึ่งตะแคงซ้ายและขวา ($8.241 \pm 1.202, 8.364 \pm 1.341 \text{ cmH}_2\text{O/L.s}^{-1}$ ในท่าอนึ่งตะแคงซ้ายและขวา ตามลำดับ) ความต้านทานของการไหลเวียนของอากาศในขณะหายใจออกเป็นไปเช่นเดียวกันโดยมีค่าต่ำสุดในท่าอนึ่งเอนหลัง ($5.618 \pm 0.623 \text{ cmH}_2\text{O/L.s}^{-1}$) สูงสุดในท่าอนึ่งหงาย ($7.397 \pm 0.996 \text{ cmH}_2\text{O/L.s}^{-1}$) และไม่แตกต่างกันในท่าอนึ่งตะแคงซ้ายและขวา ($6.255 \pm 0.753, 6.241 \pm 0.799 \text{ cmH}_2\text{O/L.s}^{-1}$ ในท่าอนึ่งตะแคงซ้ายและขวา ตามลำดับ) อัตราการไหลของอากาศสูงสุดขณะหายใจออกมีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติในแต่ละท่า ($p < 0.05$) ยกเว้นในท่าอนึ่งตะแคงซ้ายและขวา ($p > 0.05$)

การศึกษานี้ให้ข้อมูลที่เป็ประโยชน์ต่อการรักษาด้วยการจัดท่าอนึ่ง ซึ่งท่าอนึ่งมีผลต่อความต้านทานการไหลเวียนของอากาศขณะตื่นในชายไทยอายุน้อย โดยทางเดินหายใจเปิดโล่งมากที่สุด ในท่าอนึ่งเอนหลัง และท่าอนึ่งตะแคงมีแนวโน้มที่จะเปิดโล่งมากกว่าท่าอนึ่งหงาย ดังนั้นจึงเป็นการรักษาแบบง่ายสำหรับโรคที่เกี่ยวข้องกับการนอน โดยสามารถแนะนำเป็นการรักษาพื้นฐานทั้งที่คลินิกและที่บ้าน

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LIST OF ABBREVIATIONS

SAS	=	Sleep apnea syndrome
OSA	=	Obstructive sleep apnea
COPD	=	Chronic obstructive pulmonary disease
AHI	=	Apnea-hypopnea index
NCPAP	=	Nasal continuous positive airway pressure
CSA	=	Cross-sectional area
UAR	=	Upper airway resistance
BMI	=	Body mass index
W/H	=	Waist to hip ratio
BF	=	Body fat
D_b	=	Body density
ATS	=	American Thoracic Society
FVC	=	Force vital capacity
FEV_1	=	Force expiratory volume in one second
PEF	=	Peak expiratory flow
FRC	=	Functional residual capacity
BTPS	=	Body temperature and pressure saturated with water vapor
R_{aw}	=	Airway resistance
P_{crit}	=	Critical pressure
P_{alv}	=	Alveolar pressure
P_{atm}	=	Atmospheric pressure
P_{mo}	=	Mouth pressure
P_n	=	Nasal pressure
V_T	=	Tidal volume
\dot{V}_E	=	Minute ventilation
EFL	=	Expiratory flow limitation

CHAPTER I

INTRODUCTION

It is indicated that there is a remarkable increasing trend of airway obstruction, or sleep apnea syndrome (SAS) among the Thai population. In 1999, there was about 65.5% of suspected cases had been identified as obstructive sleep apnea at Ramathibodi Hospital (1). Sleep apnea syndrome is commonly divided, which based on the presence and absence of respiratory effort, into obstructive and central types. It is generally known that obstructive sleep apnea (OSA) is more common than central types (2, 3). As the numbers of people who are subjected to this syndrome become a serious health-related problem, various treatments have been proposed including new drugs, laser surgery and psychological interventions (4). As the results of such treatments, the medical expenses have been dramatically augmented. Airway obstruction is concurrently taken place with increasing in airway resistance and decreasing in respiratory flow (5, 6). These physiologic variables have been used as indicators for OSA. Some studies found that the non-invasive technique, for example adjusting the sleeping position, subjectively diminished incidence of airway obstruction (7-11). Thus, the present study will be focused on the quantitative approach on the possible effects of different body positions on the occurrence of respiratory resistance in healthy adults. Therefore, outcomes of this study might possibly raise the guideline toward the application to OSA patients as part of rehabilitation regimen.

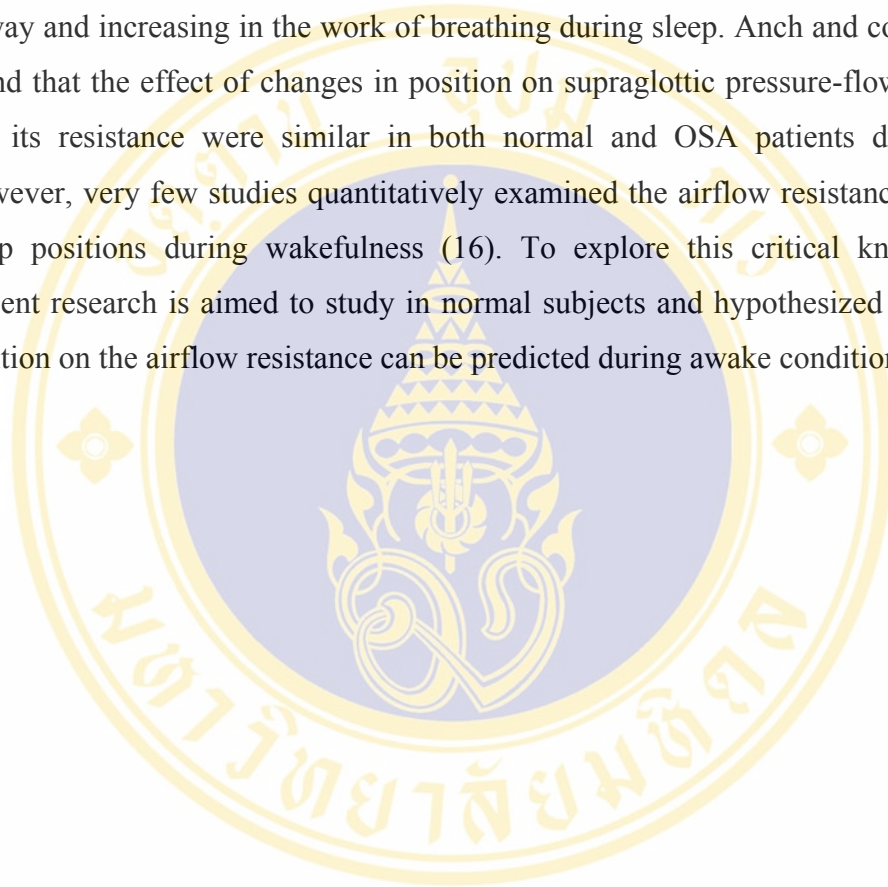
Obstructive sleep apnea (OSA) is characterized by repetitive obstruction of upper airway during sleep, caused intermittent cessation of breathing (apneas, cessation of respiratory airflow for more than 10 seconds) or reductions in airflow (hypopneas, at least 30% reduction in airflow for 10 seconds) despite continuing high

respiratory effort (2, 4, 12). Obstructive sleep apnea can be subjectively diagnosed on the basis of history characteristic including nocturnal snoring and excessive daytime sleepiness (12). Snoring is the primary stage that develops to obstructive sleep apnea afterwards (13). Untreated sleep apnea leads to stress, irritability, increasing in accidents and cardiovascular disease, reduction in functional capacity and quality of life, including increased mortality. Previously, risk factors for OSA had been identified including obesity ($\text{BMI} > 30 \text{ kg/m}^2$), male and advancing age. The other risk factors that could induce OSA are alcohol ingestion, smoking, postmenopausal status and family history (2, 12).

Mechanical changes of structures inside the nasal and oropharyngeal cavities are thought to be responsible for OSA. Many investigators demonstrated the effect of body positions on occurrence of respiratory events during sleep in adult OSA in that the frequency and duration of obstructive apnea became worse in the supine position (7-9). Studies derived from Jan (14) and Martin (15) showed that upper airway cross-sectional area became narrow in supine lying, so did the airway resistance increase when compared with the sitting (16); however, no difference between the supine and lateral position (side lying) was detected. Some studies found that the number of obstructive events during sleep was higher in the supine position than in the lateral position in patients with OSA (8, 10, 11). Thus, body position seems to play a significant role in the severity of OSA. Positional therapy, a non-invasive method routinely used in rehabilitation program, was lately proved to offer some remarkable benefit to prolonged bed rest patients (4, 12). This technique, when applied to OSA patients, was helpful in combination with continuous positive airway pressure (CPAP) therapy (4, 12). As to the present knowledge, positioning alone has never been proven on its benefit to OSA patients.

Mechanism of airway obstruction during sleep is the result from one major physiologic change: an increasing in the airway resistance, which causes a difficulty in breathing during sleep. Airway resistance (R_{aw}) is defined as the ratio of driving pressure (ΔP) to flow (\dot{V}). Previous reports (17-19) described the pressure-flow relationship of upper airway and its resistance during sleep. The mechanical narrowing

of the upper airway is related to changing in pressure from the collapsible segment. As a result, this occlusion increases airway resistance. Moreover, this resistance was found to correlate with the difference of anatomical characteristics in upper airway passage in OSA patients, snorers and normal subjects (20) and probably related to a decrease in upper airway muscle tone (21). This would lead to a narrowing of upper airway and increasing in the work of breathing during sleep. Anch and coworkers (22) found that the effect of changes in position on supraglottic pressure-flow relationship and its resistance were similar in both normal and OSA patients during awake. However, very few studies quantitatively examined the airflow resistance in different sleep positions during wakefulness (16). To explore this critical knowledge, the present research is aimed to study in normal subjects and hypothesized that effect of position on the airflow resistance can be predicted during awake condition.



Purposes of the Study

General Objective

The purpose of this study was to examine the effect of position on airflow resistances in healthy Thai males during wakefulness condition.

Specific Objectives

1. To quantitate airflow resistances that results from different positions on airway pressure and airflow during normal inspiration and expiration.
2. To examine the effect of position on airway pressures during normal inspiration and expiration.
3. To examine the effect of position on airflows during normal inspiration and expiration.
4. To examine the effect of position on peak expiratory flows.

Parameters of the Study

1. Airway pressure (P, cmH₂O)
2. Airflow (\dot{V} , liter/second)
3. Airflow resistance (R_{int} , cmH₂O/L.s⁻¹): Calculated from ratio of pressure to inspiratory and expiratory flows, used transient interruption technique

$$R_{int} = P / \dot{V}$$

4. Peak expiratory flow (PEF, liter/minute)

Scope of the Study

In order to avoid the effect of gender and ethnic differences on airway structure and function, this study was focused on examining the effect of position in healthy Thai males, aged between 18 and 24 years. The measurements were performed during wakefulness state. In addition, only the university students were recruited for the study to ensure the understanding of this specific respiratory maneuver.

Hypotheses of the Study

1. Airflow resistances, both normal inspiration and expiration, are modified significantly from different positions.
2. There is a significant effect of position on airway pressures during normal inspiration and expiration.
3. Position exerts a significant effect on airflows during normal inspiration and expiration.
4. There is a significant effect of position on peak expiratory flows.

Advantages of the Study

1. To understand basic knowledge of changing in position that leads to alterations of airflow resistance.
2. To recommend the sleep position in patient with mild OSA to prevent apnea/hypopnea during sleep.
3. To use the knowledge to develop some guideline for prospective study in patients with other disease-related airway obstruction such as chronic obstructive pulmonary disease (COPD) combined with upper airway obstruction.

CHAPTER II

LITERATURE REVIEW

2.1 Definition of Obstructive Sleep Apnea

Obstructive sleep apnea (OSA) is characterized by intermittent repetitive narrowing of the upper airway during sleep (2, 12, 13). This leads to either complete or partial obstruction of the upper airway, causing intermittent involuntarily cessation of breathing (apneas), reductions in airflow (hypopneas) or both despite the continuing respiratory effort. This results in arousals from sleep and oxygen desaturations. In adults, a complete obstruction or apnea is defined as cessation of airflow at least 10 seconds whereas a partial obstruction or hypopnea is usually defined as at least 30% reduction in airflow for 10 seconds (2, 4, 12).

Untreated sleep apnea not only leads to reduce working and functional capacity and undermines the quality of life but also exerts high incidence of mortality, the number of accidents and incidence of cardiovascular disease (2, 4, 12).

2.2 Anatomy of the Upper Airway

The upper airway is a tube from the nose down to the vocal folds but the collapsible segment involves from the nasopharynx to epiglottis where there is no rigid support (Figure 2.1). The upper airway is divided into the upper and lower portions, both are generally considered as the extrathoracic structure. The lower portion contains a cartilage framework that makes it a semirigid tube which is likely uncollapsible. Whereas the upper portion is the cartilage-free structure which makes it a collapsible part. Abnormal anatomic structure of the upper airway is the most important problem in patients with OSA (13). Anatomic narrowing contributes to upper airway collapsibility (23) where the reverse transmural pressure, pressure gradient across the tube, takes place. The major functions of the upper airway are to

conduct the air into the lung, swallow and speech. Maintaining of upper airway patency depends on the tone of three primary dilator muscles, including the tensor palatine (the muscles controlling palatal position), the genioglossus muscle (an important dilator muscle of tongue protrusion) and the hyoid muscles (13, 24) (Figure 2.1). Additionally, adipose and connective tissues surrounding this airway must be concerned. Fat deposition likely exerts a positive pressure outside the airway which will likely compress into the airspace that makes a reduction of the airway's dimension (2, 13). The site of upper airway obstruction varies among patients, mostly appears in oronasopharynx at the palatal level, the orohypopharynx at the base of tongue level and the laryngopharynx at the epiglottic level (13, 25).

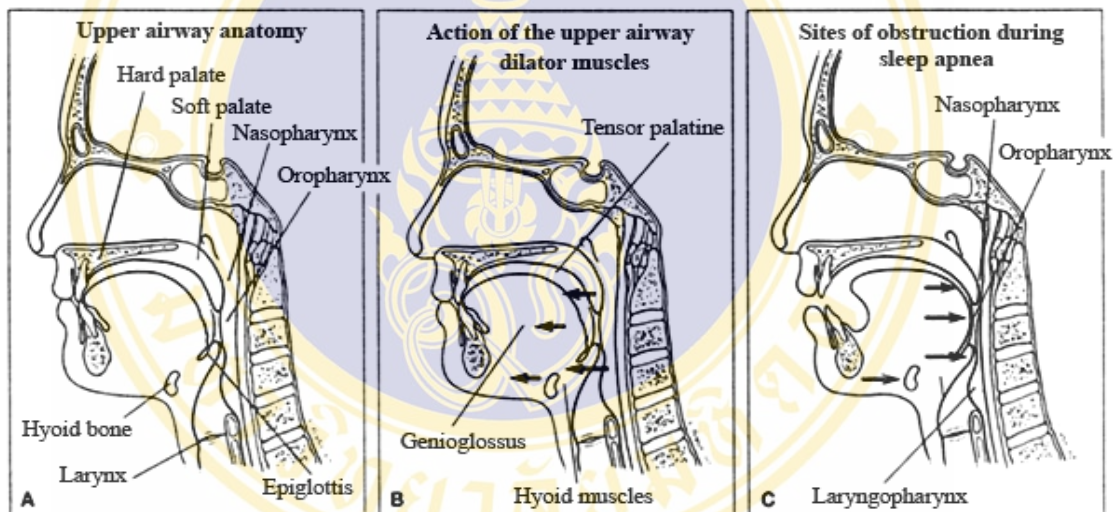


Figure 2.1 Anatomy of the upper airway (A), the dilator muscles of upper airway (B) and the sites of obstruction in Obstructive sleep apnea (C) (13).

On the basic knowledge, flow is steady within the same cross sectional tube. In a tube which is compressed by pressure outside the airway as the pathways of airflow are narrowed, this will result in an unsteady flow. The compliance of the airway tube composes of three concepts involved (13). First is the Bernoulli's principle, similar to fluid flow, a negative pressure occurs at the periphery of the flow and as the flow velocity increases, so does a negative pressure. When the inspiration is faster, a negative pressure and the force of collapse will be also greater, is like a sucking through a straw. The second is the Venturi effect, when fluid flows through a

decreased cross-sectional area, the flow velocity will increase. And the last concept involves the variable resistor. As the flow increases, so does the flow resistance. Therefore, the upper airway obstruction during inspiration and the occurrence of airflow resistance through a collapsible portion can be explained from these three concepts.

2.3 Pathophysiologic Cycle of Obstructive Sleep Apnea

Inspiration is like a negative pressure reflex that activates the upper airway dilator muscles contraction to resist the airway closure. During wakefulness, the continual neuromuscular activation of these muscles is able to maintain the airway patency but the ability of its to respond a negative pressure decreases during sleep because of involuntary muscles relaxation (2, 12, 13, 26). These result in the loss of patency so the upper airway during sleep is likely collapsed easier than in the awaken state. Previous studies found that electrical stimulation of the dilator muscles could increase respiratory airflow and decrease a critical pressure and pharyngeal resistance (27, 28).

At sleep onset, dilator muscles relax. The behaviour of the relaxed muscles depends on the transmural pressure, pressure inside minus pressure outside the lumen. With decreasing in this pressure gradient, airway tends to be narrowed or even collapsed. This results in an increase upper airway resistance and produces apnea or hypopnea. Reduction in airflow gradually develops hypercapnia and hypoxia, which negatively affected the physiologic function. As part of homeostatic readjustment, respiratory effort progressively increases in response to such stimuli and triggers an arousal. Arousal from sleep aggravates the muscle tone that leads to airway opening and restores breathing. Cycle of obstruction will occur again at sleep onset as show in Figure 2.2.

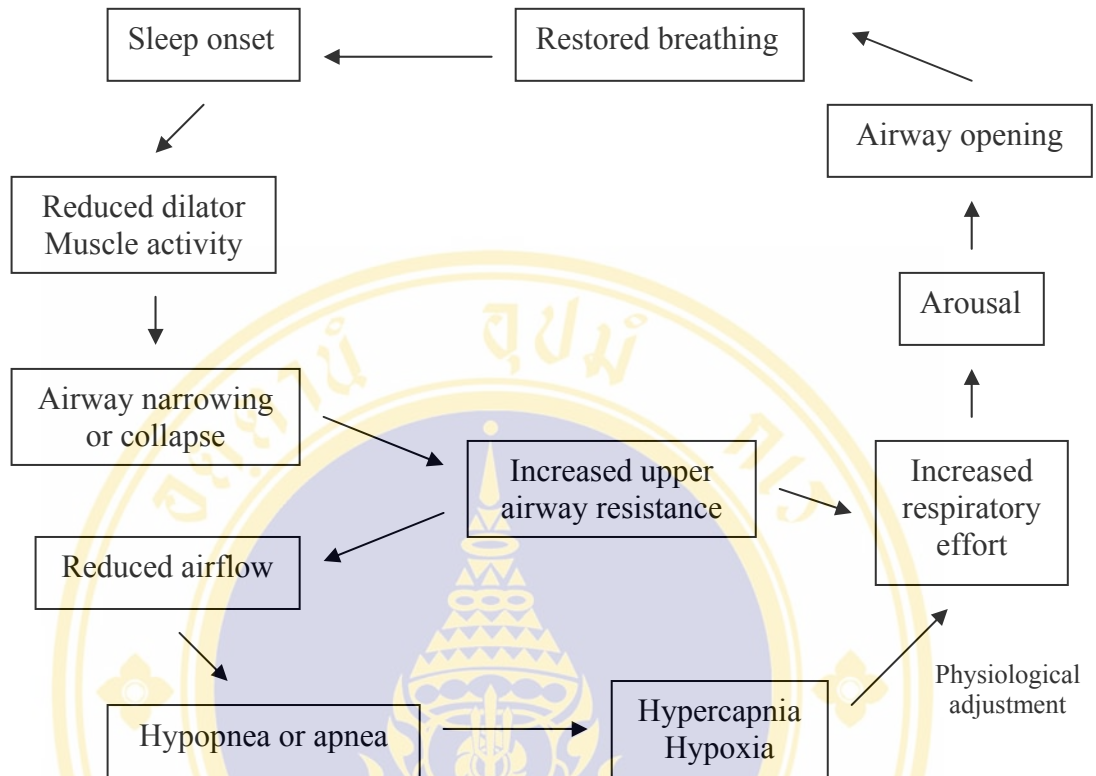


Figure 2.2 The recurrent pathophysiological consequence of Obstructive sleep apnea (12).

In normal population, slight upper airway narrowing was observed at sleep onset. The narrowing airway produced inspiratory flow limitation, then snoring was generated, and finally there was complete collapsed which produced a full apnea (29) (Figure 2.3).

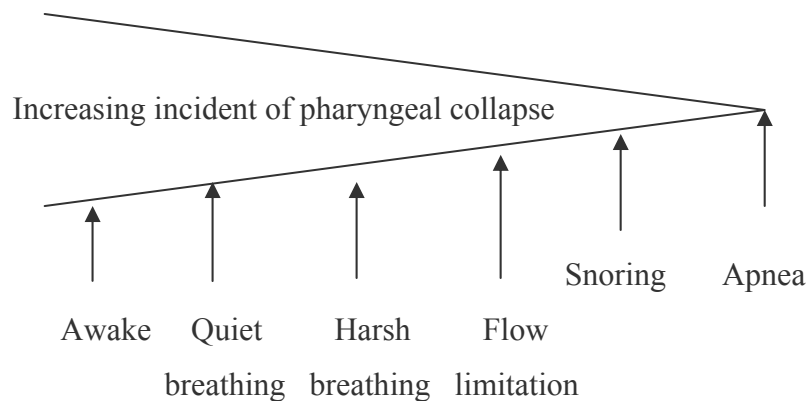


Figure 2.3 Progression of upper airway narrowing (30).

2.4 Severity of Obstructive Sleep Apnea

Severity of OSA is measured as the apnea-hypopnea index (AHI) that shows the number of events in which apnea or hypopnea has been detected during one hour of sleep. The presences of AHI at least 5 events per hour during sleep are called OSA. OSA is usually divided into 3 levels according to its severity (4).

Mild sleep apnea	AHI	5-15	events/hour
Moderate sleep apnea	AHI	16-30	events/hour
Severe sleep apnea	AHI	>30	events/hour

2.5 Common Signs and Symptoms of Obstructive Sleep Apnea

The symptoms of OSA can be divided into nocturnal and daytime symptoms. Daytime symptoms are usually the result of sleep fragmentation (12). Snoring may be the first sign that associated with OSA (4).

2.5.1 Nocturnal symptoms include:

- Snoring
- Witnessed apneas
- Nocturnal gasping
- Nocturnal choking
- Dyspnea
- Sleep fragmentation

2.5.2 Daytime symptoms include:

- Excessive daytime sleepiness
- Daytime fatigue
- Morning headaches
- Impaired memory and concentration
- Personality changes; irritability, aggressiveness, depression, anxiety

2.6 Factors Enhancing Obstructive Sleep Apnea

2.6.1 Obesity

Obesity is a significant risk factor for OSA (2, 4, 12, 31). An increasing in body weight (BMI>30 kg/m²) can be presented 70% of patients with this disorder

(2), in which the underlying mechanism are still unclear. However, increasing weight probably caused deposition of fat around the pharynx (32) and increasing the mass in pharyngeal tissues that resulted in airway compression (33).

2.6.2 Gender

Gender difference is also a risk factor for OSA. Many studies found that OSA is more common in males than females (2-4, 12, 31, 34). The male:female ratio for a prevalence was approximately 3:1 (35). In 2003, Mohsenin Vahid demonstrated that females had less collapsible airways than males due to the difference in tissues linkage which was more stable and less mobile of the upper airway structures (34).

2.6.3 Age

The prevalence of OSA tend to increase with age (2, 4, 12, 31, 36) with its maximum prevalence in the middle age group (45 to 64 years) where the peak was approximately at age 55 years (36). In 1997, Martin and coworkers showed that upper airway size decreased with increasing age in normal subjects (31). This might cause by an impaired of upper airway dilating muscle activity with age. Additionally, it was indicated the evident of age related to increase in pharyngeal resistance in male (37).

2.6.4 Alcohol consumption

Alcohol consumption have influence to reduction of upper airway dilator muscles activity (2, 38) due to the functional impairment of central nervous system (4).

2.6.5 Smoking

Smoking reduced the effectiveness of respiratory system due to airway inflammation, airway edema or both (2, 4) and increased the production of mucus which caused airway narrowing (39). Additionally, carbonmonoxide in cigarette that stored in blood results in diminished nocturnal oxygenation (4).

2.7 Treatments of Obstructive Sleep Apnea

The treatment of OSA is aimed to control the complications of the disease such as respiratory failure rather than the respiratory disturbance itself (40).

2.7.1 Life style modification

Risk factors for OSA should be modified (12). Weight reduction is primary treatment for obese patients with sleep apnea. The target weight to reduce does not need to be within the normal weight range, expected loss of 5-10%. And the next step is weight control which need to be a long-term protocol (4). However, the other risk factors should be considered to be modified. This includes stopping cigarette and alcohol consumption.

