THE INFLUENCE OF THERAPEUTIC BODY POSITIONS ON HEMODYNAMICS AND RESPIRATION IN ADULTS WITH AND WITHOUT OBESITY

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อิทธิพลของการจัดท่าเพื่อการรักษาต่อการไหลเวียนโลหิตและการหายใจในผู้ใหญ่ที่มีและไม่มีภาวะอ้วนลงพุง

น.ส.รุชดา ศรีอาหมัด

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
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Field of Study	Physical Therapy
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รุชดา ศรีอาหมัด : อิทธิพลของการจัดท่าเพื่อการรักษาต่อการไหลเวียนโลหิตและการหายใจในผู้ใหญ่ที่มีและไม่มีภาวะอ้วนลงพุง. (THE INFLUENCE OF THERAPEUTIC BODY POSITIONS ON HEMODYNAMICS AND RESPIRATION IN ADULTS WITH AND WITHOUT OBESITY) อ.ที่ปรึกษาหลัก : รศ. ดร.เปรมทิพย์ ทวีรติธรรม, อ.ที่ปรึกษาร่วม : ดร.ฐานิยา กลิ่นโสภณ

งานวิจัยฉบับนี้มีวัตถุประสงค์เพื่อตรวจสอบอิทธิพลของท่าทางที่ถูกใช้เพื่อการรักษาต่อการตอบสนองของการไหลเวียนโลหิต และการหายใจในผู้ใหญ่ที่มี และไม่มีภาวะอ้วนลงพุง งานวิจัยประกอบด้วย 3 การศึกษา คือ 1) การทบทวนวรรณกรรมอย่างเป็นระบบ เพื่อตรวจสอบผลกระทบของท่าทางต่างๆ ต่อตัวแปรที่บ่งชี้การไหลเวียนโลหิตและการหายใจในผู้ใหญ่ที่มีสุขภาพดี 2) การศึกษาการตอบสนองของการไหลเวียนโลหิตต่อท่าทางที่ถูกใช้เพื่อการรักษาในผู้ใหญ่ที่มีและไม่มีภาวะอ้วนลงพุง 3) การศึกษาการตอบสนองของการหายใจต่อท่าทางที่ถูกใช้เพื่อการรักษาในผู้ใหญ่ที่มีและไม่มีภาวะอ้วนลงพุง ผลการศึกษา จากการทบทวนวรรณกรรมพบว่า ท่าทางที่แตกต่างกันส่งผลให้การตอบสนองการไหลเวียนโลหิตและการหายใจแตกต่างกัน จากหลักฐานปรากฏว่าท่านอนหงายมีอิทธิพลเชิงบวกต่อตัวแปรการไหลเวียนโลหิตมากที่สุด ในขณะที่ท่ายืนบนเตียงปรับระดับ 70 องศา และท่ายืนมีอิทธิพลเชิงบวกต่อตัวแปรการหายใจมากที่สุด ในการศึกษาที่ 2 และ 3 ทำการศึกษาอาสาสมัครเพศชายจำนวน 52 คน ประกอบด้วย กลุ่มน้ำหนักปกติ 26 คน และกลุ่มอ้วนลงพุง 26 คน อาสาสมัครทุกคนถูกจัดให้อยู่ในท่านอนหงายศีรษะสูง 90 องศา ท่านอนตะแคงขวา ท่านอนตะแคงซ้าย ท่านอนหงาย และท่านอนคว่ำตามลำดับ โดยแต่ละท่าใช้เวลา 40 นาที ผลการศึกษาที่ 2 แสดงให้เห็นว่าท่านอนหงายส่งผลดีที่สุดต่อการไหลเวียนโลหิต ตามมาด้วยท่านอนหงายศีรษะสูง 90 องศา ยกเว้นความดันโลหิต ซึ่งพบว่าท่าที่ดีที่สุดคือท่านอนตะแคงขวา การศึกษานี้ยังแสดงให้เห็นอีกว่าท่านอนคว่ำเป็นท่าที่ส่งผลเสียต่อการไหลเวียนโลหิตมากที่สุด โดยเฉพาะอย่างยิ่งในกลุ่มอ้วนลงพุง เมื่อพิจารณาการตอบสนองของการหายใจในการศึกษาที่ 3 ผลของทั้งสองกลุ่มพบว่า ท่านอนคว่ำส่งผลดีที่สุดต่อการระบายอากาศ รองลงมาคือท่านอนหงายศีรษะสูง 90 องศา และท่านอนคว่ำเป็นท่าที่ดีที่สุดต่อการได้รับออกซิเจนของร่างกาย รองลงมาคือท่านอนตะแคงขวา ผลการศึกษาทั้งหมดแสดงให้เห็นว่าแต่ละท่าให้ผลการตอบสนองทางสรีรวิทยาแตกต่างกันทั้งทางบวกและทางลบ การค้นพบนี้มีประโยชน์ในการพิจารณาเลือกท่าทางที่เหมาะสมสำหรับผู้ป่วยทั้งในกลุ่มน้ำหนักปกติและกลุ่มอ้วนลงพุงเพื่อให้เกิดประโยชน์สูงสุดในการรักษา ขณะเดียวกันควรหลีกเลี่ยงท่าทางที่อาจทำให้อาการรุนแรงขึ้น