2.7.2 Positional therapy

Positional therapy can be applied in OSA patients or in combination with ventilator (CPAP: continuous positive airway pressure). This therapy consists of placing patients sleep in side lying or head up position. Patients who responded to this therapy are mild OSA or nonobesity (2, 4, 12). This treatment has considerably low cost. Various investigations showed the effectiveness of this therapy and will be presented in effect of sleep position on abnormal respiratory condition (see below).

2.7.3 Nasal Continuous Positive Airway Pressure (NCPAP) therapy

NCPAP treatment remains the selected choice for OSA, it becomes the most effective and widely used treatment. It is treated by providing air under positive pressure through a nasal or face mask to prevent collapse of the upper airway (12). The pressures vary between 5-15 cmH₂O and seem to depend on degree of obesity and severity of apnea (30). It should be used at least 5 nights per week, 3-4 hours per night to be an effective treatment (4).

2.7.4 Oral devices

There are various devices influencing the position of the mandible and tongue. These devices will support the protrusion of the mandible or prevent retraction of the tongue to increase a space in posterior pharyngeal area. The devices might solve

for patients with snoring or mild to moderate sleep apnea but should not be used for patients with temporomandibular joint problem (12).

2.7.5 Medication

Several medicines are used to treat sleep apnea, such as protriptyline, progestation agents, tryptophan and supplemental oxygen. These medicines are effective in some patient with mild to moderate sleep apnea. However, medication is unpopular and rarely used to treat sleep apnea due to its side effects. These include dry mouth, hair loss, rash, urinary hesitancy, constipation and impotence(4, 41, 42).

2.7.6 Surgery

Surgical treatment is the best choice in patients with mild to moderate OSA who can not use CPAP (12). The objective of surgery is to widen the airway (4), increase the air space and decrease the airway resistance. A variety of these invasive procedures depend on site of obstruction.

2.8 Effect of Sleep Position on Abnormal Respiratory Condition

Body position had a major effect on breathing during sleep in patients with OSA. Patients who had at least twice as apnea/hypopnea in the supine than side lying position were called “positional patients”. These patients were thinner, younger and had less abnormal breathing than nonpositional patients, therefore the positional treatment is effective in mild OSA (43). Snoring, hypopneas and apneas are all common in the supine than sitting due to soft tissue structures like soft palate, tongue moved posteriorly lead to reduce in the oropharyngeal dimension in supine position (44, 45).

In 1986, McEvoy and coworkers reported that in upright sleep position, the frequency of obstructive apnea and arousal from sleep decreased whereas gas exchange was improved (7). In regard to the angle of sitting, the recent studies showed that nasal patency progressively decreased from sitting upright to supine but there was no significant difference between the 30⁰ and 60⁰ dorsally reclined (46). Consequently, the OSA patients can be treated in either 30⁰ or 60⁰ dorsally reclined position.

In 2003, Nakano and coworkers studied on snoring and found that the snorers decreased snoring both duration and intensity in side lying position (47). In adult patients, sleep apnea was worse in the supine position but children with OSA was contrast to adults (48, 49). Children had a lower apnea in supine compared with prone and shorter apnea when supine than side lying (48).

Therefore, the positional effect might significantly reduce the frequency and severity of occlusion in OSA patients.

2.9 Effect of Sleep Position on Airway Dimensions

Previous studies reported the effect of posture on upper airway dimensions in normal subjects (8, 14) and patients with the sleep apnea/hypopnea syndrome (8, 15, 50). Most of the reports showed the similar result in that cross-sectional areas (CSA) of upper airway were narrower in supine than in sitting in both normal and patients, No difference between supine and side lying positions. Although the prone position had rarely been considered, Pevernagie and coworkers found that the upper airway size in prone showed no significant difference in positional and nonpositional OSA patients (45). This due to gravitational force which develops anterior pulling of the tongue and soft palate. Therefore, this upper airway cross-sectional narrowing mainly resulted from the effect of gravity.

2.10 Mechanics of Breathing

Air flows into and out of the lung according to the pressure gradients between the mouth and the alveoli, from the higher to the lower pressure region. Air will flow into the lung during inspiratory phase where the alveolar pressure (P_{alv}) is less than atmospheric pressure (P_{atm}). On the contrary, when alveolar pressure is greater than atmospheric pressure, air will flow out of the lung. These dynamic processes are the result of respiratory muscle function which exerts the rhythmic contraction-relaxation during the respiratory cycle (Figure 2.4). At the end of normal expiration where glottis is opened and respiratory muscles are in the relaxed state, mouth pressure (P_{mo}) is equal to P_{alv} and P_{atm} , thus there is no airflow into and out from the system (51-55). During inspiration, respiratory muscles actively compress on abdominal contents

while lift the lower ribs upward and outward. As a result, the intrathoracic cage becomes highly negative pressure when compared to the environment. Force generated by respiratory muscles then overcomes the impedance from, at least, inward recoil of the lung tissue itself. There is transmission of force from respiratory muscles to the lung via pleural space. This space always exhibits the negative pressure which allows the simultaneous changes of the thoracic cage and the lung. At end expiration (at FRC), the inward recoil of lungs is counteracted by the outward recoil of the chest wall which causes a negative pressure (-5 cmH₂O). As inspiration takes place (above FRC), force generated by inspiratory muscles must overcome the additive inward recoil of the lung, in accompany with the inward recoil of the thoracic cage (Figure 2.4). Thus, normal expiration is a passive process where respiratory muscle function ceases and inward recoil dominates. Like flow of fluid along the tube, pressure gradient across the alveoli must be taken into account. Transpulmonary pressure, pressure across the alveoli and pleural space, is the most important transmural pressure gradient which determines the successfulness of breathing (51-55).

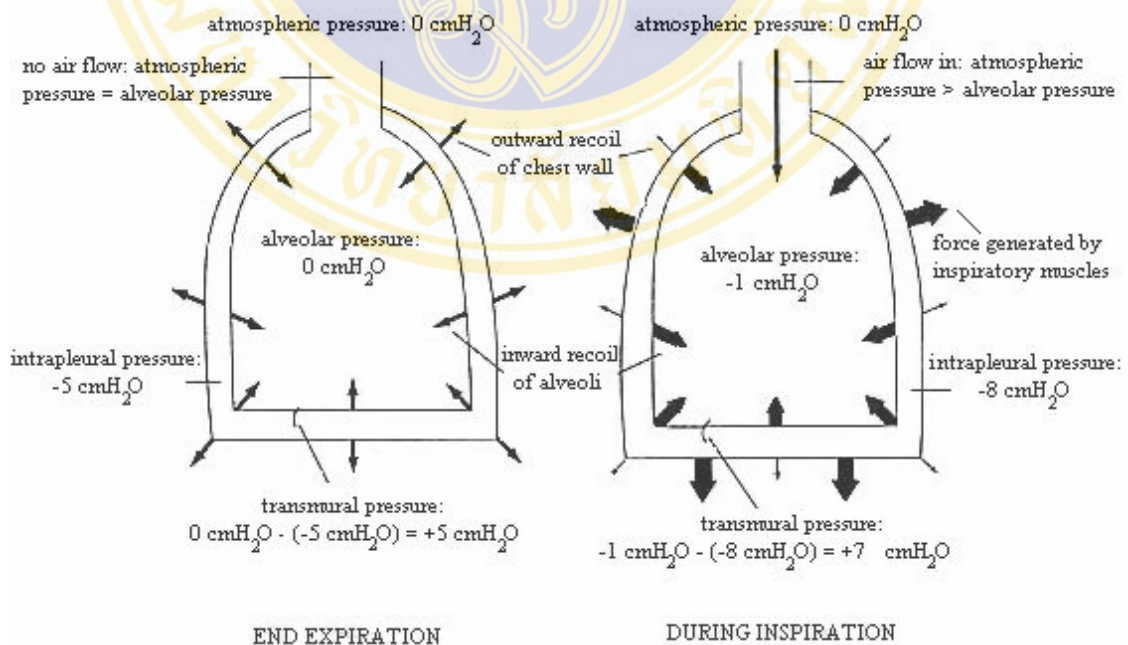


Figure 2.4 Representation of the interaction of the elasticity of lung and chest wall and transmembrane pressure during respiratory cycle (51).

During inspiration, active inspiratory muscles contraction cause an increasing in thoracic volume. The pleural pressure becomes more negative and the lungs expand. With this increased in lung volume, alveolar pressure decreases and becomes negative (-1 cmH₂O) which result in air flows into the lung down this pressure gradient. Air continues to fill the lung until the alveolar pressure again equals the atmospheric pressure. At this point, air flows stop and inspiration ends (51-54) (Figure 2.5).

During expiration, inspiratory muscles relax and lung recoil, this result in the pleural pressure becomes less negative and lung volume reduces to resting volume (FRC). This decreased lung volume compresses the alveoli and alveolar pressure becomes positive (+1 cmH₂O) which result in air flows out of the lung down this pressure gradient. As the alveolar pressure again equals to the atmospheric pressure, air flows stop, expiration ends and the next breathing cycle is initiated (51-54) (Figure 2.5).

The pleural pressure is changed during normal breathing cycle by two pathways. The dashed line shows the pleural pressure during no airflow. This pressure changes to overcome only elastic recoil force of the lungs. As the solid line shows changing in pleural pressure during airflow which is the sum of the pressure change to overcome both an elastic recoil of the lungs and airflow resistance. Thus the difference between two lines is the pressure change required to overcome an airflow resistance (53, 54).

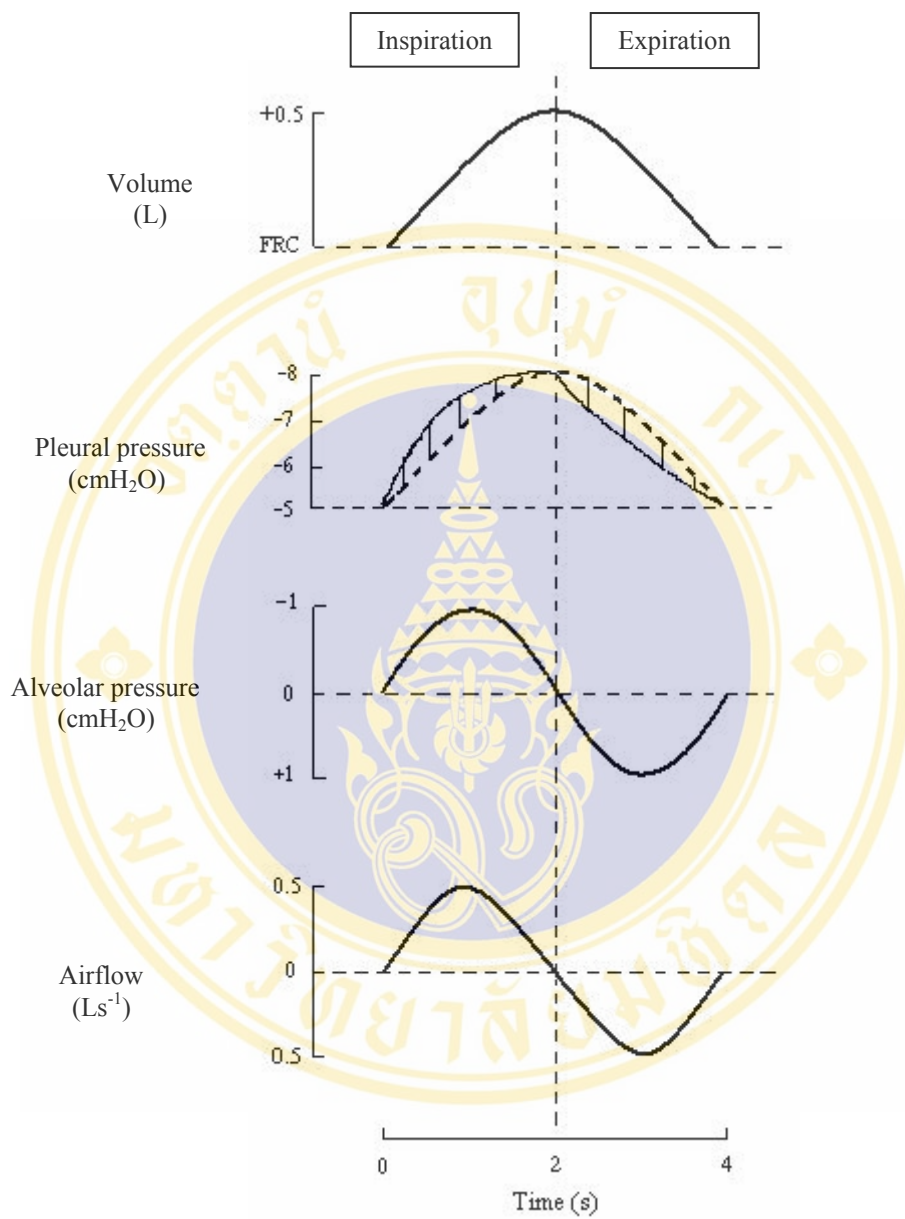


Figure 2.5 Volume, pressure and flow during the normal breathing cycle (53, 54).

2.11 Airway Resistance

Airway resistance (R_{aw}) is the friction of gas flow while molecules of flowing gas impede either with other gas molecules or the wall of branches of respiratory tract. This resistance is dynamically taken place, particularly during expiration, in normal subjects and may be aggravated in patients whose tiny airways structures are unstable (51). Airway resistance (in $\text{cmH}_2\text{O}/\text{L}\cdot\text{s}^{-1}$) is defined as the ratio of driving pressure (ΔP) to airflow (\dot{V}) (51, 52). Based on the laminar flow assumption, the approximation of airflow is as follow:

$$R_{aw} = \frac{\Delta P \quad \text{cmH}_2\text{O}}{\dot{V} \quad \text{L/s}} \quad \dots\dots\dots(1)$$

Where R_{aw} = airway resistance, ΔP = driving pressure and \dot{V} = airflow.

Measurement of R_{aw} is a simple procedure by having a subject breath through a system. However, determination of simultaneous changes of pressure and flow is not quite easily performed. Present techniques used for R_{aw} determination include highly sophisticated equipment, a plethymography body-box (Figure 2.6), oscillometry (Figure 2.7) and subjective evaluation from peak flow meter (Figure 2.8).



Figure 2.6 A plethymography “body-box” used to determine R_{aw} with multiple volume and pressure transducers mounted on the wall of this closed system make it possible to define compliance, flow, volume and resistance of airways.



Resonance Oscillometry for airways resistance testing

Figure 2.7 Determination of airway resistance (R_{aw}) using resonance oscillometry method.



Figure 2.8 Subjective evaluation of R_{aw} from peak flow meter. This technique is routinely performed in asthmatic subjects prior to and after allergic tests.

Airway resistance is not generated evenly throughout the respiratory system (Figure 2.9). This resistance varies with airway generations, it decreases in parallel with successive airway generations from a maximum in medium bronchi to almost zero at 15th generation. The upper airway resistance roughly accounts about 50% of the total resistance normal breathing. As breathing pattern is changed to nasal cavity, upper airway resistance increases to 66% of the total resistance (56). Resistance in larger airway, from trachea to segmental bronchi, provides 80% of the total airway resistance while the small or peripheral airway accounts for only 20%. It is also found that the small or peripheral airway with diameter of less than 2 mm. develops such

high R_{aw} (51, 52, 54). Thus, the airway size is the most important factor involving in airway resistance (Figure 2.9). Additionally, the other factor include airway length, airway smooth muscle tone and the physical properties of the airflow such as gas density and viscosity are also influence to airway resistance (57).

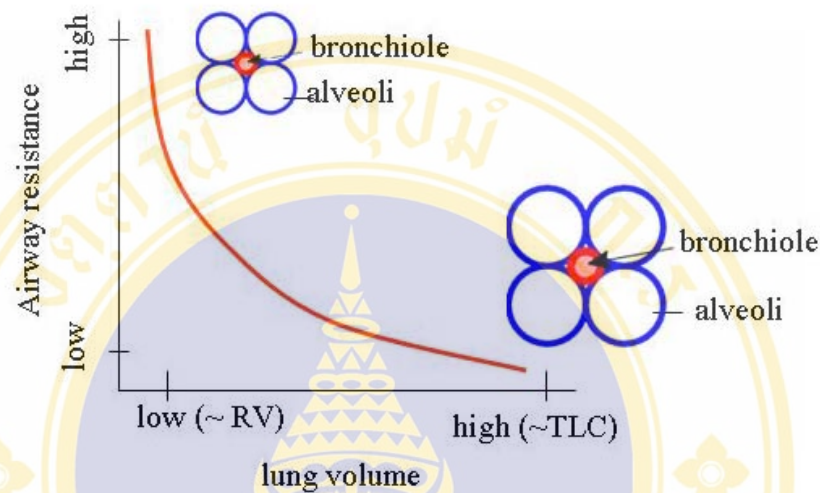


Figure 2.9 Airway resistance (R_{aw}) varies with lung volume and airways generation. R_{aw} is the highest at residual volume (RV) and the lowest at total lung capacity (TLC).

The driving pressure or transmural pressure gradient ($P_{in} - P_{out}$) is necessary to pull air into the airway during inspiration and push alveolar gas out of the lung during expiration. It depends on flow rate and pattern of flow like the other fluids, can occur as laminar, turbulent or transitional flow. The driving pressure 1 cmH₂O is adequate to cause air flow (normal airflow is 0.5 L.s⁻¹), thus a typically of airway resistance during quiet breathing about 2 cmH₂O/L.s⁻¹ (1 cmH₂O/0.5 L.s⁻¹) (54).

2.11.1 Nature of airflow

Laminar flow is characterized by streamline flow along a straight unbranched tube as series of concentric cylinder (Figure 2.10). Air flows at different rates, but the pathway in the center of tube has the highest velocity and the slowest velocity is along the wall of tube because of the frictional force with the wall. Laminar flow occurs in the small airways where airflow is very low.

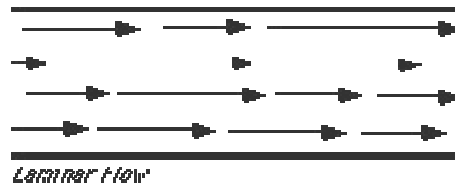


Figure 2.10 Laminar flow takes place at low velocity air passes through narrow tubes, it tends to be more orderly and streamlined and to flow in a straight line. Laminar flow is directly proportional to the driving pressure.

Airway resistance along the laminar flow varies with the viscosity of gas and the length of tube. The general equation for laminar flow resistance is estimated from Poiseuille's law as follow (51, 52, 58):

$$R_{aw} = 8 \cdot \eta \cdot l / \pi \cdot r^4 \dots\dots\dots(2)$$

Where η = viscosity of gas, l = length of the tube and r = radius of the tube. Thus, there are some variables which directly affect R_{aw} while some exerts indirect effect.

Turbulent flow consists of irregular patterns of airflow (eddy’s flow, Figure 2.11) that result in a sound during inspiration and expiration (59). Turbulent flow can occur at high flow rate, especially through the large airway or irregular tube.

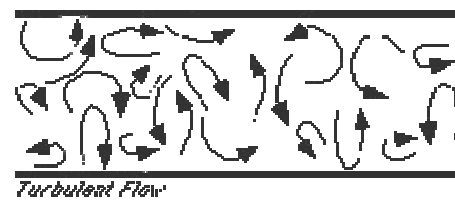


Figure 2.11 Turbulent flow takes place when air flows at higher velocities, especially through an airway with irregular walls, flow becomes disorganized, even chaotic, and tends to form eddies. This is found mainly in the largest airways, like the trachea.

Airway resistance in turbulent flow is higher than laminar flow according to the physical characteristic of airflow. The onset of turbulence under ideal conditions can be predicted by calculating the Reynolds' number (Re) as follow (51, 52, 58):

$$Re = \frac{(\bar{v} \cdot D \cdot \rho)}{\eta} \dots\dots\dots(3)$$

Where \bar{v} = flow velocity, D = tube diameter, ρ = gas density and η = gas viscosity.

It is estimated that turbulent flow might take place when Re is greater than 4000 (58). A relatively large driving pressure is required to sustain turbulent flow. Driving pressure during turbulent flow is in fact proportional to the square of the flow rate such that to double the flow rate one must quadruple the driving pressure.

$$\Delta P = K \dot{V}^2 \quad \text{where } \Delta P = \text{driving pressure, } K = \text{constant, } \dot{V} = \text{airflow}$$

Transitional flow is a mixture of laminar and turbulent flow. This type of flow occurs at the point distal to partial obstruction. It tends to occur if airflow is high, gas density is high or radius of tube is large (51).

Traditionally, the sigmoid shape of pressure-flow curve is interpreted as representing laminar flow in its straight portion but turbulent flow in its more curvilinear portion (60). Therefore, slope of linear pressure-flow relationship can be approximate the airway resistance (Figure 2.12).

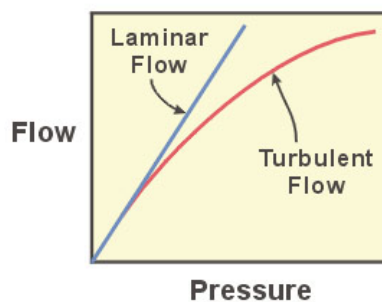


Figure 2.12 A shape of pressure-flow relationship, linear line is laminar flow and curvilinear is turbulent flow.

2.12 Effect of Sleep Position on Upper Airway Resistance

Significant increase in upper airway resistance (UAR) during sleep in humans had been studied (24, 61). An increase in UAR correlates with the decrease in tensor palatini muscle activity which could induce a narrowing of airway in the area posterior to soft palate (24). Therefore, a decreasing in the activity of pharyngeal dilator muscles during sleep had been proposed as the main mechanism for this increase in UAR in apnea patients. However, Hudgel and coworkers reported that nasal resistance alternated during sleep as well as wakefulness(62).

In 1982, Anch and coworkers found that the effect of changes in position on supraglottic pressure-flow relationship and its resistance were similar in both normal and OSA patients during awake (22).

Tvinnereim and coworkers in 1996 found that pressure-flow relationship in normal subjects during awake is a linear. Upper airway resistance trended to be higher in supine than sitting. There was no significant difference in pressure and resistance between supine and lateral position (16).

2.13 Model of Behavioral Changes of the Airway

In describing the dynamic behavior of the airway during breathing cycle, it is performed in physical model. The basic knowledge is considered the airway as a collapsible tube and its resistance is the relationship between driving pressure and flow. Negative intrathoracic pressure transmit to the upper airway passively during inspiration would promote a reduction in pharyngeal cross-sectional area (63). According to the balance of pressure concept (64), the size of the airway depends on the balance between intraluminal pressures during inspiration and outward forces of upper airway dilator muscles contraction.

Negative inspiratory pressures which lead to the airway closure generated by the upper airway and respiratory muscle activity (64-66). Pharyngeal wall can be closed completely at very little negative pressure (-1.5 cmH₂O), a positive pressure in range of 2 to 3 cmH₂O can force the wall open again (67).

The linear pressure-flow relationship was used to define a resistance (Figure 2.12). Previous reports described the pressure-flow relationship of upper airway and its resistance during sleep (17-19). The mechanical narrowing of the upper airway is related to changing in pressure from the collapsible segment and this occlusion increased airway resistance and probably related to a decrease in upper airway muscle tone (21).

2.13.1 Starling resistor model

A pattern of flow on the driving pressure occurs in “Starling resistor”, which is a specific model of collapsible tube behavior that can explain the physiologic mechanism which leads to increased upper airway resistance and collapsibility in OSA patients (68). This behavior is characterized by an initially increases flow as driving pressure increases. At flow limitation, there is a progressive plateau of flow despite continuing increase in driving pressure (19).

Collapsibility regarded from the upper airway critical pressure (P_{crit}) that surrounds the collapsible segment. The behavior physical model consists of a thin wall elastic (collapsible) tube enclosed in the chamber. The pressure in this chamber (P_{crit}) varies to be less or greater than the pressure inside the tube. When P_{crit} is greater than zero, there is airway collapsed at rest and obstruction of the tube occurs. In contrast, more negative P_{crit} is associated with remaining inspiratory airway patency (19, 68-71).

In normal awake subjects or patients on optimal CPAP, the inspiratory upper airway resistance remains low throughout their breath. As the transmural pressure gradient is inadequate to collapse, P_{crit} is a negative thus the airway remains patent. The flow increases proportionally to driving pressures in a linear pressure-flow relationship. This results in a rounded contour of the inspiratory flow during each breath (Figure 2.13A).

In patients with snoring and OSA, partial collapse may occur during inspiration, P_{crit} approaches zero in snoring (70) and might be positive in OSA patients (19, 69, 72). At higher driving pressure, greater collapse occurs and there is no further increase in flow despite greater inspiratory effort, resulting in an increased upper airway resistance. The flow increases nonproportionally to driving pressures. The flow contour of each breath differs from normal breath. The appearance of a plateau in inspiratory flow contour indicates a partial obstruction and high upper airway resistance (Figure 2.13B).

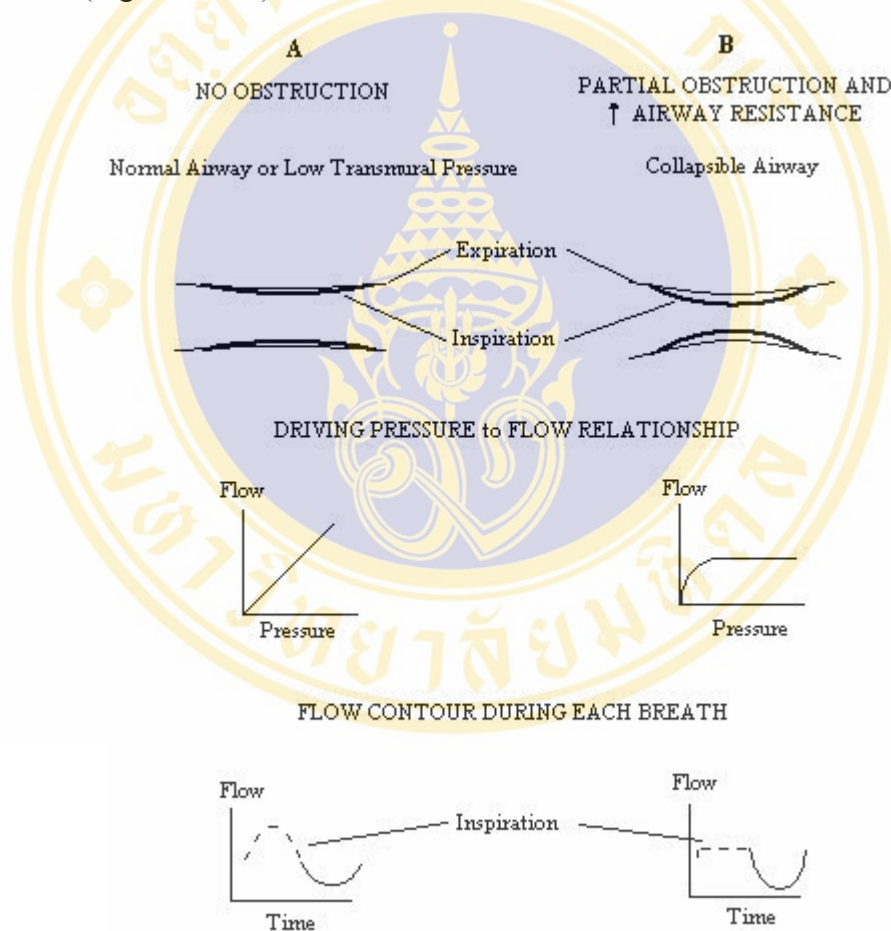


Figure 2.13 Starling resistor behavior. (A) No obstruction (normal airway or low transmural pressure), a linear pressure-flow relationship and rounded contour of inspiratory flow for each breath were shown. (B) A partial obstruction and increased airway resistance (collapsible airway), flow increases up to a point and then remains constant despite increasing in pressure, and the appearance of a plateau in inspiratory flow contour was shown (68).

In 1997, Neil and coworkers found that the upper airway in lateral position was more easily opened when compared with the supine position (9). In 2001, Penzel and coworkers compared the effect of sleep position on upper airway collapsibility, a significant reduction from supine to lateral position was found. P_{crit} in supine was positive whereas in the lateral position was negative (73) and the result implied that nasal continuous positive airway pressure (NCPAP) was lower in lateral than supine position (73-75).

According to the fact that nasal pressure is atmospheric ($P_n = 0$), a decrease in nasal pressure results in the reduction in inspiratory airflow and increases in resistance until the nasal pressure is lower than P_{crit} , as a result in inspiratory airflow ceased and upper airway occluded. P_{crit} can be defined as the level of nasal pressure at which inspiratory flow first ceased (19, 71, 76). Consequently, the application of NCPAP in OSA patients can eliminate the occlusion when level of nasal pressure is above P_{crit} .

From the literature review, most of studies determined only inspiratory resistance, very little attended separately changing in inspiratory and expiratory resistances. In 1983, Sanders and Moore showed that airway resistance increased during both inspiration and expiration (77). Recently, the study indicated that airflow obstruction also worsened during expiration (78). Therefore, the loss of airway patency does not occur only during inspiratory phase. To understand the basic knowledge, the aim of this study is to evaluate the effect of position on airflow resistance in healthy males during wakefulness condition. Its benefit will be applied as a part of treatment for OSA patients.

CHAPTER III

MATERIALS AND METHODS

3.1 Subjects

Healthy Thai males, university students aged between 18 and 24 years, voluntarily participated in this study. Preliminary interviewing and physical examination procedures were performed by an investigator prior to the test. Inclusion and exclusion criteria were specifically set for this experiment as follows:

3.1.1 Inclusion criteria

- Sedentary or active habitual physical activity (total physical activity scores between 3-8) using habitual physical activity level questionnaire (79, 80) (Appendix C.2)
- Non-obese as indicated by BMI (81), % body fat (%BF) (82) or waist to hip ratio (W/H) (81)
- Normal pulmonary function test for Thai male according to FVC, FEV₁ and the ratio of FEV₁/FVC > 80% predicted values (83) (Appendix D)
- Non-snoring (based on self- report)
- Ability to understand verbal instruction on laboratory maneuver
- Free from musculoskeletal and neurological disorders of nasopharynx cavity.
- Intact gag, swallowing and cough reflexes

3.1.2 Exclusion criteria

- Having known cardiovascular or respiratory disorders
- Taking caffeine and/or alcohol-containing beverages within 24 hours prior to the study

- Current smoking or history of heavy smoking (more than 20 cigarettes/day, longer than 5 years)
- Taking any medicine that might affect the respiratory system
- Surgical history of the upper airway and the chest
- History of accident around the chest area

3.2 Design of the Study

This study was assumed that there is no individual variability of upper airway anatomic contour. This study compared change of upper airways dimension when subject was in different position while performing quiet respiration.

3.3 Instrumentations

3.3.1 Pneumotachometer

Airflow and pressure were measured through pneumotachograph unit (Model MFP-1200, Nihon Kohden, Japan), which was connected to a mouthpiece. This unit was composed of a No.3 Fleish air resistance tube, a pneumotachograph main unit including two differential pressure transducers (MPX2050DP, Motorola Freescale Semiconductor, Inc.) for measurement of flow and pressure signals, respectively and a pneumotachograph control box (Figure 3.1). This system was specially designed by The Project of Research and Development of Biomedical Instrumentation, Institute of Science and Technology for Research and Development, Mahidol University. The control box was designed to automatically control at the constant temperature of 38⁰c inside the air resistance tube and the built-in electromagnetic shutter (an interrupter valve). This system had constant volumetric space, approximately 120 ml, and detected airflow within the range 0-10 L.s⁻¹, pressure within the range – 100 to +100 cmH₂O.

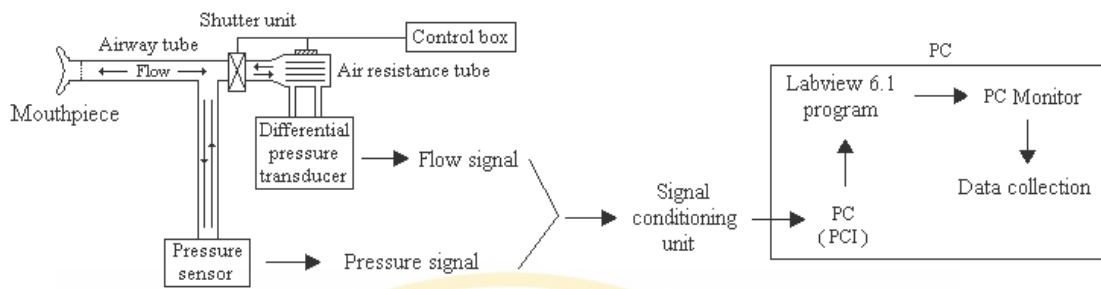


Figure 3.1 Circuit diagram illustration of pneumotachometer setup and data acquisition using transient interruption technique.

Pressure and flow signals were adjusted by signal conditioning connector block (SC 2345, National Instruments, Singapore) (Figure 3.2) and transformed to digital values and displayed on data acquisition card (PCI 6023E) in the sine-wave curve fashion using the Labview program version 6.1 for processing on computer screen (Figure 3.3). Airflow resistance was calculated from signals representing pressure and flow: separately by the ratio of pressures to inspiratory and expiratory flows. The calibration was routinely performed prior to the study using a 3-L syringe and a flow calibrator (Appendix F).

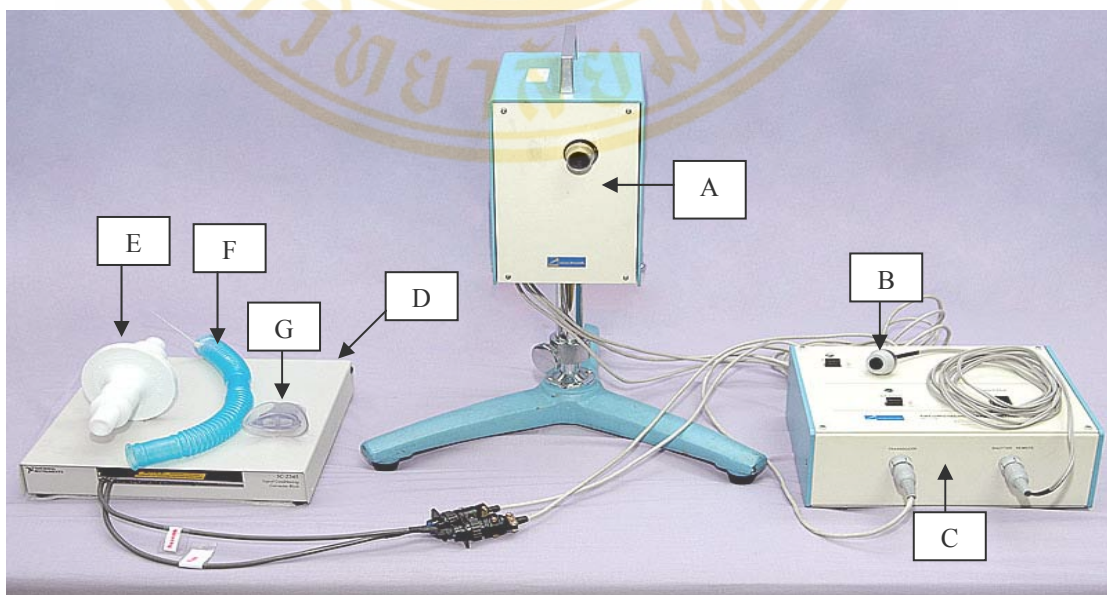


Figure 3.2 Pneumotachometer (A), shutter unit (B), control box (C), signal conditioning connector block (D), filter (E), airway tube (F) and mouthpiece (G).

This instrument was based on a transient airflow interruption technique for measuring airflow resistance. The technique was conducted by briefly interruption of airflow during spontaneous breathing cycle, whenever the subject did not recognize. It was assumed that the immediate post-occlusion (closing shutter) mouth pressure represented an instant alveolar pressure. As the occlusion was sufficiently rapid, airflow signal prior to an immediate occlusion was detected. Airflow resistance was then calculated by the ratio of mouth pressure to flow.

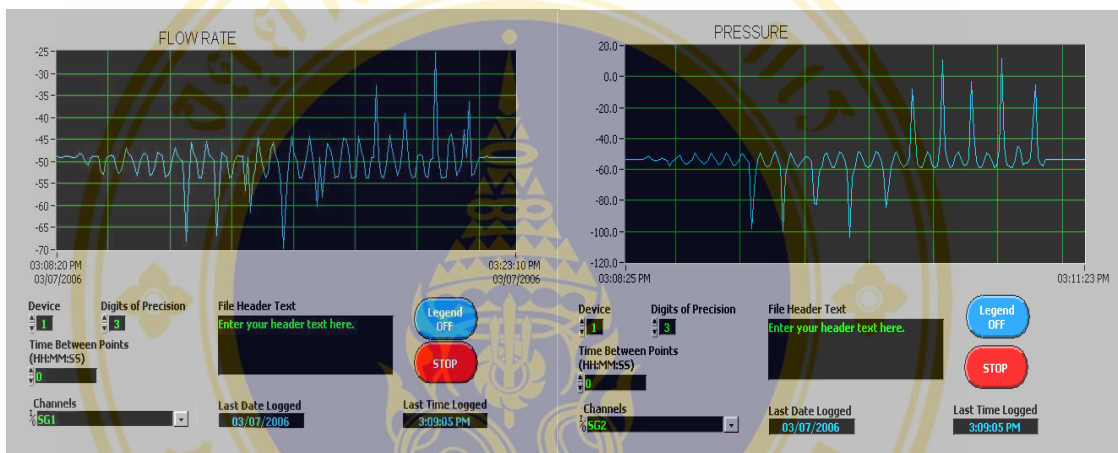


Figure 3.3 A screen display of the sine-wave curve fashion during inspiratory and expiratory cycle using the Labview program version 6.1 (flow rate signal on the left and pressure signal on the right).

3.3.2 Peak flow meter

The peak expiratory flow rate measured how fast a person maximally breath out (exhale) air. It is one of many tests that measure how well the airways work. In the present study, peak expiratory flow was measured using peak flow meter (Combivent[®], Vitalograph, INC., Ireland) (Figure 3.4). Normal values vary considerably according to a person's age, sex, and size. Peak flow measurements are most useful when a person is able to take and compare peak flow measurements on a day-to-day basis. In normal subject, peak expiratory flow rate (PEF), in the unit of L/min, apparently occurred during the initial expiratory phase, which represented the first bolus of air stream being expelled from upper airways (Figure 3.5). Determination of peak expiratory flow rate in the present study was conducted according to the standard procedure proposed by American Thoracic Society (ATS) (84).

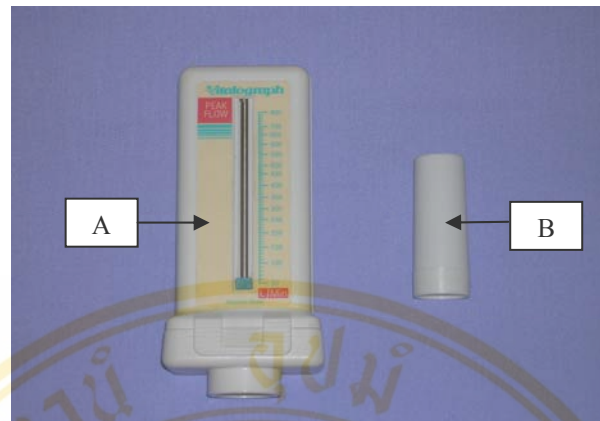


Figure 3.4 Peak flow meter (Combivent®) (A) and plastic mouthpiece (B).

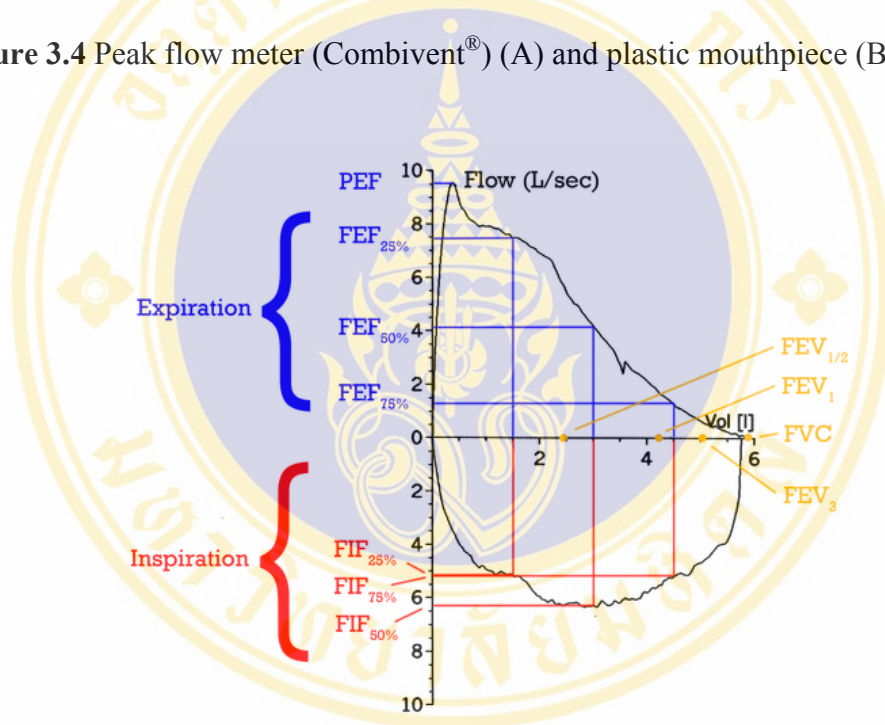


Figure 3.5 Peak flow rate appears as the highest expiratory flow from flow-volume loop.

3.3.3 Spirometer

The Digital Spirometer (Pony FX pulmonary function equipment, Cosmed, INC., Italy) (Figure 3.6) was used for pulmonary function test using technique recommended by American Thoracic Society (ATS) (83). Fast spirometric maneuvers (Figure 3.5) were conducted in the present study including force vital capacity (FVC; the total amount of air that is forcibly blown out after full inspiration, measured in liters), force expiratory volume in one second (FEV₁; the amount of air that can be forcibly blown out in one second, measured in liters. Along with FVC it is

considered one of the primary indicators of lung function), ratio of FEV_1/FVC (the amount of the FVC that can be expelled in one second. In healthy adults this should be approximately 80%) and peak expiratory flow (PEF; the speed of the air moving out of the lungs at the beginning of the expiration, measured in liters per second). The best of three acceptable test was compared with the predicted values from normal lung function in Thai male (83).



Figure 3.6 Spirometer (Pony FX pulmonary function) (A), paper mouthpiece (B) and noseclip (C).

3.3.4 Skinfold caliper

The skinfold caliper (The Accu-Measure™, Accu-Measure, Inc., USA) was used to measure the skinfold thickness in both exercise physiology laboratory and clinical basis for estimation percent body fat (%BF). It provided a simple and noninvasive method of estimating body composition from fat fold. Millimeters of selected skinfold thickness was used (Figure 3.7).



Figure 3.7 Plastic skinfold caliper (The Accu-Measure™).

3.3.5 Measuring tape**3.3.6 Weight meter****3.3.7 Height scale****3.4 Baseline Assessment**

The following measurements were performed for screening healthy subjects before starting the study. The demographic data (age, weight, height and BMI), medical history and habitual physical activity level were obtained prior to further experimental procedures.

Body physiques:

Waist to hip ratio (W/H) was assessed. Waist circumference (W, inches) was measured horizontally from the mid point between lower rib cage and iliac crest (86). Hip circumference of hip (H, inches) was measured horizontally between greater trochanters (81). This ratio indirectly defines body shape where W/H ratio >1.0 represents fatness.

The skinfold thickness measurement was used to estimate % body fat (%BF). Four skinfold thicknesses; biceps, triceps, subscapular and suprailiac areas were determined on the right side of the body while subject was standing in a relaxed condition (arms hanged freely by the side). Techniques for measuring skinfold were 1) grasped the subject's skinfold and adjacent subcutaneous tissue with tips of thumb and index finger using the left hand at specific located sites on the body. 2) raised the skinfold and hold about 1-2 seconds. Placed jaws of the caliper perpendicular to the skinfold at center between crest and base of fold. 3) repeated the measurement procedure twice and calculated the average of skinfolds. Body density (D_b), based on age and gender, was estimated from sum of four skinfold thickness (X_4), %BF was estimated according to an equation of Durnin and Womersley, 1974 (87):

$$D_b = 1.1631 - 0.0632 \log (X_4)$$

Percentage of Body fat (%BF) is calculated from density using Siri's equation, 1956:

$$\%BF = [(4.95 / D_b) - 4.5] \times 100$$

3.5 Testing Procedures

After the informed consent form was completed. Subject, who met the inclusion criteria, were clearly instructed for objectives and procedures of the test. This study was approved by Ethics Committee of Faculty of Medicine Siriraj Hospital, Mahidol University (Appendix A).

Baseline data:

After arrival to the laboratory, a subject was allowed to lie down in a bed until his resting condition was achieved. Resting respiratory rate was then observed in the supine position. In a wakefulness condition, testing was conducted under four randomized experimental positions: reclining 30°, supine lying, left and right side lying. Each position was comfortably maintained for five minutes. If needed, small pillows to support the head, neck and trunk were adjusted.

Breathing resistance determination:

The pneumotachometer unit was connected to subject's airway by a mouthpiece which was appropriately cleaned by disinfectant (Virkon®). Noseclip was worn and the investigator checked for connecting hose lines and subject's comfortable feeling. Data collection was started when flow in and flow out were considerably stable. The closing shutter for measuring airway pressure was made for approximately ten interruptions between spontaneous breathing cycle. This procedure was randomly repeated five times for inspiration and expiration, while the subject continuously breathed through the mouthpiece. Data were shown in either tabulated or sine-wave curve fashions. Airflow resistance was calculated by the equation as follow:

$$R_{int} = P / \dot{V}$$

At the end of each session, mouthpiece and noseclip were taken off. After few minutes break with the same position, peak expiratory flow (PEF) was then tested. Techniques for measuring were 1) make sure that the sliding marker on the peak flow meter is at the lowest number on the scale. 2) fully inspire and wear the noseclip. 3) put the mouthpiece of meter into the mouth. 4) expire as hard and as fast as possible. 5) each performs three trials at least one minute interval between each trial and record

the best of three rating. Subject was allowed to have 5-10 minutes break until the resting respiratory rates were achieved. The similar protocol was repeated under four randomized positions. Throughout the recording session, each subject was instructed to spontaneously breath via mouthpiece while keeping his wakefulness state. Airway pressure, airflow and airflow resistance in each position used the mean value and PEF used the highest value obtained from three trials for statistical analysis.

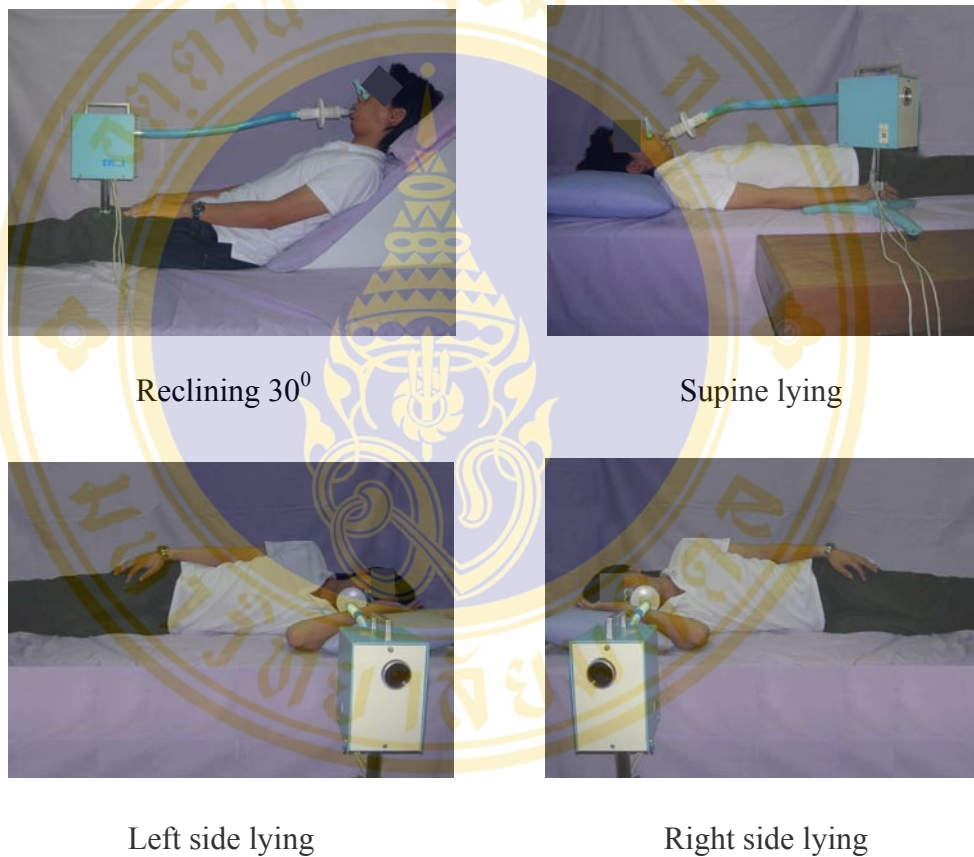
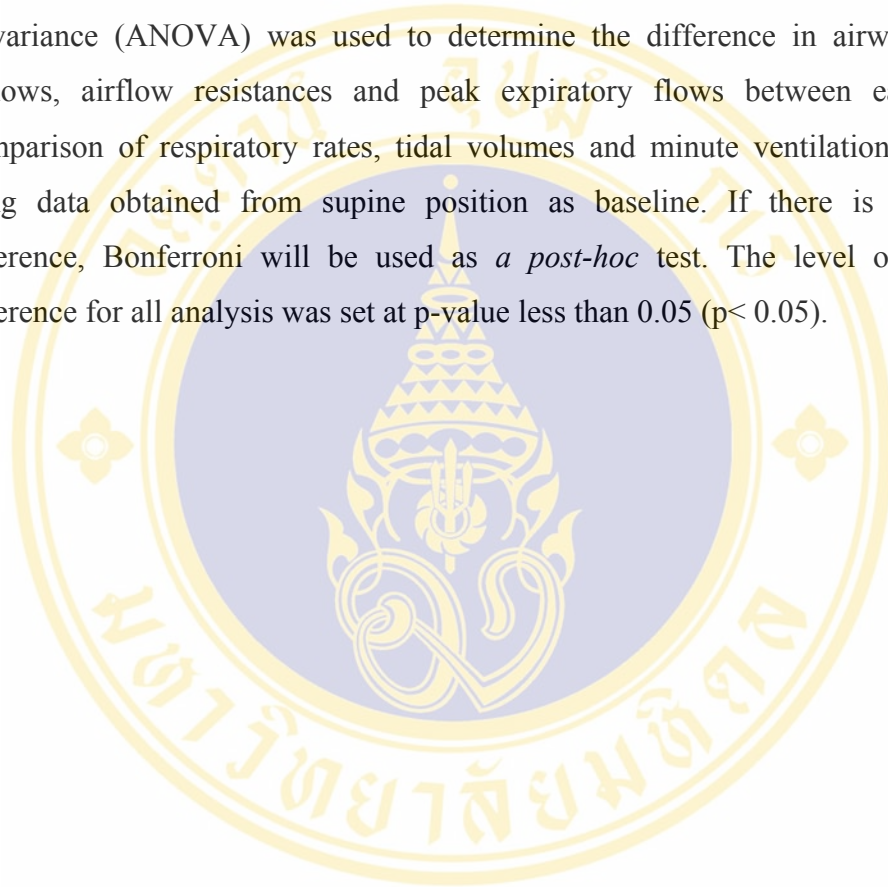


Figure 3.8 Four testing positions used in the study.