สาขาวิชา	กายภาพบำบัด	ลายมือชื่อนิสิต ....
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Ruchada Sriamad : THE INFLUENCE OF THERAPEUTIC BODY POSITIONS ON HEMODYNAMICS AND RESPIRATION IN ADULTS WITH AND WITHOUT OBESITY. Advisor: Assoc. Prof. PREMTIP THAVEERATITHAM, Ph.D. Co-advisor: THANIYA KLINSOPHON, Ph.D.

The primary objective of this research was to investigate the impact of therapeutic body positions on hemodynamic and respiratory responses in adults with and without abdominal obesity. This research comprises three studies: 1) a systematic review and meta-analyses to investigate the influence of various body positions on hemodynamic and respiratory variables in healthy adults; 2) a study on hemodynamic responses during therapeutic body positions in adults with and without abdominal obesity; 3) a study on respiratory responses during therapeutic body positions, comparing obese and non-obese adults. The results from the systematic review revealed that different positions elicit distinct hemodynamic and respiratory responses. The evidence indicated that the supine position had the greatest impact on hemodynamic variables, while 70-degree head-up tilt and standing positions had the most significant influence on respiratory variables. The second and third studies examined 52 male volunteers, comprising 26 individuals with normal weight and 26 with abdominal obesity. Each participant underwent 40 minutes in various therapeutic body positions, including Fowler's, right lateral, left lateral, supine, and prone positions, respectively. The results of the second study in both groups suggest that the supine position emerged as the most favorable for hemodynamic responses, with the exception of blood pressure, for which the right lateral position proved optimal. The study strongly discourages the use of the prone position due to its potential negative impact on hemodynamics, which may be even more pronounced in individuals with abdominal obesity. Later, when examining the respiratory response in the third study, in both groups, the prone position was the most effective for improving ventilation and oxygenation, followed by Fowler's position for ventilation, while the right lateral position ranked second in oxygenation. The results demonstrate that each position leads to varying physiological responses, both positive and negative. These findings are valuable for choosing appropriate postures for patients in both groups to maximize treatment benefits while avoiding postures that may exacerbate symptoms.

Field of Study:	Physical Therapy	Student's Signature ....
Academic Year:	2023	Advisor's Signature ....
		Co-advisor's Signature ....

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Ruchada Sriamad

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CHAPTER 1 General Introduction

1.1 Outline of thesis

The thesis consists of six chapters. The first chapter provides an overview of the study, including the background and rationale, research objectives, research hypotheses, scope of study, and expected benefits and applications. The second chapter is a literature review related to this study. The third chapter focuses on a systematic review and meta-analysis of the influence of body positions on hemodynamics and respiration in healthy adults. The fourth chapter presents the hemodynamic responses during therapeutic body positions in adults with and without abdominal obesity. The fifth chapter illustrates the respiratory responses during therapeutic body positions, assessed using the Metabolic Stress Testing System (MGC, Ultima CPX™), in adults with and without abdominal obesity. The last chapter provides a general conclusion, including a summary of the results, limitations of the study, and clinical implications.

1.2 Background and rationale

Obesity is a non-communicable disease characterized by an excess accumulation of fat, categorized into general and abdominal obesity. General obesity is defined as a body mass index (BMI) of 25.0 kg/m² or more, as per the guidelines of the World Health Organization Western Pacific Region (1). Abdominal obesity is defined as a waist circumference (WC) of 90 cm or more for men and 80 cm or more for women, according to the International Diabetes Federation's criteria for Asian populations (2).