3.6 Statistical Analysis

The present study was nested to explore differences in position on respiratory variables within the same subject group; no comparison between different subject groups was performed. Distribution of the data was tested using one-sample Kolmogorov – Smirnov Goodness of Fit test. The repeated-measures one-way analysis of variance (ANOVA) was used to determine the difference in airway pressures, airflows, airflow resistances and peak expiratory flows between each position. Comparison of respiratory rates, tidal volumes and minute ventilations were made using data obtained from supine position as baseline. If there is a significant difference, Bonferroni will be used as a *post-hoc* test. The level of statistically difference for all analysis was set at p-value less than 0.05 ($p < 0.05$).



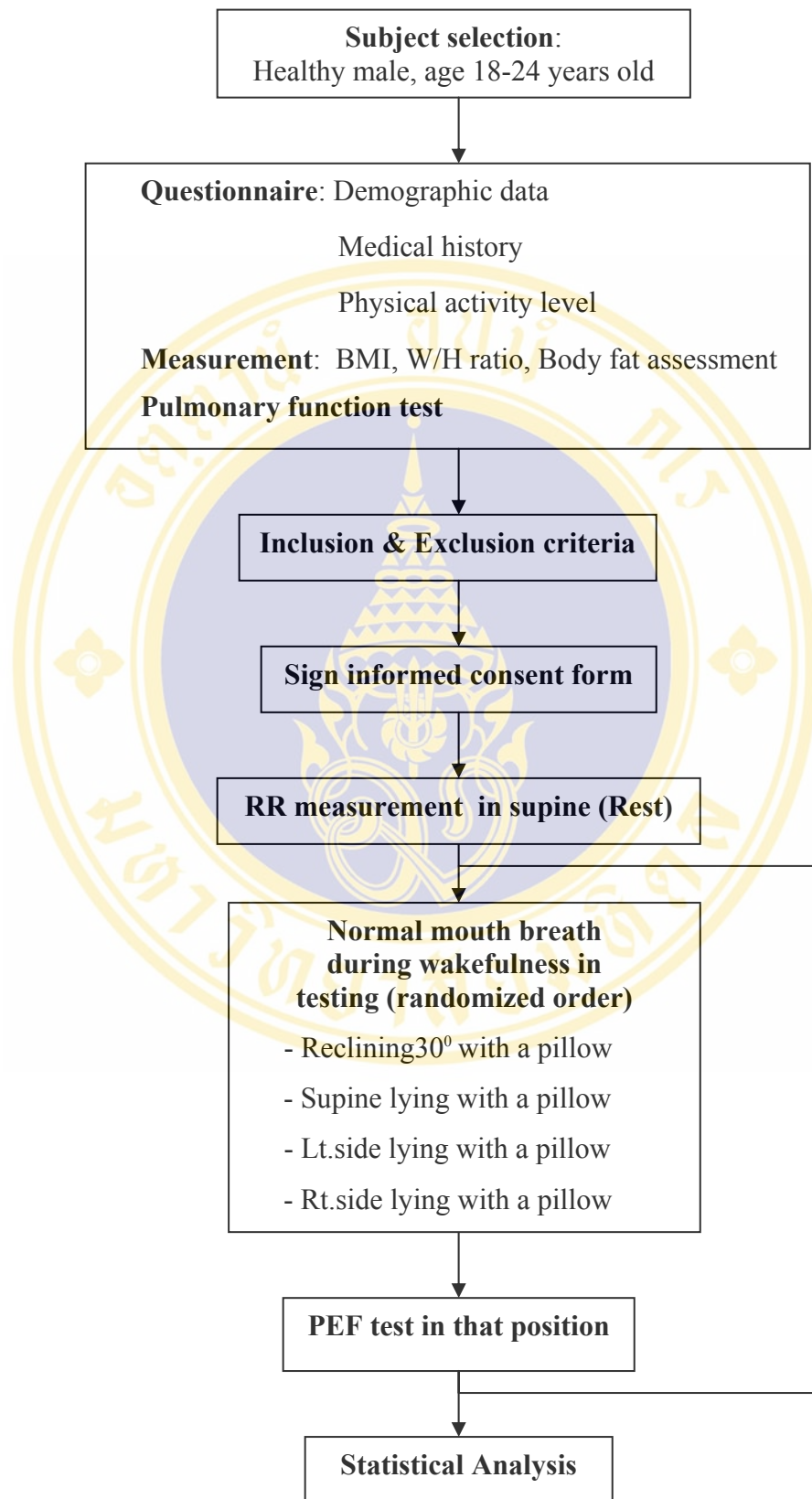


Figure 3.9 The research procedures.

CHAPTER IV

RESULTS

The purpose of this study was to examine the effect of body position on airflow resistance during wakefulness condition. To avoid effects of age, gender and complexity of the experimental procedures, only young university male students, who met the criteria, were recruited in this study. Respiratory parameters including airway pressure, airflow, airflow resistance for both inspiration and expiration and peak expiratory flow were measured in four randomised positions (reclining 30°, supine lying, left side lying and right side lying).

4.1 Characteristics of Subjects

Thirty male subjects were recruited. The characteristics including anthropometric and physiologic data were presented in Table 4.1. All subjects subjectively indicated for their active lifestyle and none had snoring history or respiratory disorders. Body fat assessment and pulmonary function test in all subjects were within the normal ranges at this age range.

Table 4.1 Subject's characteristics and baseline pulmonary function. Values are expressed as means and standard deviations of the mean. Volumes are in BTPS (body temperature and pressure saturated with water vapor pressure). (N=30)

Physical characteristics:	
Age (years)	21.73 ± 1.53
Weight (kg)	60.03 ± 6.17
Height (cm)	170.80 ± 5.34
BMI (kg.m ⁻²)	20.54 ± 1.48
W/H ratio	0.83 ± 0.03
%Body fat	12.56 ± 3.77

Lung function:	
FVC (L, BTPS)	3.96 ± 0.32
FEV ₁ (L, BTPS)	3.56 ± 0.31
FEV ₁ /FVC (%)	89.90 ± 4.57
PEF (L.s ⁻¹)	8.18 ± 1.05
Physical activity:	
Physical activity scores*	7.17 ± 0.63

* assessed from physical activity questionnaire (see Appendix C.2)

4.2 Effect of Position on Respiratory Variables

4.2.1 Characteristics of respiratory variables among different positions

In the present study, characteristics of respiratory variables during inspiratory and expiratory phases were presented separately. Respiratory rate, tidal volume, minute ventilation, airway pressure, airflow, airflow resistance and peak expiratory flow (PEF) during inspiration and expiration were consequentially presented in Table 4.2 to 4.9.

4.2.1.1 Characteristics of respiratory rates, tidal volumes and minute ventilations:

In the present study, respiratory rate, tidal volume and minute ventilation were compared. Respiratory rate (RR) in supine position was 18.07 ± 3.062 breaths/min, tidal volume (V_T) was 0.546 ± 0.002 L and minute ventilation (\dot{V}_E) was 9.857 ± 1.667 L/min. There was no significant difference of these variables ($p > 0.05$) when compared between supine vs. reclining, supine vs. left side lying and supine vs. right side lying as showed in Table 4.2. Therefore, subjects breathed at the same respiratory rate, volume and ventilation even they were in different positions.

Table 4.2 Means and standard deviations of absolute respiratory rates (RR), tidal volumes (V_T) and minute ventilations (\dot{V}_E) in different positions.

Variables	Supine	Reclining 30 ⁰	Lt.side lying	Rt.side lying	Significant level
RR (breaths/min)	18.07 ± 3.062	18.00 ± 3.051	18.10 ± 2.952	18.00 ± 3.074	NS
V_T (L, BTPS)	0.546 ± 0.002	0.546 ± 0.002	0.546 ± 0.002	0.546 ± 0.002	NS
\dot{V}_E (L/min)	9.857 ± 1.667	9.828 ± 1.660	9.880 ± 1.613	9.823 ± 1.674	NS

NS = no statistically significant different from supine position.

4.2.1.2 Characteristics of airway pressures:

During inspiration, airway pressures ranged from 3.956 ± 0.535 (in the reclining position) to 5.056 ± 0.725 cmH₂O (in supine position). However, there was similar value in pressure found between two side-lying positions (Table 4.3). Pressure decreased about 20% in reclining and 15% in side lying when compared with supine position (Table 4.4). Similarly, this pattern of changes in expiratory variables was detected in that reclining position showed the lowest (2.964 ± 0.340 cmH₂O) whereas supine position had the highest pressure (3.774 ± 0.521 cmH₂O). These values, again, showed a similar pressure between two side-lying positions.

Table 4.3 Means and standard deviations of absolute airway pressures in different positions at normal end-inspiration and end-expiration.

Phase	Supine (cmH ₂ O)	Reclining 30 ⁰ (cmH ₂ O)	Lt.side lying (cmH ₂ O)	Rt.side lying (cmH ₂ O)
Inspiration	5.056 ± 0.725	3.956 ± 0.535	4.322 ± 0.694	4.351 ± 0.711
Expiration	3.774 ± 0.521	2.964 ± 0.340	3.249 ± 0.402	3.224 ± 0.429

Table 4.4 Means and standard deviations of percent changes from supine airway pressure in different positions at normal end-inspiration and end-expiration.

Phase	Supine (%)	Reclining 30 ⁰ (%)	Lt.side lying (%)	Rt.side lying (%)
Inspiration	100	79.13 ± 10.85	85.70 ± 7.63	86.37 ± 9.04
Expiration	100	79.42 ± 10.95	86.71 ± 9.31	85.93 ± 8.56

4.2.1.3 Characteristics of respiratory airflow rates:

During inspiration, respiratory airflows fell in the narrow ranges, from 0.513 ± 0.015 (in the supine position) to 0.536 ± 0.020 L.s⁻¹ (in reclining position). However, there was similar value in airflow found between two side-lying positions (Table 4.5). Airflow increased about 4% in reclining and 2% in side lying when compared with supine position (Table 4.6). Similarly, this pattern of changes in expiratory variables was detected in that reclining position showed the highest (0.527 ± 0.018 L.s⁻¹) whereas supine position had the lowest airflow (0.509 ± 0.016 L.s⁻¹). These values, again, showed a similar airflow between two side-lying positions.

Table 4.5 Means and standard deviations of absolute airflows in different positions at normal end-inspiration and end-expiration.

Phase	Supine (L.s ⁻¹)	Reclining 30 ⁰ (L.s ⁻¹)	Lt.side lying (L.s ⁻¹)	Rt.side lying (L.s ⁻¹)
Inspiration	0.513 ± 0.015	0.536 ± 0.020	0.524 ± 0.019	0.521 ± 0.011
Expiration	0.509 ± 0.016	0.527 ± 0.018	0.519 ± 0.009	0.517 ± 0.015

Table 4.6 Means and standard deviations of percent changes from supine airflow in different positions at normal end-inspiration and end-expiration.

Phase	Supine (%)	Reclining 30 ⁰ (%)	Lt.side lying (%)	Rt.side lying (%)
Inspiration	100	104.55 ± 4.36	102.25 ± 4.28	101.71 ± 3.21
Expiration	100	104.41 ± 3.74	102.25 ± 3.50	102.23 ± 3.29

4.2.1.4 Characteristics of airflow resistances:

During inspiration, airflow resistances fell in the ranges from 7.340 ± 0.850 cmH₂O/L.s⁻¹ (in reclining position) to 9.878 ± 1.315 (in the supine position). However, there was similar value in airflow resistance found between two side-lying positions (Table 4.7). Airflow resistance decreased about 25% in reclining and 15% in side lying when compared with supine position (Table 4.8). Similarly, this pattern of changes in expiratory variables was detected in that reclining position showed the lowest (5.618 ± 0.623 cmH₂O/L.s⁻¹) whereas supine position had the highest resistance (7.397 ± 0.996 cmH₂O/L.s⁻¹). These values, again, showed a similar airflow resistance between two side-lying positions.

Table 4.7 Means and standard deviations of absolute airflow resistances in different positions at normal end-inspiration and end-expiration.

Phase	Supine (cmH ₂ O /L.s ⁻¹)	Reclining 30 ⁰ (cmH ₂ O /L.s ⁻¹)	Lt.side lying (cmH ₂ O /L.s ⁻¹)	Rt.side lying (cmH ₂ O /L.s ⁻¹)
Inspiration	9.878 ± 1.315	7.340 ± 0.850	8.241 ± 1.202	8.364 ± 1.341
Expiration	7.397 ± 0.996	5.618 ± 0.623	6.255 ± 0.753	6.241 ± 0.799

Table 4.8 Means and standard deviations of percent changes from supine airflow resistance in different positions at normal end-inspiration and end-expiration.

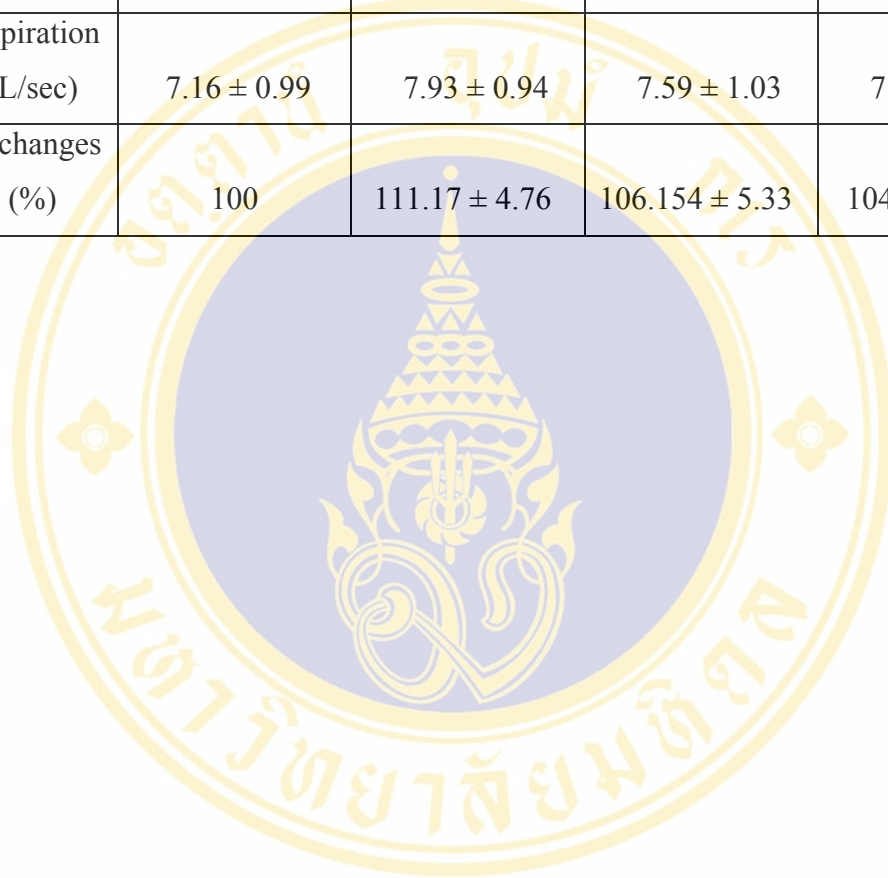
Phase	Supine (%)	Reclining 30 ⁰ (%)	Lt.side lying (%)	Rt.side lying (%)
Inspiration	100	74.90 ± 7.73	83.56 ± 6.19	84.80 ± 08.17
Expiration	100	76.55 ± 7.73	85.08 ± 7.92	84.90 ± 8.28

4.2.1.5 Characteristics of peak expiratory flows:

Peak expiratory flow (PEF) indicated that supine position had lowest flow (429.7 ± 59.6 L/min or 7.16 ± 0.99 L/sec) whereas reclining position had the highest flow (476.0 ± 56.4 L/min or 7.93 ± 0.94 L/sec). However, there was similar value in PEF found between two side-lying positions. PEF increased about 11% in reclining and 5% in side lying when compared with supine position (Table 4.9).

Table 4.9 Means and standard deviations of absolute peak expiratory flows (PEF) and percent changes from supine PEF in different positions.

Phase	Supine	Reclining 30⁰	Lt.side lying	Rt.side lying
Expiration (L/min)	429.7 ± 59.6	476.0 ± 56.4	455.3 ± 61.5	449.3 ± 56.1
Expiration (L/sec)	7.16 ± 0.99	7.93 ± 0.94	7.59 ± 1.03	7.49 ± 0.93
% changes (%)	100	111.17 ± 4.76	106.154 ± 5.33	104.86 ± 4.50



4.2.2 Comparison of mean differences of respiratory variables on position

4.2.2.1 Airway pressures, respiratory airflow rates and airflow resistances during inspiration

There were significant differences of airway pressures, airflows and airflow resistances during inspiration among positions (Table 4.10). Comparing between supine vs. reclining, supine vs. left side lying, supine vs. right side lying, reclining vs. left side lying and reclining vs. right side lying showed highly significant of pressures ($p < 0.001$ in all comparisons) with significant difference in airflows ($0.001 < p < 0.05$). It was found that in all specified comparisons airflow resistances were significantly different ($p < 0.001$). However, there was no significant difference in these variables found between two side-lying positions ($p > 0.05$).

Table 4.10 Levels of confidence obtained from multiple comparisons of mean difference (Bonferroni test) of respiratory variables on position during inspiration.

Position	Inspiration		
	Pressure	Airflow	Airflow resistance
Supine – Reclining 30 ⁰	0.001	0.001	0.001
Supine – Lt.side lying	0.001	0.038	0.001
Supine – Rt.side lying	0.001	0.036	0.001
Reclining 30 ⁰ – Lt.side lying	0.001	0.005	0.001
Reclining 30 ⁰ – Rt.side lying	0.001	0.001	0.001
Lt.side lying – Rt.side lying	1.000	1.000	0.816

4.2.2.1.1 Comparisons on inspiratory airway pressures:

During inspiration, there was significant difference of airway pressures (cmH₂O) among positions (Figure 4.1). Comparing the inspiratory pressures between supine vs. reclining, supine vs. left side lying, supine vs. right side lying, reclining vs. left side lying and reclining vs. right side lying showed highly significant differences of pressures ($p < 0.001$) in all the above comparisons. Airway pressure in supine position was significantly highest among all other positions ($p < 0.05$) whereas airway pressure in the reclining posture was lowest ($p < 0.05$) among four positions specified in this study. No significant difference in airway pressure values was found between two side-lying positions ($p > 0.05$).

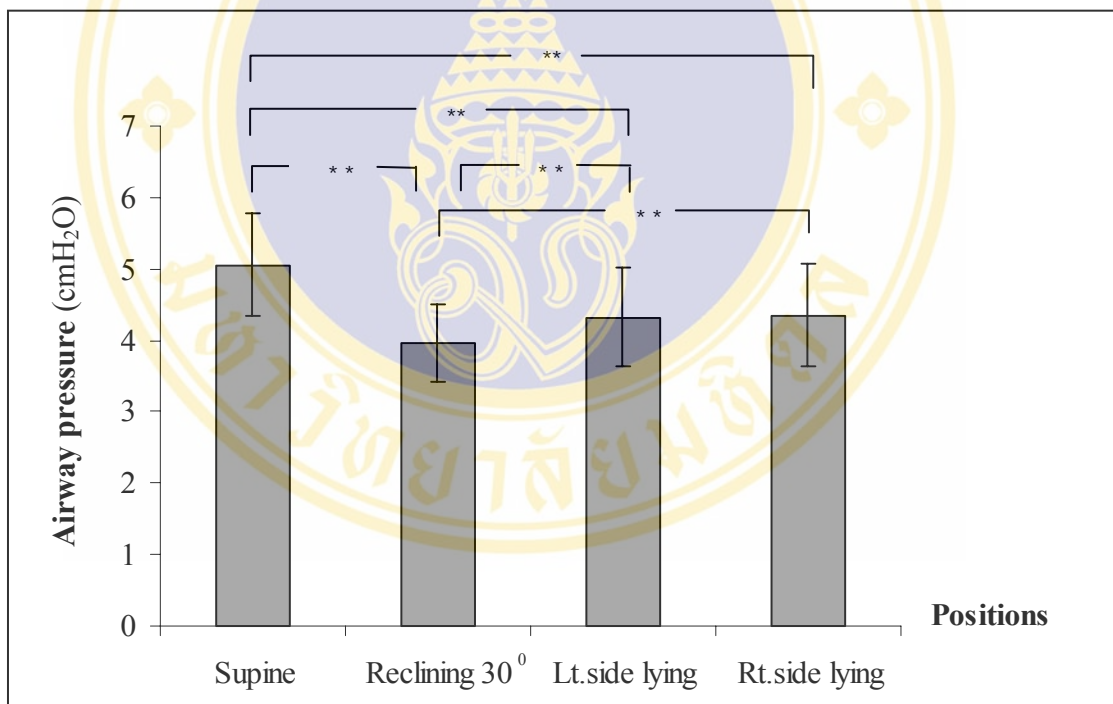


Figure 4.1 Comparison of mean difference of airway pressures among different positions during inspiration (** statistically significant at $p < 0.001$).

4.2.2.1.2 Comparisons on inspiratory airflow rates:

During inspiration, there was significant difference of airflows ($L.s^{-1}$) among positions (Figure 4.2). Comparing the inspiratory airflows between supine vs. reclining, supine vs. left side lying, supine vs. right side lying, reclining vs. left side lying and reclining vs. right side lying showed highly significant differences airflows ($0.001 < p < 0.05$) in all the above comparisons. However, no significant difference in airflow values was found between two side-lying positions ($p > 0.05$).

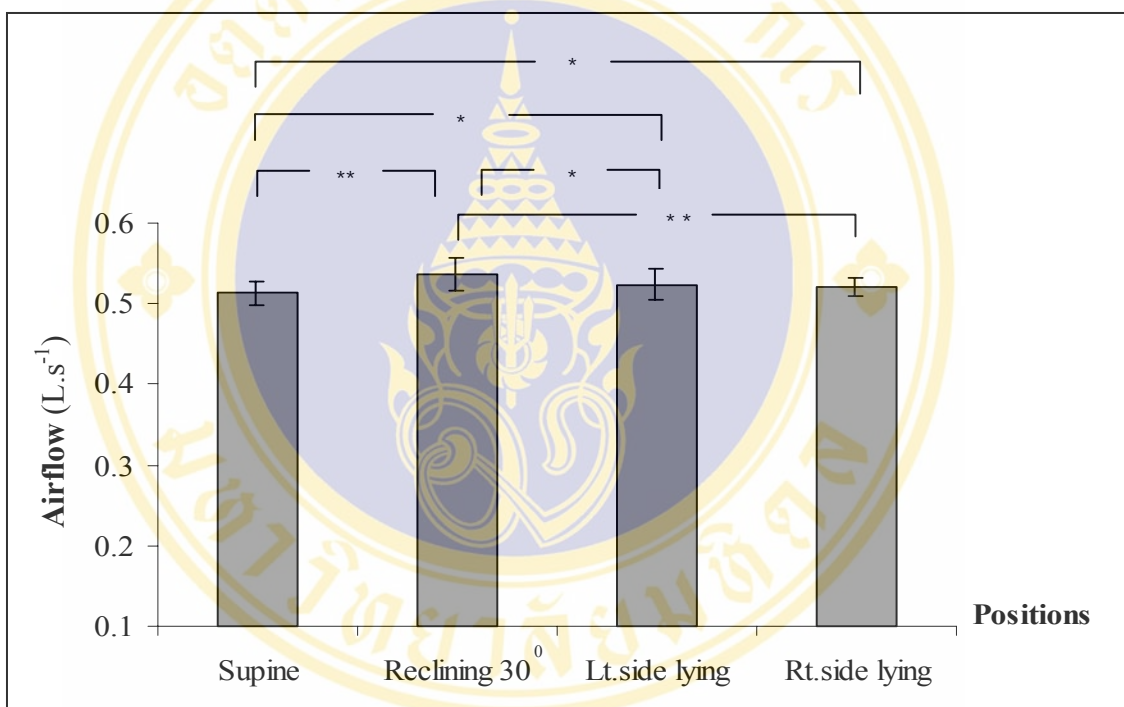


Figure 4.2 Comparison of mean difference of airflows among different positions during inspiration (** statistically significant at $p < 0.001$, * statistically significant at $p < 0.05$).

4.2.2.1.3 Comparisons on inspiratory airflow resistances:

During inspiration, there was significant difference of airflow resistance ($\text{cmH}_2\text{O}/\text{L}\cdot\text{s}^{-1}$) among positions (Figure 4.3). Comparing the inspiratory airflow resistances between supine vs. reclining, supine vs. left side lying, supine vs. right side lying, reclining vs. left side lying and reclining vs. right side lying showed highly significant differences of airflow resistances ($p < 0.001$) in all the above comparisons. Airflow resistance in supine position was significantly highest among all other positions ($p < 0.05$) whereas airflow resistance in the reclining posture was lowest ($p < 0.05$) among four positions specified in this study. No significant difference in airflow resistance values was found between two side-lying positions ($p > 0.05$).

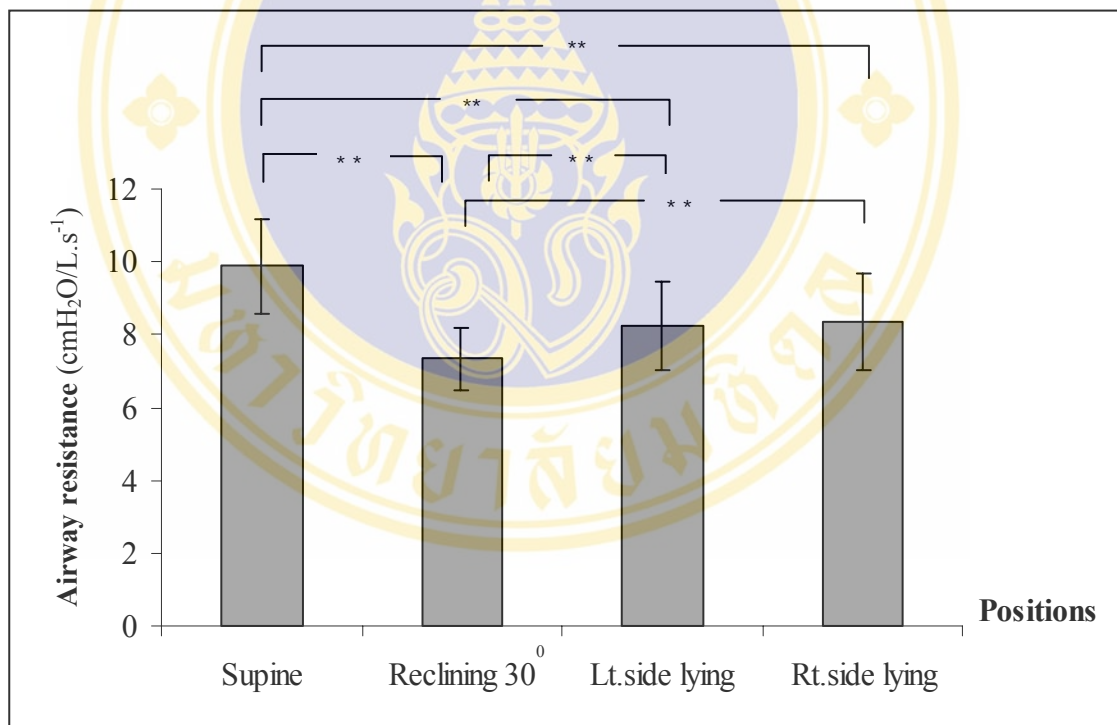


Figure 4.3 Comparison of mean difference of airflow resistances among different positions during inspiration (** statistically significant at $p < 0.001$).

4.2.2.2 Airway pressures, respiratory airflow rates, airflow resistances and peak expiratory flows during expiration

There were significant differences of airway pressures, airflows, airflow resistances and peak expiratory flows during expiration among positions (Table 4.11). Comparing between supine vs. reclining, supine vs. left side lying, supine vs. right side lying, reclining vs. left side lying and reclining vs. right side lying showed highly significant ($0.001 < p < 0.05$) of pressures, airflows, airflow resistances and peak expiratory flows. It was found that in all specified comparisons airflow resistance were significantly different ($p < 0.001$). However, there was no significant difference in these variables found between two side-lying positions ($p > 0.05$).

Table 4.11 Levels of confidence obtained from multiple comparison of mean difference (Bonferroni test) of respiratory variables on position during expiration.

Position	Expiration			
	Pressure	Airflow	Airflow resistance	Peak expiratory flow
Supine – Reclining 30 ⁰	0.001	0.001	0.001	0.001
Supine – Lt.side lying	0.001	0.007	0.001	0.001
Supine – Rt.side lying	0.001	0.004	0.001	0.001
Reclining 30 ⁰ – Lt.side lying	0.001	0.001	0.001	0.001
Reclining 30 ⁰ – Rt.side lying	0.008	0.001	0.001	0.001
Lt.side lying – Rt.side lying	1.000	1.000	1.000	0.355

4.2.2.2.1 Comparisons on expiratory airway pressures:

During expiration, there was significant difference of airway pressures (cmH₂O) among positions (Figure 4.4). Comparing the expiratory pressures between supine vs. reclining, supine vs. left side lying, supine vs. right side lying, reclining vs. left side lying and reclining vs. right side lying showed highly significant differences of pressures (0.001<p<0.05) in all the above comparisons. Airway pressure in supine position was significantly highest among all other positions (p<0.05) whereas airway pressure in the reclining posture was lowest (p<0.05) among four positions specified in this study. No significant difference in airway pressure values was found between two side-lying positions (p>0.05).

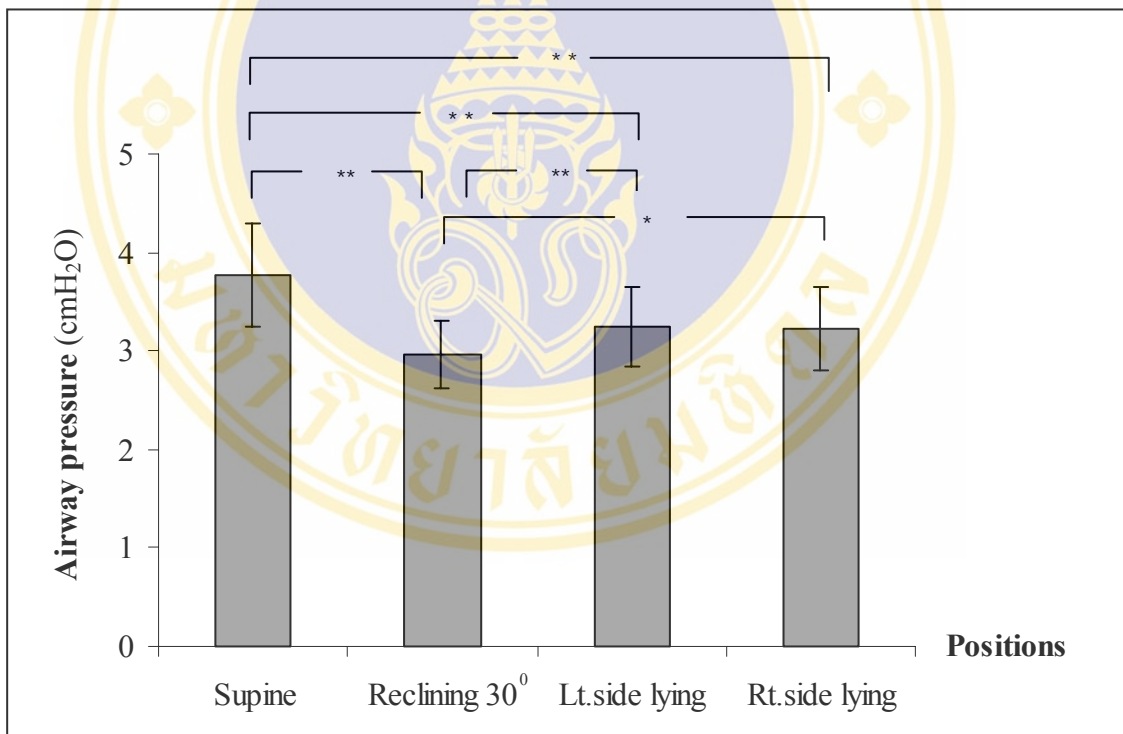


Figure 4.4 Comparison of mean difference of airway pressures among different positions during expiration (** statistically significant at p<0.001, * statistically significant at p<0.05).

4.2.2.2.2 Comparisons on expiratory airflow rates:

During expiration, there was significant difference of airflows ($L \cdot s^{-1}$) among positions (Figure 4.5). Comparing the expiratory airflows between supine vs. reclining, supine vs. left side lying, supine vs. right side lying, reclining vs. left side lying and reclining vs. right side lying showed highly significant differences airflows ($0.001 < p < 0.05$) in all the above comparisons. However, no significant difference in airflow values was found between two side-lying positions ($p > 0.05$).

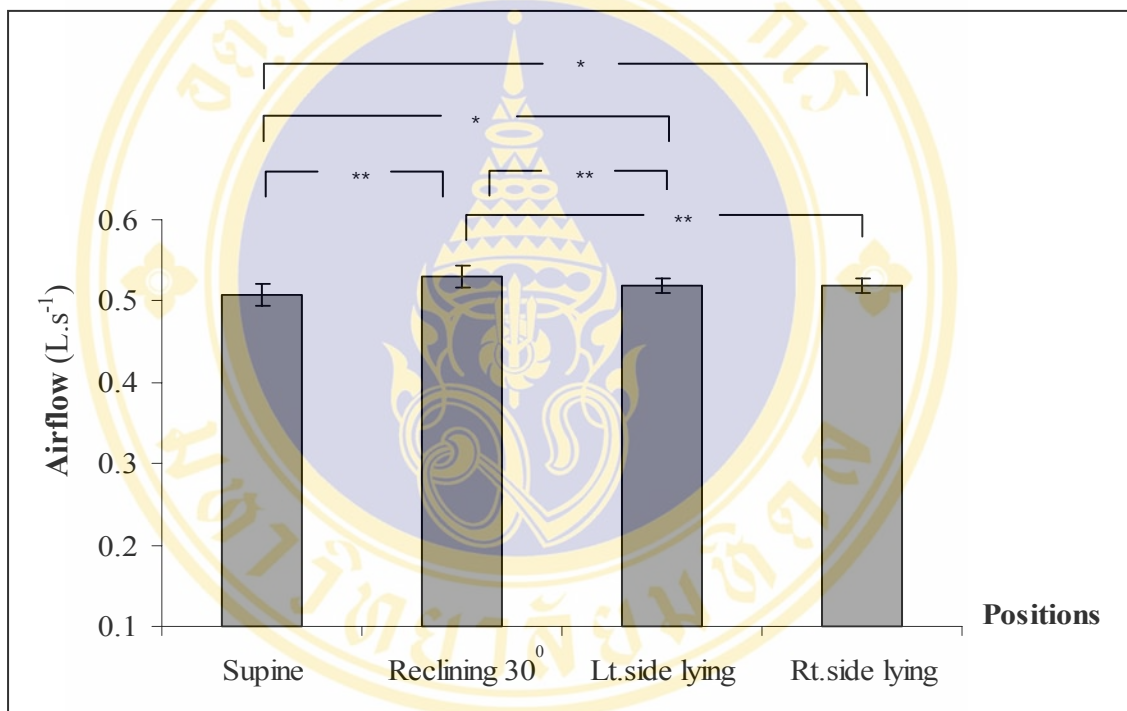


Figure 4.5 Comparison of mean difference of airflows among different positions during expiration (** statistically significant at $p < 0.001$, * statistically significant at $p < 0.05$).

4.2.2.2.3 Comparisons on expiratory airflow resistances:

During expiration, there was significant difference of airflow resistance among positions (Figure 4.6). Comparing the expiratory airflow resistances between supine vs. reclining, supine vs. left side lying, supine vs. right side lying, reclining vs. left side lying and reclining vs. right side lying showed highly significant differences of airflow resistances ($p < 0.001$) in all the above comparisons. Airflow resistance in supine position was significantly highest among all other positions ($p < 0.05$) whereas airflow resistance in the reclining posture was lowest ($p < 0.05$) among four positions specified in this study. No significant difference in airflow resistance values was found between two side-lying positions ($p > 0.05$).

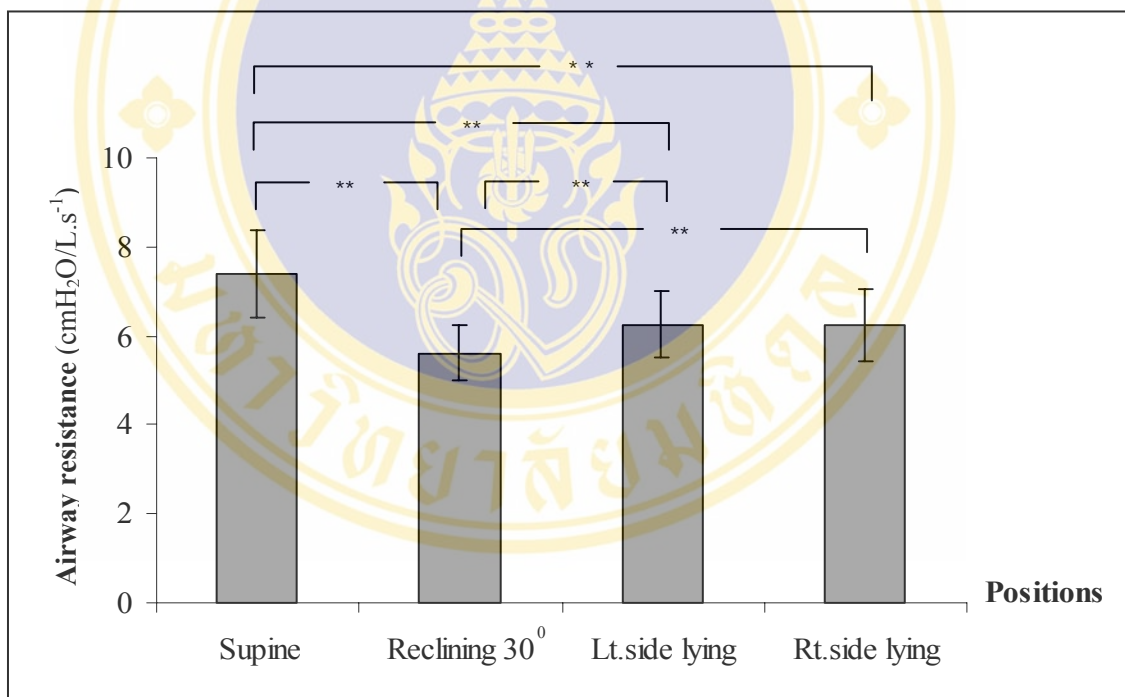


Figure 4.6 Comparison of mean difference of airflow resistances among different positions during expiration (** statistically significant at $p < 0.001$).

4.2.2.2.4 Comparisons on expiratory peak expiratory flows:

There was significant difference of peak expiratory flows (PEF, L/min) among positions (Figure 4.7). Comparing the peak expiratory flows between supine vs. reclining, supine vs. left side lying, supine vs. right side lying, reclining vs. left side lying and reclining vs. right side lying showed highly significant differences of PEF ($p < 0.001$) in all the above comparisons. However, no significant difference in PEF values was found between two side-lying positions ($p > 0.05$).

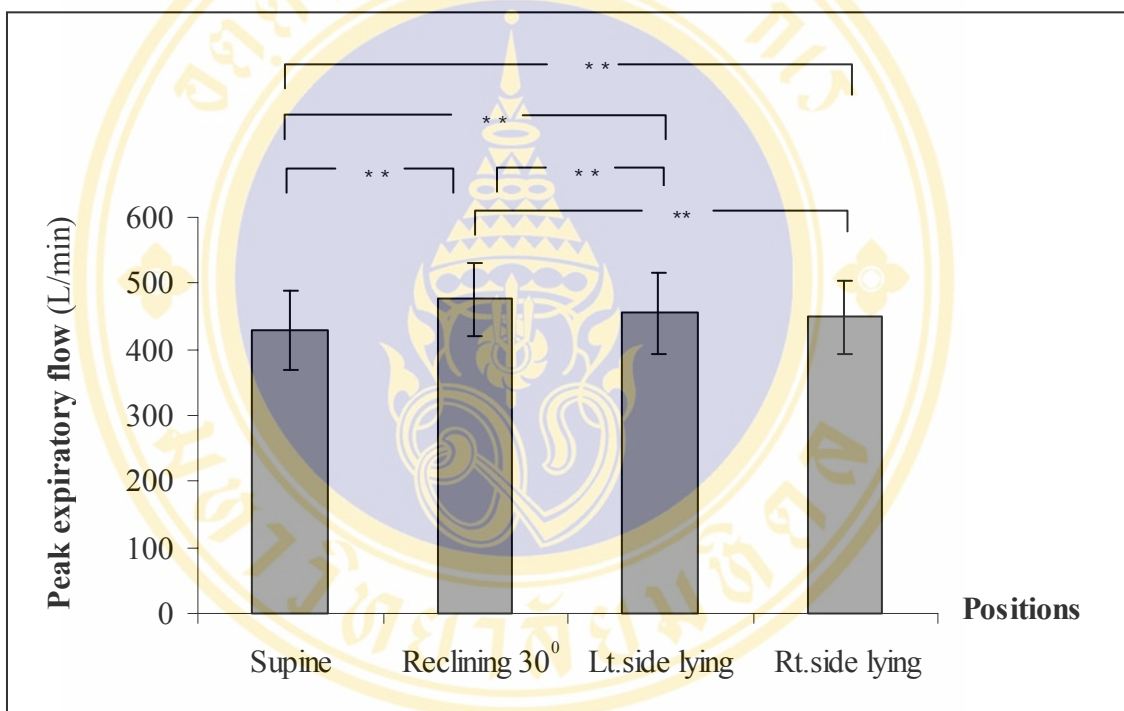


Figure 4.7 Comparison of mean difference of peak expiratory flows among different positions during expiration (** statistically significant at $p < 0.001$).

CHAPTER V

DISCUSSION

5.1 Characteristics of Subjects

Thirty healthy male subjects were voluntarily participated in the present study. They were screened according to demographic information, medical history and habitual physical activity level. Habitual physical activity composed of three components as physical activity at work, sport participation and leisure time. This questionnaire was derived from reliable published data (79). Additionally, all subjects underwent body fat assessment and pulmonary function test, in which the results subjectively ensured healthy status of subjects. It was found that anthropometric data of subjects such as BMI indicated the non-obese characteristics of subjects in this study.

5.2 Respiratory Rates, Tidal Volumes and Minute Ventilations

During data collection of the main variables (i.e. airway pressure, flow rate, airflow resistance and peak expiratory flow), respiratory rates (RR) and tidal volumes (V_T) in supine, reclining, left and right side lying positions were all in the same range. However, the high RR found in this study might be the result of unfamiliar mouth breathing. Breathing through the nose exhibits many benefits since each nostril is innervated by fifth cranial nerves from the opposite side of the brain. Each nostril functions independently and synergistically in filtering, warming, moisturizing, dehumidifying and smelling. Breathing through the mouth, in contrast, associated with hyperventilation. This causes an exacerbates airway narrowing, high blood pressure, heart disease and many other medical problems (88). Mouth breathing in sleep is frequently accompanied with snoring and leads also to obstructive sleep apnea.

Minute ventilation (\dot{V}_E) obtained from this study was slightly higher than the literature due to higher respiratory rates and tidal volumes. Resting minute ventilation in human was about 6 L/min which was the multiplication of the frequency of breathing (12 breaths/min) and the volume of each breath (0.5 L). This normal ventilation maintains concentrations of oxygen and carbon dioxide in the alveolar gas through the process of diffusion and also maintains normal partial pressures of oxygen and carbon dioxide in the blood flowing from the capillaries (51, 53, 54, 57). Hyperventilation, refers to overbreathing in which ventilation exceeds the metabolic requirement, could cause dizziness, numbness, tingling and respiratory alkalosis. On the contrary, hypoventilation caused by too shallow breathing which produced hypoxemia, hypercapnia and respiratory acidosis (89). In the present study, no signs and symptoms of ventilatory deviation were identified from subjects. Thus the unfamiliar mouth breathing might cause higher ventilation. However, the minute ventilation in each position tested was not statistically different (Table 4.2). Comparisons of main variables (i.e. airway pressure, airflow, airflow resistance and peak expiratory flow) among position could be done conclusively.

5.3 Effect of Position on Airway Pressures

In the present study, it was postulated that changing in position would induce an alteration in airway pressure. The results showed a significant difference of airway pressures among positions during inspiration. However, no significant difference was found between two side-lying positions. The pattern of changes in pressures during inspiration was similar to that of expiration. Airway pressure in this study decreased about 20% in reclining and 15% in side lying when compared with the supine position. Results obtained from this study was similar to a previous study in that the differential pressure was the highest in supine and side lying airway pressure was greater than sitting (16).

It was possible that gravity might induce narrowing of the collapsible portion of airway, which resulted in a more negative pressure during inspiration in supine following reflex activation of genioglossal tone (90). Mouth breathing would make the pharyngeal pressure became more negative and some susceptible portion of upper

airway might be collapsed. This required more upper airway muscle activation to maintain airway patency (91). As muscle activation during sleep was reduced (2, 12, 13, 26), apneas often occur during sleep when insufficient muscle activation failed to counteract the high negative pharyngeal pressure during inspiration.

Neil and coworkers in 1997 compared the upper airway closing pressure (UACP), the minimum pressure generated in the last two breaths before an arousal occurred in a nasal occlusion test and upper airway opening pressure (UAOP), the minimal continuous positive airway pressure required to prevent apneas and hypopneas, in obese patients with severe OSA. Results showed that the upper airway became less collapsible (reduced UACP) and was more easily opened (reduced UAOP) when reclining 30° compared with supine. It was also indicated that side lying did not reduce the upper airway collapsibility but did reduce UAOP, which the part of airway could be easier to open when compared with supine. Therefore, a change from supine to side lying increased the stability of upper airway. This also implied that both reclining 30° and side lying resulted in 50% reduction in nasal continuous positive airway pressure (NCPAP) (9). It seemed possible that UACP might be related to upper airway dimension in different body position (15, 45). Comparing between supine and side lying position, there was significant reduction of P_{crit} in side lying (pressure surrounding the tissue), which presumed by a change of the shape of collapsible segment during sleep (73). Previous studies showed that P_{crit} in supine was positive whereas in side lying was negative (9, 69, 70, 73).

It was reported that respiratory effort during inspiration is always greater than expiratory effort. During spontaneous breathing, inspiratory muscles were activated during inspiration which induced dropping in intrathoracic pressure. During expiratory phase, elastic recoil of chest wall and lung tissue were responsible for increasing intrathoracic pressure (51, 53, 54, 57). The present study did not compare between inspiratory and expiratory pressures but inspiratory pressure seemed to be higher than expiratory pressure. Inspiratory and expiratory transmural pressure in tidal breathing is +7 and +5 cmH₂O, respectively in which inspiration is more positive than expiration (51).

5.4 Effect of Position on Respiratory Airflows

There was a significant effect of body position on airflow. Side lying caused high airflow and the highest in reclining which supine offered the lowest airflows. Neither left nor right side lying induced difference in airflow. Based on the assumption of postural-induced changes in airway dimension (8, 14, 15, 50), it is assumed that both side-lying postures cause similar deviations of lung tissues. There was tendency of supine which offers the lowest airflows. Tendency of the present study was similar to previous study that airflow was 0.25, 0.21 and 0.23 L/s in sitting, supine and side lying, respectively (16). Airflow in this study increased about 5% in reclining and 2% in side lying when compared with supine position.

Improvement of airflow in reclining might be due to an increase in pharyngeal diameter (92, 93). A previous study had demonstrated that airflow was improved by changed in upper airway dimension induced by a mechanism called “caudal tracheal traction”, which presumably lengthened the upper airway (94). Two mechanisms might explain these changes in airway dimension. First, P_{crit} (pharyngeal critical closing pressure, an index of airway collapsibility) had been decreased when airway lengthened. The airway should have been distended if environmental pressure decreased. P_{crit} indicated that obese female have less tendency of airway collapse than male (95). Second, airway lengthening would increase the tension in pharyngeal mucosa which resulted in resistant of extra-airway collapsing pressure from surrounding tissues (94, 96). Additionally, the changes in position related to changes an extrinsic compression to the airway in normal adults (97).