According to the World Health Organization (WHO) in 2020, the global prevalence of obesity nearly tripled between 1975 and 2020, with a higher occurrence among adults. In 2020, over 2 billion adults worldwide were overweight, comprising 39 percent of the adult population. Of these, more than 600 million were considered obese (3). In Thailand, this trend is also on the rise, with the highest prevalence of obesity observed among individuals aged 30-59 years (4). The increasing prevalence of obesity poses significant challenges for the Ministry of Public Health, as it is associated with an elevated risk of numerous diseases, increased disease severity, and extended hospital stays. Obesity serves as a major risk factor for various non-communicable diseases (NCDs) (5), including cardiovascular diseases (CVDs), diabetes, chronic respiratory diseases, and cancers, among others. These NCDs collectively account for 41 million deaths annually, representing 71 percent of all global fatalities (6).

The accumulation of an excessive amount of body fat in obesity is associated with the abnormal function of the body, leading to various complications and diseases. High fat, or adipocytes, triggers increased production of leptin, a hormone found in adipose tissue. Elevated leptin levels have been linked to inflammation-related disorders. Additionally, pro-inflammatory cytokines such as tumor necrosis factor (TNF) and interleukin-6 (IL-6) are secreted in greater quantities by adipocytes. These cytokines inhibit the production and secretion of adiponectin (ApN) from fat cells, which plays a crucial role in reducing blood sugar levels and increasing tissue sensitivity to insulin. Reduced ApN is associated with elevated levels of insulin resistance. These abnormalities disrupt the normal functioning of various organ systems. Furthermore, visceral fat in cases of abdominal obesity can induce hemodynamic dysfunctions. These dysfunctions play a significant role in left ventricular (LV) remodeling, characterized by reduced LV dimensions and can contribute to the development of cardiovascular diseases (CVDs) (7). Visceral fat can also reduce the diameter of the respiratory tract, increasing airway resistance and leading to insufficient ventilation. This is a contributing factor to chronic respiratory diseases (8). These abnormalities exacerbate the severity of diseases in obese patients, particularly those with CVDs (9, 10, 11). Recent studies have highlighted the association between obesity and increased risks in patients with Coronavirus (COVID-19). Preliminary data indicate that individuals with obesity are at a significantly higher risk of developing severe COVID-19 (12). One study reported a mortality rate of 62 percent among COVID-19 patients with obesity, which is notably higher than that of the normal-weight group (13). Consequently, obesity is associated with elevated all-cause mortality and an increased likelihood of hospitalization. During hospitalization, numerous complications may arise, including increased secretions, impaired respiratory mechanics, lung atelectasis, and other obesity-related pathophysiological features such as reduced respiratory muscle strength and lung volumes. These factors contribute to inefficient gas exchange, resulting in inadequate oxygen delivery to the body's target organ cells. This can lead to severe illness and/or require prolonged hospitalization.

After being admitted to the hospital, patients receive various treatments aimed at restoring or improving their health, ultimately facilitating their return home. One fundamental aspect of patient care is the use of therapeutic body positions, which include Fowler’s, right lateral, left lateral, supine, and prone positions. These positions serve several crucial purposes, such as preventing further complications, promoting normal physiological function, and enhancing patient comfort (14). Therapeutic body positions are non-invasive techniques that do not result in any long-term negative effects on patients. Furthermore, they are cost-effective and easy to implement both within the ward and in off-site medical settings. However, it is essential that therapeutic body positions prioritize the physical well-being of patients and the prevention of harm. Additionally, they should aim to alleviate the stress on hemodynamic and respiratory functions in patients.

Previous studies have provided the information about the influence of therapeutic body positions on physiological changes, particularly in hemodynamics, among healthy individuals. Hemodynamic parameters such as cardiac output (CO) and stroke volume (SV) have been reported to be higher in the supine position when compared to upright positions (15, 16, 17, 18). When comparing the supine position to the left lateral position, it was observed that CO was reduced in the supine position, primarily due to hydrostatic pressure gradients between the caval veins and the heart (20, 21). Moreover, in a previous study involving healthy adults, alveolar ventilation was found to be greater in the sitting position compared to the supine position (19). This suggests that different therapeutic body positions can yield varying effects on respiration. However, there is currently no investigation into the respiratory responses of individuals with obesity. Prior research has mainly focused on how obesity and body positioning affect chest wall volumes, lung function, and respiratory muscle strength. These studies have indicated that the seated position offers advantages in terms of chest wall volume, inspiratory muscle strength, and lung function (20). Additionally, it was observed that both seated positions, with and without back support, resulted in an expansion of chest wall diameter and positively influenced the kinematics of chest wall movements (21).