The present study demonstrated that there are fluctuations of pressure and resistance which caused by position. However, airflows in both inspiration and expiration change in the relatively narrow ranges. A previous study found no effect of changing body position from upright to supine on inspiratory airflow either oral or nasal breathing route (98). However, there was a small decrease in expiratory airflow in supine position in which the authors proposed the possibility of an expiratory airflow resistance was increased (98). Partial expiratory flow limitation, occurred in supine position in obese subjects, was associated with orthopnea. Expiratory flow

limitation could induce dynamic hyperinflation, resulted in an increase in the subsequent inspiratory work of breathing (99). However, a collapse of the upper airway during expiration was rare in non OSA patients (100).

5.5 Effect of Position on Airflow Resistances

Airflow resistance during spontaneous breathing cycle in this study was the result of reverse transmural pressure on the non-cartilaginous collapsible structure of upper airway. It is known that about 50-80% of airflow resistance was taken place in the upper respiratory system. Small airways, collapsible part in the lung, accounted for another 20-50% (51, 53, 54, 57).

Most studies determined nasal resistance, very few had been attempted to investigate the oral resistance (16). The present study used a transient airflow interruption technique to measure oral airflow resistance. It was difficult to compare airflow resistance values in this study with previous investigations due to the differences in methods and modalities of measurement. Many direct and indirect measurements include spirometry, pneumotachography, body plethysmography, forced oscillation technique, airflow interruption technique and esophageal balloon catheter technique (101, 102).

Previous investigations correspondingly indicated that oral airway resistance during wakefulness in supine was greater than upright position in OSA (103) and normal subjects (104). The present study, as well as the previous study (16), confirmed that upper airway resistance was higher in supine than sitting. Effect of position had influenced on airflow resistance which was determined that reclining position showed the lowest whereas supine position had the highest resistance. These studies and the present study showed a similar airway resistance between two side-lying positions. Higher impedance of airflow during normal inspiration was found in both oral and nasal pathways (22). Value obtained from the present study was higher than that obtained from the previous study (16), which might be due to method of resistance calculation. In this study, the resistance was the ratio of pressure and flow. Changing

in pressure signal was more obviously observed than flow resulted in the resistance was changed following tendency of changes in pressure.

Airflow resistance in this study decreased about 25% in reclining and 15% in side lying when compared with supine position. Therefore, postural effect played a dominant role on the respiratory patency (105). In the supine position, gravity increased airway resistance and reduced upper airway size for the reason that upper airway structure (include the tongue, soft palate, uvula and epiglottis) moved toward the posterior pharyngeal wall (8, 44, 50, 64). Additionally, the cross-sectional area of tongue, uvular width and soft palate thickness became greater by the effect of gravity, which resulted in a reduction in upper airway diameter (8). It was also indicated that in supine position, posterior airway space depended mainly on the hyoid bone position (20). Sitting position appeared to increase upper airway size (14, 15, 44, 50, 106) due to changing in gravitational vector (64) possibly via caudal traction of upper airway (94) but side lying position did not (14, 15, 45). These inferred that supine position might be one of primary causes of upper airway resistance syndrome (43). Side lying position, on the other hand, showed less evident on the reduction of posterior deviation of the tongue (10). Controversially, Meysman and Vincken in 1998 demonstrated that there was no detectable evident of upper airway dimension in recumbent postures (supine, left and right side lying) in young non-obese subjects (107). The importance of upper airway length was the major mechanical factor for upper airway patency (8, 96). The mechanisms that could explain an improvement of upper airway patency were a stretching of trachea and upper airway structures resulted in the reduction of its compliance and made it more resistant to prevent the collapsing by negative pressure during inspiration. In addition, caudal displacement of fat and other structures surrounding the pharynx reduced extrinsic compression thus improved the upper airway patency in sitting position (94, 96). However, Series and coworkers in 1990 suggested that caudal traction of upper airway could only be applied to laryngeal and oropharyngeal structures but not to the nasopharynx due to its flabby non-cartilaginous structure which could not impede the high extrathoracic pressure on nasal flare (108).

Additionally, effect of gravity in sitting position offered higher FRC due to changing shape and length of diaphragm (106). These change resulted in less muscle force and also less negative airway pressure (109). Like other skeletal muscles, changing in position might exert some effects on the respiratory muscle function, which were described as changing in the optimal length of muscle contraction and mechanical efficiency. The rib cage was expanded passively by action of the diaphragm during quiet breathing in sitting position. However in supine position, changing in shape of diaphragm, the compliance of abdominal wall and rib cage and the mechanical interaction between diaphragm and rib cage was less efficient, resulting in less expansion of rib cage (110). It was indicated that change in position affected lung volumes (44) and pharyngeal size in normal subjects (111) by increased airway resistance both in an experimental animals (94) and human (111-113). This mechanism might be related to the pathophysiology of sleep apnea onset (108).

A change in oral airway shape might be related to head and neck position during mouth breathing thus the head position also should be considered. Therefore, the prevention of upper airway obstruction produced by neck extension or forward displacement of the mandible or closures the mouth (92). However, in this study head and neck position were hold in neutral position.

Previous studies showed the narrowing of the upper airway in normal, snorer and OSA patients (77, 114). Occurrence of airway resistance in sleep apnea syndrome could occur not only during inspiration but also during expiration (20, 77, 115). It was demonstrated that there trended to be higher in inspiratory than expiratory resistance which was similar to previous studies (8, 61, 116). These promoted the dynamic hyperinflation, which resulted in an increase work of breathing and occurrence of hypercapnia or hypoxia during sleep (115). Contrary to the study of Hyatt and Wilcox that found mean upper airway resistance during expiration ($1.16 \text{ cmH}_2\text{O/L.s}^{-1}$) was higher than during inspiration ($1.06 \text{ cmH}_2\text{O/L.s}^{-1}$) (112) which differed from other reports. However, an increase in upper airway expiratory resistance in OSA patients did not explained by the Starling resistor theory (77) and might induce transient interruptions and/or a prolongation of expiration (114).

It was possible that an increase in airway resistance from wakefulness to deep sleep might be due to the loss of muscle tone (117). Oral airflow resistance occurred during sleep even in normal subjects (118) and might be increased in sleep breathing disorders patients (119) and led to an increase work of breathing during sleep (21, 120). The present study indicated that increased airflow resistance contributed to the occurrence of OSA and implied that controlling airway patency was essential for the treatment of OSA patients. These results suggested that sleep in reclining or side lying was suitable for sleep therapy.

5.6 Effect of Position on Peak Expiratory Flows

The present study showed that peak expiratory flow (PEF) in normal subjects was significantly influenced by body position. Supine position had the lowest whereas reclining position had the highest flow, with similar values found between two side-lying positions. PEF increased about 11% in reclining and 5% in side lying when compared with supine position.

Previous investigations showed that standing caused higher PEF than all other positions (121) and lower in recumbent postures (supine, left and right side lying) than sitting (107). PEF were 10.02, 9.32, 9.19 and 8.98 L/s in sitting, supine, left and right side lying, respectively (107). The mechanism that could explain the reduction in maximal expiratory flow rate and lung volume were due to increasing in resistance of upper airway in these postures (14).

A previous report found a small change in total lung capacity due to compensation of human body between supine and side lying. The abdominal contents moved forward and placed which positive affects function and length of abdominal muscles when compared side lying with supine (122).

5.7 Limitation of the Study

First limitation of the present study is due to the incapability to explore nasal and oral cavities of subjects. It is assumed that all subjects had similar anatomic contour and dimension of upper airways.

Second limitation of the methods used in this study should be considered as a non-invasive method for measuring airway resistance which combined upper airway resistance and total airway resistance. It requires an invasive study design, insertion of esophageal balloon, in order to differentiate lower airway resistance from total airway resistance. These differences in experimental design make it difficult to compare with previously performed using invasive studies. However, this non-invasive study on airway resistance is very practical. The present study, the effect of sleep positions on airflow resistance were examined in young and slim subjects without OSA during wakefulness and remains a possibility that the same effect was seen in the other age and obese patients with OSA during sleep. These combinations of subjects and technical differences among the study may explain the differences in the results.

5.8 Clinical Implications and Further Study

This study provided the information about airflow resistances on different sleep positions during awake condition. In addition, this study provided preliminary data of airflow resistances in healthy young males. The importance of studying positional changes in airflow resistance at least in normal subjects was related to better understanding of pathophysiology of OSA. The beneficial information for positional therapy could be as simple intervention in hospital or at home. A role of physical therapy is a recommendation the sleep position for snorer in order to decrease snoring and in treatment mild OSA patients to prevent apnea/hypopnea during sleep.

For further study, improving method for measuring airflow resistance in order to obtain more accurate airflow resistances is need. Comparative study between standard method by whole body plethymograph and pneumotachometer should be done. It is also interesting to study in other disease-related airway obstruction such as chronic obstructive pulmonary disease (COPD) combined with upper airway obstruction.

CHAPTER VI

CONCLUSION

The present finding is unique in that it is an initial non-invasively measurement of two physical variables: upper airway pressure and flow, which are affected by position during wakefulness condition. It can be indicated from the present study that positions affected on airway pressure, airflow, airflow resistance and peak expiratory flow in both inspiration and expiration as follows.

1. Airway pressures during inspiratory and expiratory phases showed the highest values in supine, followed by in side lying and the lowest in reclining. No difference of airway pressure between left and right side lying.
2. Airflows during inspiratory and expiratory phases showed the highest values in reclining, followed by in side lying and the lowest in supine. No difference of airflow between left and right side lying.
3. Airflow resistances during inspiratory and expiratory phases showed the highest values in supine, followed by in side lying and the lowest in reclining. No difference of airflow resistance between left and right side lying.
4. Peak expiratory flows showed the highest values in reclining, followed by in side lying and the lowest in supine. No difference of peak expiratory flow between left and right side lying.

The airway patency was observed the highest in reclining and side lying tended to higher than supine position. Therefore, this simple intervention might be useful in treatment of sleep disorders. It could be recommended as alternative treatment modalities.

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APPENDIX A

THE ETHICAL COMMITTEE ON RESEARCH INVOLVING HUMAN SUBJECT

2 ถนนพหลโยธิน 2 PRANNOK Rd.
บางกอกน้อย BANGKOKNOI
กรุงเทพมหานคร 10700 BANGKOK 10700



Tel. (662) 4197000 ต่อ 6405-6
FAX (662) 4197000 ต่อ 6405

Siriraj Ethics Committee

Certificate of Approval

COA no.Si 230/2004

Protocol Title : Sleep position on airflow resistance during wakefulness in healthy Thai males.
SiEC number : 194/2547
Principal Investigator/Affiliation : Miss Soontaree Chayawatcharakul / School of Physiotherapy : Department of Orthopedic Surgery
 Faculty of Medicine Siriraj Hospital, Mahidol University
Research site : Faculty of physical therapy and applied movement science project 4th floor
Approval includes :

1. EC Submission form
2. Participant information sheet
3. Informed consent form
4. Principal Investigator's Curriculum vitae

Approval date : November 12, 2005
Expired date : November 11, 2006

This is to certify that Siriraj Ethics Committee is in full Compliance with International Guidelines For Human Research Protection such as Declaration of Helsinki, The Belmont Report, CIOMS Guidelines and the International Conference on Harmonization in Good Clinical Practice (ICH-GCP)

.....
(Prof. Sumalee Nimmannit, M.D.)
Chair Person

November 24, 2005
date

.....
(Clin. Prof. Piyasakol Sakolsathayadorn)
Dean of Faculty of Medicine Siriraj Hospital

November 24, 2005
date

APPENDIX B.1

CONSENT FORM

(หนังสือแสดงเจตนายินยอมเข้าร่วมการศึกษา)

วันที่.....เดือน.....พ.ศ.....
 ข้าพเจ้า..... อายุ.....ปี อาศัยอยู่บ้านเลขที่.....
 ถนน.....ตำบล.....อำเภอ.....
 จังหวัด.....รหัสไปรษณีย์.....โทรศัพท์.....

ขอแสดงเจตนายินยอมเข้าร่วมโครงการวิจัยเรื่อง ทำนองต่อความต้านทานของกร
 ไหลเวียนของอากาศในทางเดินหายใจขณะตื่นในชายไทยสุขภาพดี

โดยข้าพเจ้าได้รับทราบรายละเอียดเกี่ยวกับที่มาและจุดมุ่งหมายในการทำวิจัย รายละเอียด
 ขั้นตอนต่างๆที่จะต้องปฏิบัติหรือได้รับการปฏิบัติ ประโยชน์ที่คาดว่าจะได้รับการวิจัยและความ
 เสี่ยงที่อาจเกิดขึ้นจากการเข้าร่วมการวิจัย รวมทั้งแนวทางป้องกันและแก้ไขหากเกิดอันตรายขึ้น
 โดยได้อ่านข้อความที่มีรายละเอียดอยู่ในเอกสารชี้แจงผู้เข้าร่วมการวิจัยโดยตลอด อีกทั้งยังได้รับ
 คำอธิบายและตอบข้อสงสัยจากหัวหน้าโครงการวิจัยเป็นที่เรียบร้อยแล้ว

ข้าพเจ้าจึงสมัครใจเข้าร่วมโครงการวิจัยนี้

หากข้าพเจ้ามีข้อข้องใจเกี่ยวกับขั้นตอนของการวิจัย หรือหากเกิดผลข้างเคียงที่ไม่พึง
 ประสงค์จากการวิจัยขึ้นในกับข้าพเจ้า ข้าพเจ้าจะสามารถติดต่อกับ นางสาวสุนทรี ชยาวัชรกุล ที่
 โทรศัพท์ 0-9880-2264 ได้ตลอด 24 ชม.

หากข้าพเจ้าได้รับการปฏิบัติไม่ตรงตามที่ได้รับไว้ในเอกสารชี้แจงผู้เข้าร่วมการวิจัย
 ข้าพเจ้าจะสามารถติดต่อกับประธานคณะกรรมการจริยธรรมการวิจัยในคน หรือผู้แทน ได้ที่
 สำนักงานคณะกรรมการจริยธรรมการวิจัยในคน ตึกอศุขเวชวิกรม ชั้น 5 ร.พ.ศิริราช โทร.
 (02)419-7000 ต่อ 6405

ข้าพเจ้าได้รับทราบถึงสิทธิ์ที่ข้าพเจ้าจะได้รับข้อมูลเพิ่มเติมทั้งทางด้านประโยชน์และโทษ
 จากการเข้าร่วมการวิจัย และสามารถถอนตัวหรืองดเข้าร่วมการวิจัยได้ทุกเมื่อ โดยจะไม่มีผลกระทบ
 ต่อการบริการและการรักษาพยาบาลที่ข้าพเจ้าจะได้รับต่อไปในอนาคตและยินยอมให้ผู้วิจัยใช้ข้อมูล
 ส่วนตัวของข้าพเจ้าที่ได้รับจากการวิจัย แต่จะไม่เผยแพร่ต่อสาธารณะเป็นรายบุคคล โดยจะนำเสนอ
 เป็นข้อมูลโดยรวมจากการวิจัยเท่านั้น

หากผู้วิจัยมีข้อมูลเพิ่มเติมทั้งด้านประโยชน์และโทษที่เกี่ยวข้องกับการวิจัยนี้ ผู้วิจัยจะแจ้งให้ทราบอย่างรวดเร็วโดยไม่ปิดบัง

ข้าพเจ้าได้เข้าใจข้อความในเอกสารชี้แจงผู้เข้าร่วมการวิจัย และหนังสือแสดงเจตนายินยอมนี้โดยตลอดแล้ว จึงลงลายมือชื่อไว้

ลงชื่อ.....ผู้เข้าร่วมการวิจัย/ผู้แทนโดยชอบธรรม/วันที่.....
(.....)

ลงชื่อ.....ผู้ให้ข้อมูลและขอความยินยอม/หัวหน้าโครงการวิจัย/วันที่.....
(นางสาวสุนทรี ชยวัชรกุล)

ในกรณีที่ผู้เข้าร่วมการวิจัยอ่านหนังสือไม่ออก ผู้ที่อ่านข้อความทั้งหมดแทนผู้เข้าร่วมการวิจัย คือจึงลงลายมือชื่อไว้เป็นพยาน

ลงชื่อ.....พยาน/ วันที่.....
(.....)

APPENDIX B.2

PARTICIPANT INFORMATION SHEET

(เอกสารแนะนำสำหรับอาสาสมัคร)

ชื่อโครงการ	ทำนอต่อความต้านทานของการไหลเวียนของอากาศในทางเดินหายใจขณะตื่น ในชายไทยสุขภาพดี
ชื่อผู้วิจัย	นางสาวสุนทรี ชยาวัชรกุล
สถานที่วิจัย	คณะกายภาพบำบัดและวิทยาศาสตร์การเคลื่อนไหวประยุกต์ ชั้น 4 มหาวิทยาลัยมหิดล เชียงสะพานปิ่นเกล้า กรุงเทพฯ โทรศัพท์ 0-2433-7090
ผู้ให้ทุน	ไม่มี

โครงการวิจัยนี้ทำขึ้นเพื่อศึกษาผลของท่านต่อการเปลี่ยนแปลงของการต้านทานการไหลเวียนอากาศที่อาจมีต่อทางเดินหายใจขณะตื่นในชายสุขภาพดี ซึ่งจะมีประโยชน์ที่คาดว่าจะได้รับคือ

1. เพื่อใช้เป็นแนวทางในการแนะนำท่านสำหรับผู้ป่วยที่มีภาวะอุดกั้นของทางเดินหายใจขณะนอนหลับในระดับที่ไม่รุนแรง เพื่อป้องกันการหยุดหายใจหรือการได้รับอากาศลดลงขณะนอนหลับ
2. เพื่อใช้เป็นแนวทางสำหรับการศึกษาในอนาคตในผู้ป่วยที่มีอาการของโรคทางระบบหายใจอื่นๆ เช่น โรคปอดอุดกั้นเรื้อรัง

ขั้นตอนการวิจัย

1. ขั้นเตรียมการ

ผู้วิจัยคัดเลือกผู้เข้าร่วมวิจัยที่มีคุณสมบัติตามที่กำหนด โดยสอบถามเกี่ยวกับข้อมูลส่วนตัว ประวัติทางสุขภาพ ประเมินระดับกิจกรรมทางร่างกายด้วยแบบสอบถาม ทำการชั่งน้ำหนัก วัดส่วนสูง ประเมินการสะสมของไขมันในร่างกาย ได้แก่

- การหาค่าอัตราส่วนเส้นรอบเอวต่อเส้นรอบสะโพก โดยใช้สายวัดวัดเส้นรอบของบริเวณที่แคบที่สุดเหนือสะดือ แต่ต่ำกว่าซี่โครง และเส้นรอบสะโพกในส่วนที่หนูนที่สุด และนำค่าที่ได้มาหาอัตราส่วน

- การหาเปอร์เซ็นต์ไขมัน ซึ่งเริ่มต้นจากดึงผิวหนังส่วนที่จะวัด หนีบด้วยเครื่องมือวัดความหนาของผิวหนัง ค้างไว้ 1-2 วินาที ทำการวัด 4 จุดแต่ละจุดวัด 2 ครั้ง โดยวัดจุดอื่นแล้ววนกลับมาวัดที่จุดต้องการ เพื่อให้เวลาผิวหนังได้คืนตัว จากนั้นนำผลรวมของของทั้ง 4 จุดไปคำนวณหาเปอร์เซ็นต์ไขมัน

ประเมินสมรรถภาพปอด โดยใช้เครื่องมือทดสอบสมรรถภาพปอด ซึ่งเริ่มต้นจากให้ผู้เข้าร่วมวิจัยนั่งพัก เมื่อเริ่มทำผู้วิจัยจะอธิบายให้ผู้เข้าร่วมวิจัยเข้าใจชัดเจน ใช้ที่บีบจมูก อมท่อเป่าให้สนิทไม่มีรูรั่วและผู้ทดสอบหายใจเข้าออกธรรมดา เมื่อผู้วิจัยให้สัญญาณผู้เข้าร่วมวิจัยจึงหายใจเข้าลึกจนสุดปอดแล้วเป่าออกมาเข้าไปในเครื่องอย่างแรงและเร็ว และนานที่สุดเท่าที่จะทำได้อย่างน้อย 4-6 วินาที ผู้เข้าร่วมวิจัยเป่าทั้งหมด 3 ครั้งแต่ละครั้งพักอย่างน้อย 1 นาที

เมื่อผู้เข้าร่วมวิจัยผ่านการคัดเลือกตามเกณฑ์ที่กำหนด ผู้วิจัยจะอธิบายวัตถุประสงค์ ขั้นตอน และประโยชน์ของการวิจัยครั้งนี้ จากนั้นผู้เข้าร่วมวิจัยลงนามในใบยินยอมเข้าร่วมการวิจัย

2. ขั้นตอนการเก็บข้อมูล

- วัดค่าความดันอากาศและอัตราการไหลของอากาศ โดยก่อนเริ่มการเก็บข้อมูลจะทำการวัดอัตราการหายใจขณะพักในท่านั่งหลังตรงบนเตียง หลังจากนั้นให้ผู้เข้าร่วมวิจัยนอนในท่าที่สุ่มเลือกไว้อันดับแรก อมท่อเป่าและใส่ที่บีบจมูก และให้ผู้เข้าร่วมวิจัยหายใจตามปกติทางปากเป็นเวลา 5 นาที เครื่องมือจะบันทึกความดันและการไหลเวียนของอากาศอย่างต่อเนื่องในรูปแบบของกราฟ และตัวเลข ค่าความต้านทานของอากาศในทางเดินหายใจสามารถคำนวณได้จากสมการ

$$\text{ความต้านทานอากาศในทางเดินหายใจ (cmH}_2\text{O/Ls}^{-1}) = \frac{\text{ความดันอากาศในทางเดินหายใจ}}{\text{อัตราการไหลเวียนอากาศ}}$$

- วัดค่าอัตราการไหลของอากาศสูงสุดขณะหายใจออก โดยหลังจากเก็บข้อมูลในขั้นตอนแรกเรียบร้อยแล้ว ผู้วิจัยจะถอดท่อเป่าและที่บีบจมูกออก และให้ผู้เข้าร่วมวิจัยพักในท่านั้นประมาณ 5-10 นาที หลังจากนั้นจะวัดค่าการไหลของอากาศสูงสุดขณะหายใจออกในท่านั้นๆ โดยให้ผู้เข้าร่วมวิจัยหายใจเข้าลึกจนสุดปอดใส่ที่บีบจมูก อมท่อเป่าให้สนิทไม่มีรูรั่วแล้วเป่าออกมาเข้าไปในเครื่องอย่างแรงและเร็ว ผู้เข้าร่วมวิจัยเป่าทั้งหมด 3 ครั้งแต่ละครั้งพักอย่างน้อย 1 นาที

- เก็บข้อมูลในแต่ละท่าดังขั้นตอนการเก็บข้อมูลข้างต้นตามลำดับจนครบ 4 ท่า โดยแต่ละท่าให้ผู้เข้าร่วมวิจัยพักจนกว่าอัตราการหายใจจะเท่ากับขณะพักจึงจะเปลี่ยนท่านอน และนำผลการทดสอบในแต่ละท่าไปเปรียบเทียบกันทางสถิติ

ระยะเวลาในการทำวิจัยประมาณ 1 ชั่วโมง/คน

การศึกษาครั้งนี้จะมีผู้เข้าร่วมวิจัยทั้งสิ้นประมาณ 30 คน ระยะเวลาที่จะทำการวิจัยทั้งสิ้นประมาณ 1 ปี

ความเสี่ยงที่อาจจะเกิดขึ้นเมื่อเข้าร่วมการวิจัย ผู้เข้าร่วมวิจัยอาจรู้สึกหยาใจไม่สะดวก ผู้เข้าร่วมวิจัยสามารถตัดสินใจด้วยตนเองที่จะหยุดการทดสอบได้ทันที เมื่อพักแล้วอาการเหล่านั้นยังไม่ทุเลาลง ส่งผลให้ไม่สามารถทำการทดสอบต่อไปได้ ผู้วิจัยจะยุติการวิจัยทันที และจะคอยสังเกตอาการจนมั่นใจว่าอาการเหล่านั้นหายไป และหากมีข้อข้องใจที่จะสอบถามเกี่ยวข้องกับการวิจัย หรือเมื่อบาดเจ็บ/เจ็บป่วยจากการวิจัยสามารถติดต่อผู้วิจัย (นางสาวสุนทรี ชยาวัชรกุล) ได้ตลอดเวลาที่เบอร์โทรศัพท์ของผู้วิจัย 0-9880-2264

หากมีข้อมูลเพิ่มเติมทั้งด้านประโยชน์และโทษที่เกี่ยวข้องกับการวิจัยนี้ ผู้วิจัยจะแจ้งให้ทราบโดยเร็วไม่ปิดบัง

ข้อมูลส่วนตัวของผู้เข้าร่วมการวิจัยจะถูกเก็บรักษาไว้ ไม่เปิดเผยต่อสาธารณะเป็นรายบุคคล แต่จะรายงานผลการวิจัยเป็นข้อมูลส่วนรวม ข้อมูลของผู้เข้าร่วมการวิจัยเป็นรายบุคคลอาจมีคณะบุคคลบางกลุ่มเข้ามาตรวจสอบได้ เช่น ผู้ให้ทุนวิจัย, สถาบันหรือองค์กรของรัฐที่มีหน้าที่ตรวจสอบ, คณะกรรมการจริยธรรมฯ เป็นต้น

ผู้เข้าร่วมการวิจัยมีสิทธิถอนตัวออกจากโครงการวิจัยเมื่อใดก็ได้ โดยไม่ต้องแจ้งให้ทราบล่วงหน้า และการไม่เข้าร่วมการวิจัยหรือถอนตัวออกจากโครงการวิจัยนี้จะไม่ผลกระทบต่อค่าบริการและการรักษาที่สมควรได้รับแต่ประการใด

หากท่านได้รับการปฏิบัติที่ไม่ตรงตามที่ได้ระบุไว้ในเอกสารชี้แจงนี้ ท่านจะสามารถแจ้งให้ประธานคณะกรรมการจริยธรรมฯ ทราบได้ที่ สำนักงานคณะกรรมการจริยธรรมการวิจัยในคน ตึกอศุขเวชวิกรม ชั้น 5 ร.พ. ศิริราช เบอร์โทร. (02)419-7000 ต่อ 6405

ข้าพเจ้าได้อ่านรายละเอียดในเอกสารนี้ครบถ้วนแล้ว

ลงชื่อ...../วันที่.....
(.....)

APPENDIX C.1

SCREENING QUESTIONNAIRE

(แบบสอบถามเพื่อการคัดกรอง)

วันที่.....เดือน.....พ.ศ.....
 ชื่อ.....ที่อยู่บ้านเลขที่.....หมู่.....แขวง/ตำบล.....
 เขต/อำเภอ.....จังหวัด.....เบอร์โทรศัพท์.....

ตอนที่ 1 ข้อมูลเกี่ยวกับผู้ตอบแบบสอบถาม

1. เพศ หญิง ชาย อายุ.....ปี อาชีพ.....
2. น้ำหนัก.....กิโลกรัม ส่วนสูง.....เซนติเมตร
3. การศึกษา ปริญญาตรีหรือเทียบเท่า
 สูงกว่าระดับปริญญาตรี
 อื่นๆ โปรดระบุ.....

ตอนที่ 2 ข้อมูลเกี่ยวกับสุขภาพ

1. ท่านมีโรคประจำตัวและปัญหาสุขภาพใดดังต่อไปนี้
 - โรคประจำตัว ไม่มี มีโปรดระบุ.....
 - มีโรคทางระบบหัวใจและหลอดเลือด ไม่มี มีโปรดระบุ.....
 - มีโรคทางระบบหายใจ ไม่มี มีโปรดระบุ.....
 - มีประวัติการผ่าตัดทางเดินหายใจตอนบน ไม่มี มีโปรดระบุ.....
 - มีประวัติการผ่าตัดบริเวณทรวงอก ไม่มี มีโปรดระบุ.....
 - เคยได้รับบาดเจ็บบริเวณทรวงอก ไม่เคย เคยโปรดระบุ.....
 - มีประวัตินอนกรน ไม่มี มีโปรดระบุ.....
 - ดื่มแอลกอฮอล์ภายใน 24 ชม. ไม่ดื่ม ดื่มโปรดระบุ.....
 - สูบบุหรี่ ไม่เคย เคย...มวน/วัน เป็นเวลา...ปี
 ถ้าเคย ปัจจุบันยังสูบบุหรี่อยู่ เลิกสูบบุหรี่แล้ว ปี
 - ปัจจุบันท่านต้องรับประทานยาเป็นประจำหรือไม่
 ไม่รับประทานยา รับประทานยา โปรดระบุ.....
2. การรักษาที่ท่านได้รับในปัจจุบัน.....

APPENDIX C.2

แบบสอบถามกิจกรรมที่ทำเป็นประจำ

ชื่อ..... อายุ.....ปี เพศ.....

กรุณาทำเครื่องหมาย ลงใน ที่ตรงกับกิจกรรมที่ท่านทำมากที่สุด

1. อาชีพหลักของท่าน คือ.....

2. ขณะทำงาน ท่านนั่งบ่อยแค่ไหน ?

 ไม่เคย นานๆครั้ง บางครั้ง บ่อย ตลอดเวลา

3. ขณะทำงาน ท่านยืนบ่อยแค่ไหน?

 ไม่เคย นานๆครั้ง บางครั้ง บ่อย ตลอดเวลา

4. ขณะทำงาน ท่านเดินบ่อยแค่ไหน?

 ไม่เคย นานๆครั้ง บางครั้ง บ่อย ตลอดเวลา

5. ขณะทำงาน ท่านยกของหนักบ่อยแค่ไหน?

 ไม่เคย นานๆครั้ง บางครั้ง บ่อย ตลอดเวลา

6. หลังเลิกงาน ท่านรู้สึกเหนื่อยบ่อยแค่ไหน?

 บ่อยมาก บ่อย บางครั้ง นานๆครั้ง ไม่เคย

7. ขณะทำงาน ท่านมีเหงื่อออกบ่อยแค่ไหน?

 บ่อยมาก บ่อย บางครั้ง นานๆครั้ง ไม่เคย

8. เมื่อเปรียบเทียบกับคนที่อายุเท่ากับท่าน ท่านคิดว่างานที่ท่านทำหนักหรือเบากว่าแค่ไหน?

 หนักกว่ามาก หนักกว่า หนักเท่ากัน เบากว่า เบากว่ามาก

9. ท่านเล่นกีฬาหรือไม่?

 เล่น ไม่เล่นถ้าเล่น

- กีฬาที่ท่านเล่นบ่อยที่สุด คือ.....

- ท่านเล่นกีฬากี่ชั่วโมงต่อสัปดาห์?

 น้อยกว่า 1 ชม. 1-2 ชม. 2-3 ชม. 3-4 ชม. มากกว่า 4 ชม.

- ท่านเล่นกีฬากี่เดือนต่อปี?

น้อยกว่า 1 เดือน 1-3 เดือน 4-6 เดือน 7-9 เดือน มากกว่า 9 เดือน

ถ้าท่านมีกีฬาอื่นที่เล่นรองลงมา

- กีฬาที่ท่านเล่นบ่อยรองลงมาคือ.....

- ท่านเล่นกีฬาที่ชั่วโมงต่อสัปดาห์?

น้อยกว่า 1 ชม. 1-2 ชม. 2-3 ชม. 3-4 ชม. มากกว่า 4 ชม.

- ท่านเล่นกีฬากี่เดือนต่อปี?

น้อยกว่า 1 เดือน 1-3 เดือน 4-6 เดือน 7-9 เดือน มากกว่า 9 เดือน

10. เมื่อเปรียบเทียบกับคนที่อายุเท่ากับท่าน ท่านคิดว่างานที่ท่านทำในเวลาว่างมากหรือน้อยกว่า
แค่ไหน?

มากกว่ามาก มากกว่า เท่ากัน น้อยกว่า น้อยกว่ามาก

11. ในเวลาว่าง ท่านมีเหงื่อออกบ่อยแค่ไหน?

บ่อยมาก บ่อย บางครั้ง นานๆครั้ง ไม่เคย

12. ในเวลาว่าง ท่านเล่นกีฬาบ่อยแค่ไหน?

ไม่เคย นานๆครั้ง บางครั้ง บ่อย ตลอดเวลา

13. ในเวลาว่าง ท่านดูโทรทัศน์บ่อยแค่ไหน?

ไม่เคย นานๆครั้ง บางครั้ง บ่อย ตลอดเวลา

14. ในเวลาว่าง ท่านเดินบ่อยแค่ไหน?

ไม่เคย นานๆครั้ง บางครั้ง บ่อย ตลอดเวลา

15. ในเวลาว่าง ท่านปั่นจักรยานบ่อยแค่ไหน?

ไม่เคย นานๆครั้ง บางครั้ง บ่อย ตลอดเวลา

16. ท่านใช้เวลากี่นาทีต่อวัน ในการเดินและ/หรือปั่นจักรยาน เพื่อไปและกลับจากที่ทำงาน โรงเรียน
และชื่อของ?

น้อยกว่า 5 นาที 5-15 นาที 15-30 นาที 30-45 นาที มากกว่า 45 นาที

การคำนวณคะแนนกิจกรรมที่ทำเป็นประจำ

การทำงาน = [(1)...+ (6)-(2)...+ (3)...+ (4)...+ (5)...+ (6)...+ (7)...+ (8)...]/8 =.....

การออกกำลังกาย = [(9)...+ (10)...+ (11)...+ (12)...]/4 =.....

เวลาว่าง = [(6)-(13)...+ (14)...+ (15)...+ (16)...]/4 =.....

คะแนนรวม =.....

ระดับกิจกรรม

ระดับกิจกรรม:

Sedentary lifestyle subject = scores below 6

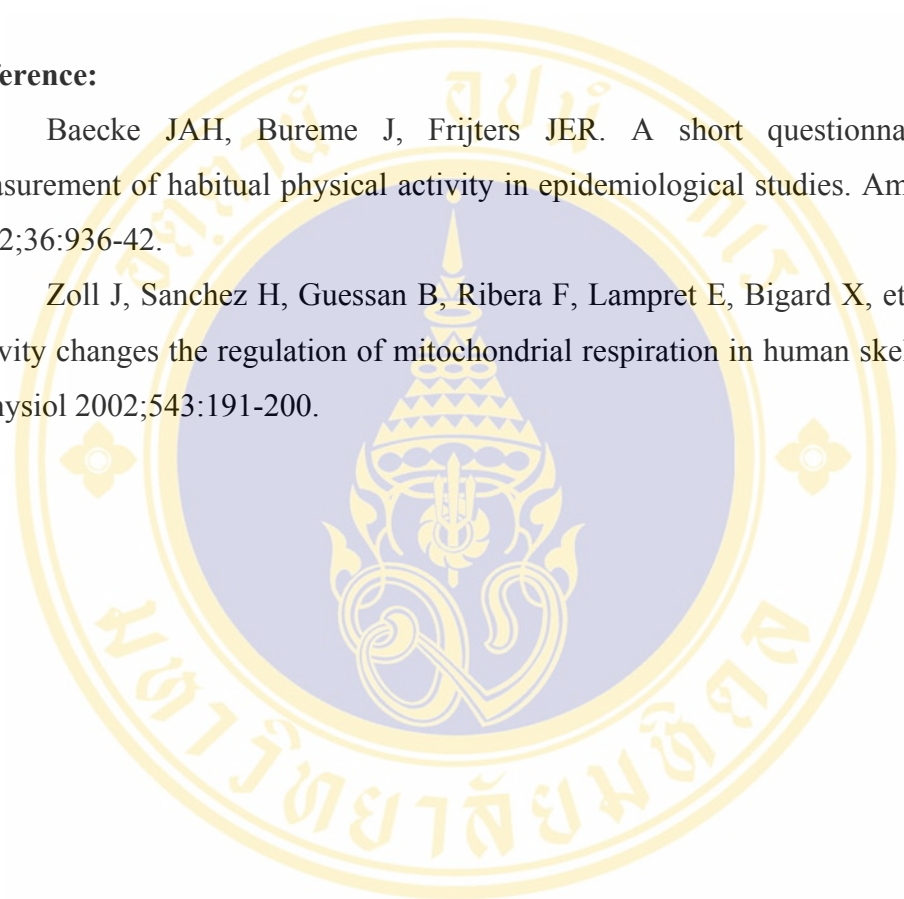
Active lifestyle subject = scores 6-8

Athletic subject = scores above 8

Reference:

Baecke JAH, Bureme J, Frijters JER. A short questionnaire for the measurement of habitual physical activity in epidemiological studies. *Am J Clin Nutr* 1982;36:936-42.

Zoll J, Sanchez H, Guessan B, Ribera F, Lampret E, Bigard X, et al. Physical activity changes the regulation of mitochondrial respiration in human skeletal muscle. *J Physiol* 2002;543:191-200.



APPENDIX C.3

Data Recording Form

Date.....

Name.....

Age.....yrs. Weight.....kg. Height.....cm. BMI.....kg/m²

1. Waist to hip ratio

Waist circumference =inches Hip circumference = inches

W/H =

2. Skinfold thickness:

Skinfold (mm)	Trial 1	Trial 2	Average
Triceps			
Biceps			
Subscapular			
Suprailiac			
Total (X ₄)			

3. Calculation of body density (D_b) and percent body fat (%BF)

Calculation of body density (D_b) = 1.1631-0.0632 log (X₄)

D_b =gm/cc

Calculation of percent body fat (%BF) = [(4.95/ D_b)- 4.5] x 100

%BF =

Interpretation:.....

4. Pulmonary function test

Variable	Trial 1	Trial 2	Trial 3	Best	Predicted	%Predicted
FVC (L)						
FEV ₁ (L)						
FEV ₁ /FVC (%)						
PEF (L/s)						

Interpretation:.....



Data Recording Form Of Airway Responses

Name.....Age.....yrs.

Respiratory rate at rest :breaths/min

Position	No. of breath	Pressure (cmH ₂ O)		Flow (L.s ⁻¹)		R _{int} (cmH ₂ O/L.s ⁻¹)	
		Insp.	Exp.	Insp.	Exp.	Insp.	Exp.
Supine	1						
	2						
	3						
	4						
	5						
	Mean						
Reclining 30 ⁰	1						
	2						
	3						
	4						
	5						
	Mean						
Lt.side lying	1						
	2						
	3						
	4						
	5						
	Mean						
Rt.side lying	1						
	2						
	3						
	4						
	5						
	Mean						

Peak Expiratory Flow (L/min)

Position	Trial 1	Trial 2	Trial 3	Best
Supine				
Reclining 30 ⁰				
Lt.side lying				
Rt.side lying				

APPENDIX D

REFERENCE SPIROMETRIC VALUES FOR HEALTHY LIFETIME NONSMOKERS IN THAILAND

	Equations	r^2	SEE
FVC(L):			
Male:	$-2.601+0.122A+0.00046A^2+0.00023H^2-0.00061AH$	0.669	0.434
FEV ₁ (L):			
Male:	$-7.697+0.123A+0.067H-0.00034A^2-0.0007AH$	0.70	0.371
FEV ₁ /FVC(%):			
Male:	$19.362+0.49A+0.829H-0.0023H^2-0.0041AH$	0.24	5.364
PEFR (L/s):			
Male:	$-16.859+0.307A+0.141H-0.0018A^2-0.001AH$	0.443	1.543

A = age (years), H = height (cms)

Dejsomritrutai W, Nana A, Maranetra KN, Chuaychoo B, Maneechotesuwan K, Wongsurakiat P, et al. Reference spirometric values for healthy lifetime nonsmokers in Thailand. J Med Assoc Thai 2000;83:457-66.

APPENDIX E

TEST-RETEST RELIABILITY OF AIRWAY PRESSURES, AIRFLOWS AND AIRFLOW RESISTANCES

The measurement of airway pressures, airflows and airflow resistances for test-retest reliability in seven healthy subjects. They were tested by the same procedure as described in the method. Subjects performed two trials of randomized positions for the reliability test. Intraclass correlation coefficient $ICC_{(3,1)}$ was used to determine the intratester reliability of the measurement. The $ICC_{(3,1)}$ and raw data are shown in Table E.1. Good intratester reliability of airway pressure, airflow and airflow resistance values were illustrated.

Table E.1 ICC_(3,1) of airway pressures, airflows and airflow resistances

Positions	No.	Inspiratory pressure (cmH ₂ O)		Expiratory pressure (cmH ₂ O)		Inspiratory flow (L.s ⁻¹)		Expiratory flow (L.s ⁻¹)		Inspiratory resistance (cmH ₂ O/L.s ⁻¹)		Expiratory resistance (cmH ₂ O/L.s ⁻¹)	
		Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
Supine	1	5.740	5.763	3.430	3.388	0.522	0.520	0.527	0.515	10.996	11.083	6.509	6.579
	2	4.624	4.609	3.594	3.516	0.506	0.509	0.490	0.487	9.138	9.055	7.335	7.220
	3	6.331	6.424	4.412	4.104	0.523	0.528	0.550	0.548	12.105	12.167	8.022	7.489
	4	5.802	5.796	3.301	3.394	0.505	0.506	0.489	0.487	11.489	11.455	6.751	6.969
	5	5.768	5.801	3.376	3.381	0.517	0.520	0.509	0.511	11.157	11.156	6.633	6.616
	6	4.853	4.862	3.712	3.801	0.502	0.507	0.489	0.494	9.667	9.590	7.591	7.694
	7	5.427	5.387	3.421	3.502	0.513	0.520	0.509	0.506	10.579	10.360	6.721	6.921
	ICC_{3,1}	0.9988		0.9513		0.9680		0.9856		0.9977		0.9297	
Reclining 30°	1	4.359	4.415	2.782	2.826	0.576	0.573	0.563	0.557	7.568	7.705	4.941	5.074
	2	4.057	4.133	2.811	2.798	0.535	0.533	0.525	0.524	7.583	7.754	5.354	5.340
	3	4.373	4.279	2.793	2.814	0.584	0.579	0.538	0.539	7.488	7.390	5.191	5.221
	4	4.246	4.352	2.804	2.819	0.528	0.523	0.509	0.505	8.042	8.321	5.509	5.582
	5	4.408	4.403	2.776	2.787	0.625	0.624	0.578	0.582	7.053	7.056	4.803	4.789
	6	4.135	4.208	2.909	2.893	0.533	0.529	0.514	0.519	7.758	7.955	5.660	5.574
	7	4.323	4.400	3.106	3.094	0.529	0.532	0.519	0.515	8.172	8.271	5.985	6.008
	ICC_{3,1}	0.9128		0.9905		0.9986		0.9936		0.9765		0.9925	

Table E.1 ICC_(3,1) of airway pressures, airflows and airflow resistances (cont.)

Positions	No.	Inspiratory pressure (cmH ₂ O)		Expiratory pressure (cmH ₂ O)		Inspiratory flow (L.s ⁻¹)		Expiratory flow (L.s ⁻¹)		Inspiratory resistance (cmH ₂ O/L.s ⁻¹)		Expiratory resistance (cmH ₂ O/L.s ⁻¹)	
		Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
Lt.side lying	1	5.450	5.359	3.169	3.112	0.554	0.550	0.522	0.521	9.838	9.744	6.071	5.973
	2	4.378	4.421	3.378	3.311	0.520	0.521	0.515	0.517	8.419	8.486	6.559	6.404
	3	5.365	5.418	3.391	3.426	0.543	0.545	0.533	0.534	9.880	9.941	6.362	6.416
	4	5.399	5.356	3.158	3.092	0.511	0.509	0.494	0.497	10.566	10.523	6.393	6.221
	5	5.413	5.404	3.086	3.137	0.594	0.589	0.536	0.534	9.113	9.175	5.757	5.875
	6	4.682	4.599	3.545	3.551	0.512	0.511	0.500	0.505	9.145	9.000	7.090	7.032
	7	5.081	5.087	3.291	3.322	0.522	0.517	0.518	0.513	9.734	9.839	6.353	6.476
	ICC_{3,1}	0.9953		0.9753		0.9977		0.9869		0.9952		0.9747	
Rt.side lying	1	5.513	5.518	3.068	3.095	0.544	0.548	0.522	0.524	10.134	10.069	5.877	5.906
	2	4.418	4.503	3.257	3.286	0.515	0.517	0.521	0.527	8.579	8.710	6.251	6.235
	3	5.612	5.615	3.127	3.101	0.547	0.545	0.534	0.544	10.260	10.303	5.856	5.700
	4	5.622	5.624	3.106	3.124	0.526	0.523	0.493	0.491	10.688	10.753	6.300	6.363
	5	5.520	5.621	3.111	3.116	0.584	0.579	0.547	0.544	9.452	9.708	5.687	5.728
	6	4.599	4.594	3.601	3.604	0.514	0.516	0.508	0.501	8.947	8.903	7.089	7.194
	7	5.102	5.110	3.303	3.301	0.523	0.520	0.520	0.526	9.755	9.827	6.352	6.276
	ICC_{3,1}	0.9980		0.9974		0.9951		0.9735		0.9946		0.9917	

APPENDIX F

STANDARDIZATION OF PNEUMOTACHOMETER

In this study, two pressure transducers mounted within the pneumotachometer were used to measure airflows and pressures in the unit of $L.s^{-1}$ and cmH_2O , respectively. However, the quantitative values from pneumotachometer presented in the unit of millivolt (mV). Therefore, this instrument needed to be standardised to determine the value in the unit of $L.s^{-1}$ for airflows and cmH_2O for pressures, respectively.

The methods for standardization the value of airflow were as follows.

1. Connect the pneumotachometer to a Spirometer (Pony FX pulmonary function equipment, Cosmed, INC., Italy) as shown in Figure F.1.

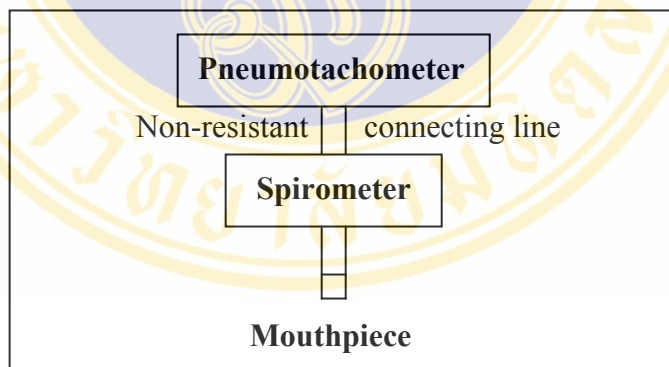


Figure F.1 Diagram demonstrated connection of signal between pneumotachometer to a spirometer and mouthpiece for flow calibration.

2. Test the value of airflow from expiratory flow (EF). Starting with inspiration via nostrils, subject was asked to expel air forcefully to the mouthpiece.
3. Record the value of flow from pneumotachometer (mV) and spirometer (L/s).
4. Then repeat the same procedure at different expiration force.

- Construct a graph to represent relationship between values of flow from pneumotachometer (mV on y-axis) and EF (L/s on x-axis) as shown in Figure F.2.

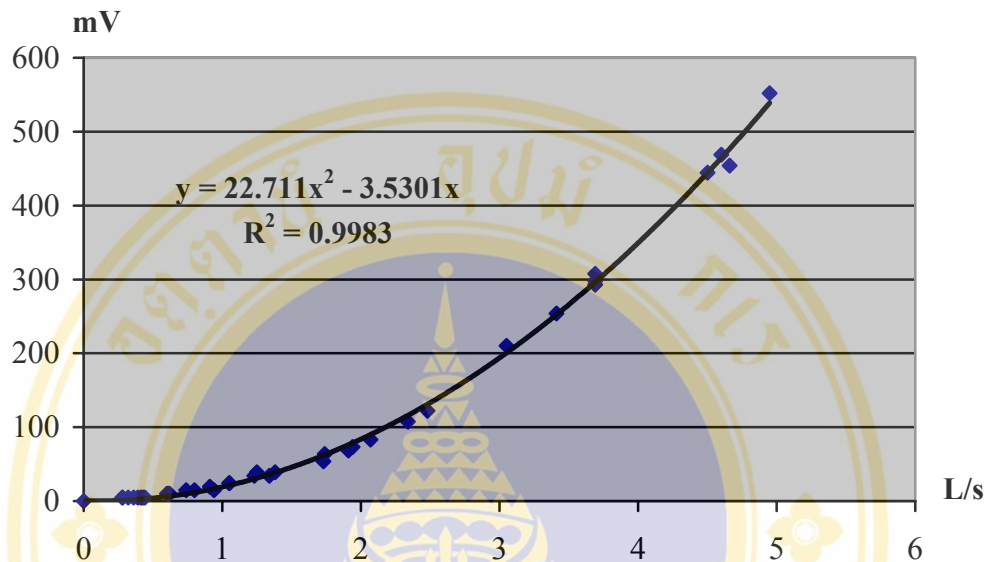


Figure F.2 Relationship between the value of expiratory airflow from spirometer and voltage changes obtained from pneumotachometer.

Figure F.2 showed a non-linear relationship. Therefore, the calculation airflows from mV to L/s was determined using an equation as follow:

If $ax^2 + bx + c = 0$ or $ax^2 + bx = -c$

Then $x = [(-b \pm \sqrt{b^2 - 4ac})] / 2a$

An equation $y \text{ (mV)} = 22.711x^2 - 3.5301x$ was derived from curve-fitting software

Thus $22.711x^2 - 3.5301x - y = 0$

$$x = [(-(-3.5301) \pm \sqrt{(-3.5301)^2 - (4 \cdot 22.711 \cdot (-y))}] / 2 \cdot 22.711$$

$$x = [(3.5301) \pm \sqrt{(-3.5301)^2 + (90.844y)}] / 2 \cdot 22.711$$

$$x = [(3.5301) \pm \sqrt{(12.462 + 90.844y)}] / 45.422$$

Use only +value, not -value since a graph shows all positive values,

Thus $x = [(3.5301) + \sqrt{(12.462 + 90.844y)}] / 45.422 \quad \text{L.s}^{-1}$

The methods for standardization the value of pressure were as follows.

1. Connect the pneumotachometer to a Mouth pressure meter (Micro Medical) microcomputer unit using three-way tube as shown in Figure F.3.