Based on the available evidence, it can be inferred that therapeutic body positions significantly influence physiological functions related to hemodynamics and respiration. However, to date, there has been no comprehensive systematic review or meta-analysis that has synthesized these findings comprehensively. Furthermore, there has been a lack of research into the hemodynamic and respiratory responses during therapeutic body positions in obese individuals, particularly those with abdominal obesity. Given that obese patients often receive treatment involving therapeutic body positions. Morphological changes associated with obesity may lead to responses that differ from those observed in healthy individuals.

1.3 Research objectives

1. To conduct a systematic review of the influence of therapeutic body positions on hemodynamics and respiration in healthy adults

2. To compare hemodynamic responses during therapeutic body positions within and between groups of adults with and without abdominal obesity

3. To compare respiratory responses during therapeutic body positions within and between groups of adults with and without abdominal obesity

1.4 Research hypotheses

1. Different therapeutic body positions can have varying effects on hemodynamic and respiratory responses in healthy adults

2. There are differences in hemodynamic responses during therapeutic body positions within and between groups of adults with and without abdominal obesity

3. There are differences in respiratory responses during therapeutic body positions within and between groups of adults with and without abdominal obesity

1.5 Scope of study

According to the gaps and limitations identified in the systematic review and meta-analysis, a cross-sectional study was conducted to investigate the impact of therapeutic body positions on hemodynamics and respiration in individual adults, both with and without abdominal obesity. The study enrolled 52 male volunteers aged 30-59 years, comprising 26 individuals with normal weight and 26 with abdominal obesity. The study involved five conditions, including Fowler's position (upright at 90 degrees), right lateral, left lateral, supine, and prone positions, each lasting for 40 minutes. The average assessment of hemodynamic and respiratory parameters was conducted for 1 minute.

1.6 Expected benefit and application

The research would provide valuable information on suitable therapeutic body positions for optimizing hemodynamic and respiratory functions in individuals, both with and without abdominal obesity. The appropriate therapeutic body position not only optimizes physiological function but also possesses the potential to reduce various complications, shorten hospitalization durations, and improve overall chances of recovery. The findings from this study can be applied to patients, whether they have abdominal obesity or not, both in hospital settings and at home. This treatment approach offers a safe and side-effect-free option for patients. Furthermore, it can also be beneficial for individuals without underlying illnesses who seek to enhance their hemodynamics, respiratory function, and gas exchange.

CHAPTER 2 Literature Review

2.1 Obesity

2.1.1 Defining obesity

Obesity is described as an intricate, multifaceted non-communicable ailment (NCD) marked by an excessive build-up of body fat, which can have adverse impacts on an individual's well-being. This condition mainly emerges due to a disparity between the consumption and expenditure of calories.

2.1.2 Type of obesity

Obesity can be classified based on the age of onset, which represents critical periods in the development of obesity. These stages include early childhood obesity, where obesity can result from adverse nutritional factors during fetal development, directly influencing the size, shape, and body composition of the fetus. Childhood obesity is characterized by metabolic challenges in handling macronutrients, contributing to excess weight. Middle-age obesity often arises from a combination of factors, including excessive calorie intake and a lower metabolism, resulting in fewer calories burned at rest and during activity (7). Furthermore, obesity can also be categorized based on fat distribution into general or subcutaneous obesity and abdominal or visceral obesity. General obesity typically involves subcutaneous fat deposition. In contrast, abdominal obesity is characterized by an increased accumulation of fat in visceral organs, even though it may have some subcutaneous fat involvement. Abdominal obesity is considered more hazardous and is associated with a higher risk of comorbidities and mortality (22).

2.1.3 Classification of obesity in adults

Classification of obesity relies on a system that encompasses various measurement methods. The choice of measurement method is typically based on its availability and its suitability for predicting health risks and guiding treatment strategies and goals (23).