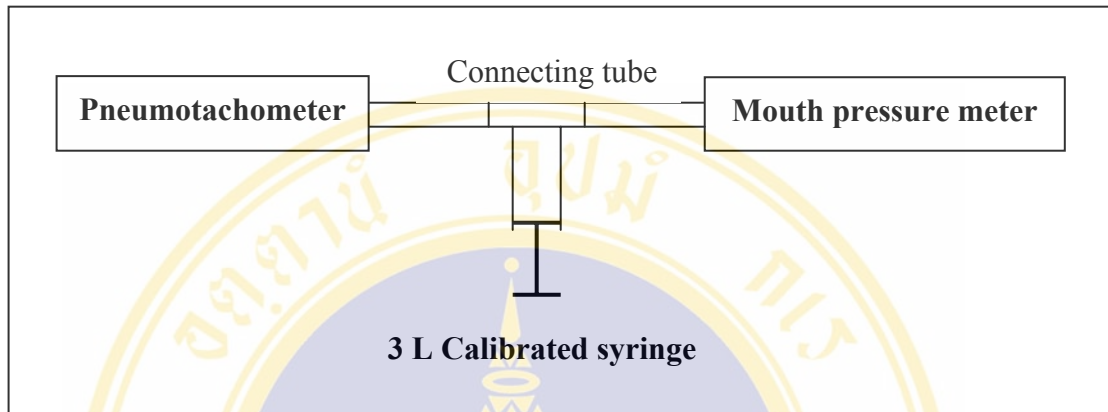


Figure F.3 Diagram demonstrated connection of signal between pneumotachometer to a mouth pressure meter and 3 L Calibrated syringe for pressure calibration.

2. Test the value of pressure from Sniff Nasal Inspiratory Pressure (SNIP) by pumping the calibrated syringe.
3. Record the value of pressure from pneumotachometer (mV) and mouth pressure meter (cmH₂O).
4. Then repeat the same procedure at different pump force.
5. Construct a graph to represent relationship between value of pressure from pneumotachometer (mV on y-axis) and mouth pressure meter (cmH₂O on x-axis) as shown in Figure F.4.

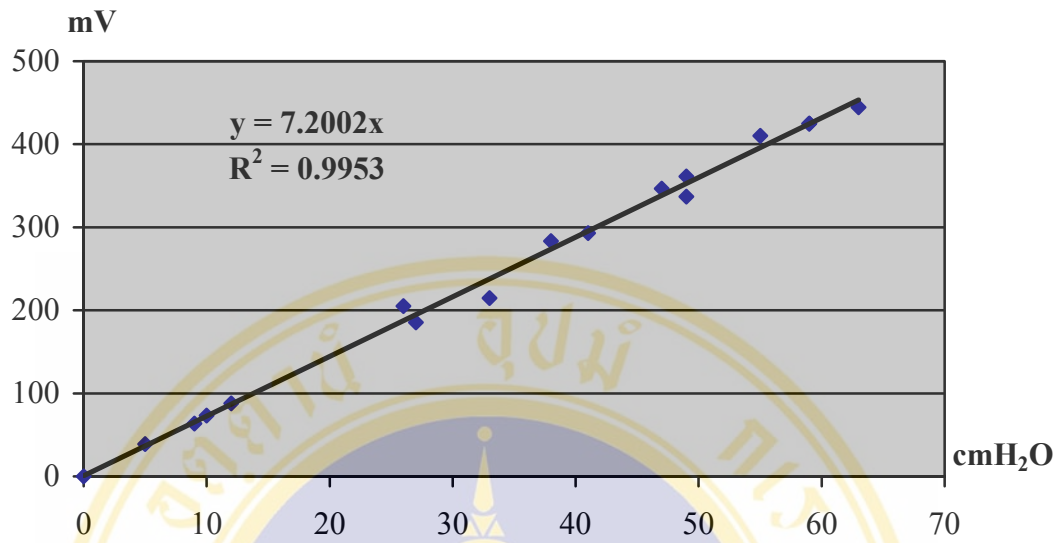


Figure F.4 Relationship between the value of pressure from mouth pressure meter and voltage changes obtained from pneumotachometer.

Figure F.4 showed a linear relationship in the estimation of sensitivity of pressure. Results from calculation provided the sensitivity of 7.2002 mV/cmH₂O.

Table F.1 Raw data of airflow and pressure calibration.

Airflow calibration		Pressure calibration	
mV	L/s	mV	cmH ₂ O
0.000	0.00	0.000	0
9.766	0.60	386.914	49
14.649	0.80	444.336	63
4.583	0.32	292.969	41
24.414	1.05	424.805	59
14.649	0.74	283.203	38
4.883	0.28	346.680	47
19.531	0.91	185.547	27
53.711	1.73	205.078	26
4.883	0.36	214.844	33
34.180	1.34	361.328	49
63.477	1.74	410.156	55
107.422	2.34	63.477	9
122.070	2.48	73.242	10
34.180	1.23	39.062	5
14.649	0.94	87.891	12
39.063	1.25		
9.766	0.61		
4.883	0.41		
83.008	2.07		
4.883	0.39		
4.883	0.42		
24.414	1.05		
39.063	1.38		
4.883	0.43		
4.883	0.28		
73.250	1.94		
68.360	1.91		
297.852	3.69		
209.961	3.41		
454.102	4.66		
444.336	4.50		
551.758	4.95		

APPENDIX G

RESULT OF PILOT STUDY

The major aim of this pilot study was to examine the effect of position on airflow resistances during wakefulness condition. Seven healthy Thai male subjects participated in this pilot study. The subjects' characteristics and baseline assessment were presented in Table G.1.

Table G.1 Characteristics and baseline assessment of the subjects

Subject's characteristics	Mean \pm SD
Age (years)	21.00 \pm 1.73
Weight (kg)	59.57 \pm 7.14
Height (cm)	171.57 \pm 4.31
BMI (kg.m ⁻²)	20.18 \pm 1.58
Physical activity scores*	7.20 \pm 0.41
Baseline assessment	
W/H ratio	0.83 \pm 0.02
%BF	12.75 \pm 3.55
FVC (L, BTPS)	3.85 \pm 0.30
FEV ₁ (L, BTPS)	3.53 \pm 0.28
FEV ₁ /FVC (%)	91.43 \pm 2.64
PEF (Ls ⁻¹)	8.33 \pm 1.32

BTPS = body temperature and pressure saturated with water vapor

* derived from physical activity questionnaire (Appendix C.2)

Comparison of the means and standard deviations of airway pressures, airflows and airflow resistances between different positions for all subjects were showed in Table G.2-G.4.

Table G.2 Means and standard deviations of absolute airway pressures (cmH₂O) between different positions (n = 7).

Phase of breathing	Supine	Reclining 30 ⁰	Lt.side lying	Rt.side lying
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Inspiration	5.36 ± 0.61	4.60 ± 0.43	4.93 ± 0.66	5.07 ± 0.60
Expiration	3.69 ± 0.46	3.02 ± 0.46	3.20 ± 0.26	2.95 ± 0.39

Table G.3 Means and standard deviations of absolute airflows (L.s⁻¹) between different positions (n = 7).

Phase of breathing	Supine	Reclining 30 ⁰	Lt.side lying	Rt.side lying
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Inspiration	0.52 ± 0.02	0.58 ± 0.04	0.55 ± 0.04	0.53 ± 0.02
Expiration	0.51 ± 0.03	0.53 ± 0.05	0.53 ± 0.01	0.52 ± 0.03

Table G.4 Means and standard deviations of absolute airflow resistance (cmH₂O /Ls⁻¹) between different positions (n = 7).

Phase of breathing	Supine	Reclining 30 ⁰	Lt.side lying	Rt.side lying
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Inspiration	10.33 ± 1.03	8.03 ± 0.66	9.02 ± 0.96	9.60 ± 1.11
Expiration	7.24 ± 0.73	5.67 ± 0.66	6.10 ± 0.49	5.72 ± 0.63

APPENDIX H

CALCULATION OF THE SAMPLE SIZE

The sample size for this study was calculated by the following equation

$$n = \left[\frac{(Z_{\frac{\alpha}{2}} + Z_{\beta})\sigma}{\mu_0 - \mu_1} \right]^2$$

n = number of subject

$Z_{\alpha/2}$ = Z-value when set the confident level equal to 95% or significant level equal to 0.05 ($\alpha = 0.05$) = 1.96

Z_{β} = Z-value when set the power of testing equal to 80% ($\beta = 0.2$) = 0.84

σ = estimated standard deviation

$\mu_0 - \mu_1$ = the difference of means of parameter between positions in the pilot study

From the sample size calculation, the airflow resistance is of concern for this study. Below is an example of sample size calculation using airflow resistance between reclining 30° and left side lying during expiration.

$$\begin{aligned} n &= \left[\frac{(Z_{\frac{\alpha}{2}} + Z_{\beta})\sigma}{\mu_0 - \mu_1} \right]^2 \\ &= \left[\frac{(1.96+0.84) 0.67}{5.67- 6.10} \right]^2 \\ &= 19.03 \end{aligned}$$

APPENDIX I
RAW DATA OF THE STUDY



Table I.1 Characteristics and baseline assessment of the subjects

No.	Age (yrs)	Wt (kg)	Ht (cm)	BMI (kg/m ²)	Physical activity scores	W/H	%BF	FVC (L)	FEV ₁ (L)	FEV ₁ /FVC (%)	PEF (L/s)
1	20	53	171	18.13	7.750	0.77	11.02	3.81	3.75	98	7.14
2	20	55	169	19.26	7.000	0.80	13.70	3.74	3.64	97	7.31
3	21	54	169	18.91	6.250	0.84	7.36	3.57	2.91	87	7.53
4	24	56	158	22.43	7.500	0.85	11.02	3.89	3.44	88	7.53
5	22	56	172	18.93	7.875	0.80	11.24	4.39	3.91	89	9.91
6	22	62	170	21.45	6.375	0.83	13.00	4.27	4.06	95	9.33
7	23	58	166	21.05	6.250	0.83	15.53	3.78	3.16	83	8.08
8	22	68	174	22.46	7.750	0.82	16.76	4.11	3.49	84	9.60
9	20	57	173	19.05	7.125	0.82	9.61	3.67	3.52	96	7.14
10	24	62	175	20.24	7.125	0.85	7.95	3.72	3.42	92	9.19
11	20	62	169	21.68	6.625	0.83	16.89	3.52	3.15	89	6.43
12	20	51	167	18.29	7.250	0.82	13.31	3.90	3.69	93	7.60
13	23	54	168	19.13	7.500	0.79	10.08	3.65	3.33	91	8.38
14	20	73	179	22.78	7.875	0.85	16.19	4.39	4.02	91	9.77
15	20	58	170	20.07	6.875	0.86	15.23	4.09	3.61	88	9.77

Table I.1 Characteristics and baseline assessment of the subjects (cont.)

No.	Age (yrs)	Wt (kg)	Ht (cm)	BMI (kg/m ²)	Physical activity scores	W/H	%BF	FVC (L)	FEV ₁ (L)	FEV ₁ /FVC (%)	PEF (L/s)
16	22	55	173	18.38	6.500	0.80	5.38	3.66	3.56	97	7.91
17	22	65	171	22.23	6.625	0.88	17.33	4.01	3.56	89	7.84
18	22	75	185	21.91	8.000	0.86	17.60	4.38	3.97	90	9.68
19	22	61	165	22.41	7.875	0.85	11.02	3.67	3.21	87	7.23
20	19	70	175	22.86	6.125	0.89	17.60	4.05	3.52	86	8.00
21	21	63	171	21.55	7.875	0.83	15.05	4.13	4.07	98	9.25
22	24	52	164	19.33	7.875	0.85	13.87	3.67	3.14	86	6.98
23	22	58	168	20.55	7.875	0.82	5.72	3.63	3.23	89	7.38
24	24	62	173	20.72	6.375	0.86	10.08	4.17	3.66	88	8.68
25	24	57	170	19.72	7.250	0.80	12.75	4.12	3.57	87	8.42
26	21	65	182	19.62	6.375	0.78	15.53	4.85	3.98	82	9.21
27	22	68	175	22.20	6.625	0.83	17.33	4.18	3.86	92	8.29
28	22	56	169	19.61	7.125	0.77	10.08	4.37	3.75	85	8.14
29	20	58	165	21.30	8.000	0.83	15.23	3.76	3.21	85	7.34
30	24	57	168	20.05	7.500	0.76	6.05	3.66	3.49	95	6.30

Table I.2 Respiratory rates (RR, breaths/min), tidal volumes (V_T , L, BTPS) and minute ventilations (\dot{V}_E , L/min)

No.	Supine			Reclining 30°			Lt.side lying			Rt.side lying		
	RR	V_T	\dot{V}_E	RR	V_T	\dot{V}_E	RR	V_T	\dot{V}_E	RR	V_T	\dot{V}_E
1	23	0.541	12.443	23	0.542	12.466	23	0.542	12.466	23	0.542	12.466
2	23	0.547	12.581	23	0.547	12.581	23	0.548	12.604	23	0.547	12.581
3	15	0.546	8.190	14	0.547	7.658	15	0.545	8.175	14	0.547	7.658
4	20	0.544	10.880	20	0.545	10.900	20	0.546	10.920	20	0.544	10.880
5	21	0.543	11.403	21	0.542	11.382	21	0.544	11.424	20	0.543	10.860
6	21	0.548	11.508	21	0.548	11.508	21	0.548	11.508	21	0.547	11.487
7	16	0.548	8.768	16	0.548	8.768	16	0.547	8.752	16	0.547	8.752
8	15	0.547	8.205	15	0.546	8.190	16	0.546	8.736	15	0.546	8.190
9	21	0.547	11.487	20	0.548	10.960	21	0.548	11.508	22	0.547	12.034
10	21	0.546	11.466	21	0.546	11.466	20	0.546	10.920	20	0.546	10.920
11	22	0.547	12.034	22	0.550	12.100	22	0.549	12.078	22	0.549	12.078
12	14	0.544	7.616	15	0.546	8.190	15	0.546	8.190	15	0.546	8.190
13	23	0.545	12.535	23	0.544	12.512	23	0.544	12.512	23	0.543	12.489
14	16	0.547	8.752	16	0.547	8.752	16	0.546	8.736	15	0.547	8.205
15	15	0.548	8.220	15	0.548	8.220	16	0.548	8.768	15	0.548	8.220

Table I.2 Respiratory rates (RR, breaths/min), tidal volumes (V_T , L, BTPS) and minute ventilations (\dot{V}_E , L/min) (cont.)

No.	Supine			Reclining 30°			Lt. side lying			Rt. side lying		
	RR	V_T	\dot{V}_E	RR	V_T	\dot{V}_E	RR	V_T	\dot{V}_E	RR	V_T	\dot{V}_E
16	14	0.545	7.630	14	0.545	7.630	14	0.545	7.630	14	0.545	7.630
17	16	0.546	8.736	16	0.548	8.768	16	0.547	8.752	16	0.547	8.752
18	18	0.546	9.828	18	0.546	9.828	18	0.546	9.828	18	0.546	9.828
19	16	0.547	8.752	16	0.547	8.752	16	0.546	8.736	16	0.546	8.736
20	17	0.547	9.299	17	0.548	9.316	17	0.548	9.316	17	0.548	9.316
21	23	0.545	12.535	23	0.545	12.535	23	0.545	12.535	23	0.545	12.535
22	18	0.539	9.702	18	0.54	9.720	18	0.54	9.720	18	0.54	9.720
23	16	0.547	8.752	16	0.547	8.752	16	0.547	8.752	16	0.547	8.752
24	15	0.542	8.130	15	0.543	8.145	15	0.541	8.115	15	0.54	8.100
25	17	0.546	9.282	16	0.546	8.736	16	0.546	8.736	17	0.546	9.282
26	17	0.545	9.265	17	0.547	9.299	17	0.547	9.299	17	0.547	9.299
27	20	0.55	11.000	20	0.549	10.980	20	0.549	10.980	20	0.55	11.000
28	14	0.545	7.630	14	0.545	7.630	14	0.545	7.630	14	0.544	7.616
29	16	0.547	8.752	16	0.548	8.768	16	0.547	8.752	16	0.548	8.768
30	19	0.544	10.336	19	0.544	10.336	19	0.543	10.317	19	0.544	10.336

Table I.3 Airway pressures (cmH₂O)

No.	Supine		Reclining 30 ⁰		Lt.side lying		Rt.side lying	
	Insp.	Exp.	Insp.	Exp.	Insp.	Exp.	Insp.	Exp.
1	3.596	3.235	3.489	3.132	3.491	3.694	3.576	3.421
2	4.516	3.283	3.864	2.486	3.843	2.456	4.039	3.192
3	4.051	3.420	3.437	2.680	3.351	2.737	3.132	2.813
4	3.319	2.641	3.158	2.328	3.254	2.539	3.418	2.474
5	5.527	3.408	3.376	2.554	3.720	2.815	3.307	2.845
6	4.662	4.006	3.478	2.662	3.639	2.886	3.673	3.000
7	5.017	3.424	3.407	2.556	3.639	2.877	3.975	2.944
8	4.619	3.508	3.309	2.908	3.534	3.020	3.641	2.979
9	5.846	3.260	4.058	2.368	5.754	3.409	5.787	2.637
10	4.913	3.594	4.255	3.347	4.735	3.291	4.852	3.129
11	6.148	4.289	4.300	2.494	5.107	2.930	5.655	3.503
12	4.407	3.080	4.592	3.607	3.779	3.007	4.091	2.836
13	5.795	4.217	5.288	3.206	5.514	3.618	5.118	2.324
14	5.288	3.852	4.805	3.249	5.072	3.207	5.343	3.198
15	5.144	3.510	4.899	2.872	4.545	2.919	4.629	3.007
16	4.810	3.455	3.379	3.025	3.660	3.238	3.702	3.281
17	5.760	4.523	4.388	3.628	4.973	3.989	4.690	3.839
18	4.786	3.705	3.521	2.979	4.117	3.243	4.031	3.114
19	5.638	4.520	4.202	3.164	4.774	3.588	4.894	3.778
20	5.734	4.227	3.395	2.810	4.632	3.236	4.589	3.237
21	4.988	3.700	3.808	2.931	3.979	3.400	3.983	3.331
22	4.874	3.863	3.797	3.050	4.059	3.428	4.002	3.418
23	5.432	3.495	4.277	3.035	4.831	3.240	4.721	3.153
24	5.096	3.593	4.010	2.956	4.379	3.224	4.240	3.364
25	4.664	3.675	3.943	3.037	4.212	3.295	4.319	3.322
26	6.135	4.577	4.074	3.284	5.340	3.701	5.373	4.021
27	6.036	4.679	4.454	3.275	5.148	4.182	5.187	4.171
28	5.355	4.548	4.177	3.089	4.519	3.715	4.520	3.767
29	3.980	3.461	3.405	2.862	3.645	3.044	3.642	3.029
30	5.516	4.485	4.124	3.334	4.421	3.553	4.393	3.589

Table I.4 Airflows ($L \cdot s^{-1}$)

No.	Supine		Reclining 30 ⁰		Lt.side lying		Rt.side lying	
	Insp.	Exp.	Insp.	Exp.	Insp.	Exp.	Insp.	Exp.
1	0.459	0.499	0.537	0.549	0.540	0.541	0.522	0.541
2	0.531	0.533	0.563	0.560	0.521	0.516	0.526	0.521
3	0.525	0.517	0.536	0.539	0.527	0.520	0.522	0.528
4	0.489	0.472	0.529	0.523	0.513	0.504	0.526	0.496
5	0.507	0.493	0.528	0.520	0.527	0.518	0.518	0.512
6	0.516	0.502	0.539	0.520	0.513	0.513	0.520	0.503
7	0.507	0.512	0.526	0.523	0.507	0.517	0.507	0.515
8	0.517	0.514	0.534	0.535	0.524	0.514	0.526	0.521
9	0.520	0.517	0.576	0.527	0.554	0.518	0.532	0.518
10	0.506	0.490	0.535	0.539	0.533	0.520	0.533	0.519
11	0.544	0.520	0.523	0.528	0.545	0.521	0.517	0.522
12	0.505	0.465	0.557	0.540	0.507	0.535	0.530	0.535
13	0.517	0.509	0.584	0.546	0.594	0.534	0.538	0.527
14	0.545	0.513	0.572	0.545	0.567	0.540	0.562	0.538
15	0.515	0.508	0.577	0.555	0.510	0.518	0.505	0.515
16	0.515	0.499	0.529	0.526	0.519	0.520	0.518	0.516
17	0.515	0.526	0.533	0.530	0.526	0.524	0.521	0.526
18	0.517	0.520	0.529	0.528	0.517	0.522	0.523	0.520
19	0.515	0.514	0.520	0.518	0.517	0.516	0.516	0.514
20	0.517	0.516	0.519	0.526	0.517	0.518	0.517	0.521
21	0.519	0.522	0.533	0.544	0.521	0.526	0.528	0.529
22	0.503	0.504	0.528	0.530	0.511	0.514	0.512	0.520
23	0.508	0.503	0.527	0.517	0.519	0.512	0.518	0.520
24	0.507	0.505	0.528	0.527	0.513	0.509	0.513	0.513
25	0.514	0.512	0.521	0.518	0.513	0.515	0.515	0.512
26	0.512	0.511	0.515	0.512	0.514	0.512	0.513	0.511
27	0.514	0.516	0.517	0.521	0.516	0.518	0.517	0.517
28	0.511	0.513	0.520	0.518	0.516	0.515	0.516	0.516
29	0.508	0.511	0.521	0.524	0.508	0.513	0.513	0.514
30	0.503	0.503	0.515	0.511	0.509	0.507	0.509	0.508

Table I.5 Airflow resistances (cmH₂O/L.s⁻¹)

No.	Supine		Reclining 30 ⁰		Lt.side lying		Rt.side lying	
	Insp.	Exp.	Insp.	Exp.	Insp.	Exp.	Insp.	Exp.
1	7.965	6.517	6.505	5.713	6.472	6.327	6.879	6.352
2	8.536	6.175	6.874	4.434	7.405	4.776	7.677	6.124
3	7.761	6.649	6.406	4.969	6.392	5.294	6.028	5.315
4	6.799	5.000	5.984	4.453	6.343	5.045	6.506	4.981
5	10.934	6.918	6.416	4.912	7.065	5.447	6.387	5.554
6	9.057	7.994	6.453	5.127	7.160	5.637	7.067	5.968
7	9.942	6.698	6.482	4.895	7.177	5.562	7.846	5.718
8	8.946	6.826	6.196	5.433	6.753	5.884	6.927	5.718
9	11.452	6.138	7.109	5.255	10.560	6.621	10.954	5.679
10	9.805	7.366	7.978	6.608	8.924	6.323	9.108	5.871
11	11.339	7.792	8.252	4.723	9.388	5.636	10.945	6.736
12	8.719	6.634	7.411	5.798	7.435	5.631	7.771	5.320
13	11.235	8.276	9.075	5.872	9.446	6.805	9.580	4.683
14	9.739	7.543	7.885	6.276	8.489	6.048	9.680	5.978
15	10.038	6.928	8.512	5.190	8.925	5.638	9.153	5.806
16	9.338	6.927	6.412	5.750	7.067	6.227	7.148	6.362
17	11.185	8.799	8.264	6.851	9.448	7.615	9.003	7.304
18	9.273	7.129	6.657	5.643	7.962	6.214	7.717	5.989
19	10.951	8.788	8.081	6.110	9.237	6.965	9.482	7.355
20	11.112	8.197	6.539	5.351	8.959	6.251	8.886	6.216
21	9.615	7.095	7.142	5.388	7.637	6.471	7.548	6.302
22	9.691	7.665	7.194	5.752	7.943	6.662	7.826	6.574
23	10.702	6.950	8.095	5.865	9.306	6.334	9.120	6.071
24	10.050	7.112	7.589	5.611	8.535	6.342	8.264	6.563
25	9.084	7.174	7.575	5.874	8.214	6.400	8.392	6.490
26	12.006	8.965	7.911	6.434	10.391	7.233	10.496	7.877
27	11.751	9.077	8.617	6.286	9.982	8.089	10.031	8.065
28	10.499	8.860	8.033	5.963	8.752	7.226	8.761	7.297
29	7.844	6.780	6.533	5.466	7.179	5.930	7.099	5.887
30	10.963	8.929	8.012	6.534	8.677	7.024	8.638	7.074

Table I.6 Peak expiratory flows (L/min)

No.	Supine	Reclining 30 ⁰	Lt.side lying	Rt.side lying
1	360	410	400	400
2	430	440	400	400
3	380	430	400	400
4	430	470	460	450
5	530	560	550	550
6	510	540	510	510
7	400	470	460	450
8	470	490	480	480
9	380	430	420	400
10	520	610	600	540
11	370	410	400	370
12	360	420	370	380
13	450	480	480	470
14	370	450	450	420
15	440	500	480	450
16	400	450	430	420
17	540	550	540	540
18	400	460	420	410
19	450	510	470	460
20	340	390	350	360
21	420	470	440	450
22	350	410	370	400
23	480	520	490	500
24	480	520	500	500
25	500	540	520	500
26	480	510	500	490
27	360	400	390	390
28	400	450	430	430
29	390	430	400	410
30	500	560	550	550

APPENDIX J

LABVIEW LICENSE NUMBER



341083C-01

BIOGRAPHY



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