2.1.3.1 Body mass index (BMI)

The Body Mass Index (BMI) is the currently most widely employed classification system, as recommended by the World Health Organization (WHO). It assesses the relationship between an individual's weight and height, calculated as weight (in kilograms) divided by the square of height (in meters). According to WHO guidelines, a BMI greater than or equal to 30 is considered indicative of obesity (3). However, for the Asia-Pacific region, a BMI greater than or equal to 25 kg/m² is utilized to classify obesity in Asian and South Asian populations (24, 25). The classification of obesity based on BMI further subdivides individuals into various categories, as shown in Table 1 (24, 25, 26). This classification system is invaluable for identifying individuals who may be at a heightened risk of obesity-related morbidity and mortality (27).

Table 1 Classification of obesity in adult according to body mass index

Classification	BMI Cut-Off Points (kg/m²)		Risk of co-morbidities based on WHO schema
	WHO	Asia-Pacific	
Underweight	< 18.5	< 18.5	Low (but risk of other clinical problems increased)
Normal weight	18.5-22.9	18.5-22.9	Average
Over weight	25-29.9	23-24.9	Mildly increased
Obese class l	30-34.9	25-29.9	Moderate
Obese class ll	35-39.9	≥ 30	Severe
Obese class lll	≥ 40		Very severe

2.1.3.2 Body fat mass

The BMI possesses certain clinical limitations that warrant consideration. It serves as a representative measure of excess weight rather than an accurate indicator of excess body fat. Furthermore, BMI fails to differentiate between various components of body composition, such as excess fat, muscle, or bone mass. It also does not provide insight into the distribution of fat among individuals. Direct measurement of fat mass can be achieved through various imaging modalities, including dual-energy X-ray absorptiometry (DEXA) (28), computed tomography (CT) scans, and magnetic resonance imaging (MRI). However, these methods are often impractical and cost-prohibitive for routine clinical use. Indirect estimation of body fat mass can be performed using methods such as underwater weighing or air displacement (BODPOD) and bioelectric impedance analysis (BIA). It is important to note that the interpretation of results from BODPOD and BIA may be confounded, particularly when an individual's fluid status is altered, as is the case in conditions like congestive heart failure (CHF) or chronic kidney disease (CKD). Additionally, clear norms for defining normal and abnormal ranges are not well-established for these methods (23).

2.1.3.3 Body fat distribution

While BMI is the most commonly used measure for assessing overall obesity, it is insufficient as a standalone indicator of health risk. BMI alone cannot classify the specific type of obesity. In clinical practice, fat distribution is employed to distinguish between peripheral (gynoid) and abdominal (android) types of obesity (23, 29). Peripheral obesity is characterized by an excess accumulation of subcutaneous fat in the buttocks, hips, and thighs (30), whereas central obesity is defined by the excessive accumulation of fat in the abdominal region, particularly due to an excess of visceral fat (30). Having a higher proportion of fat in the abdomen or trunk compared to the hips and lower extremities has been linked to an increased risk of comorbidities (23). To address this, anthropometric indicators such as waist circumference (WC) and waist-hip ratio (WHR) are employed to assess visceral fat, which surrounds vital organs like the stomach, heart, liver, intestine, and kidneys, and is strongly indicative of abdominal obesity (31). However, the relationships between these indicators and comorbidities exist on a continuum and can vary by gender, race, and ethnicity (Table 2) (32, 33, 34).

Table 2 Abdominal obesity according to waist circumference and waist hip ratio

Gender	Cut-Off Points			
	European ancestry		Asian and South Asian origin	
	WC	WHR	WC	WHR
Male	> 94	> 0.90	≥ 90 cm	> 0.95
Female	> 80	> 0.85	≥ 80 cm	> 0.80

Body fat distribution can also be assessed using skinfold thickness (SFT) measurements. SFT involves measuring the thickness of subcutaneous fat at various locations on the body (35). These measurements are categorized into limb sites, which include the biceps, triceps, quadriceps, and calf regions, as well as central sites such as the pectoral, subscapular, abdomen, and suprailiac regions (36). SFT measurements can be used to estimate body fat distribution using equations that have been validated, such as those provided by Jackson and Pollock (37).

Male

Body fat (%) = (0.29288 X sum of skinfolds, mm) – (0.0005 X sum of skinfolds, mm squared) + (0.15845 X age, years) – 5.76377

Female

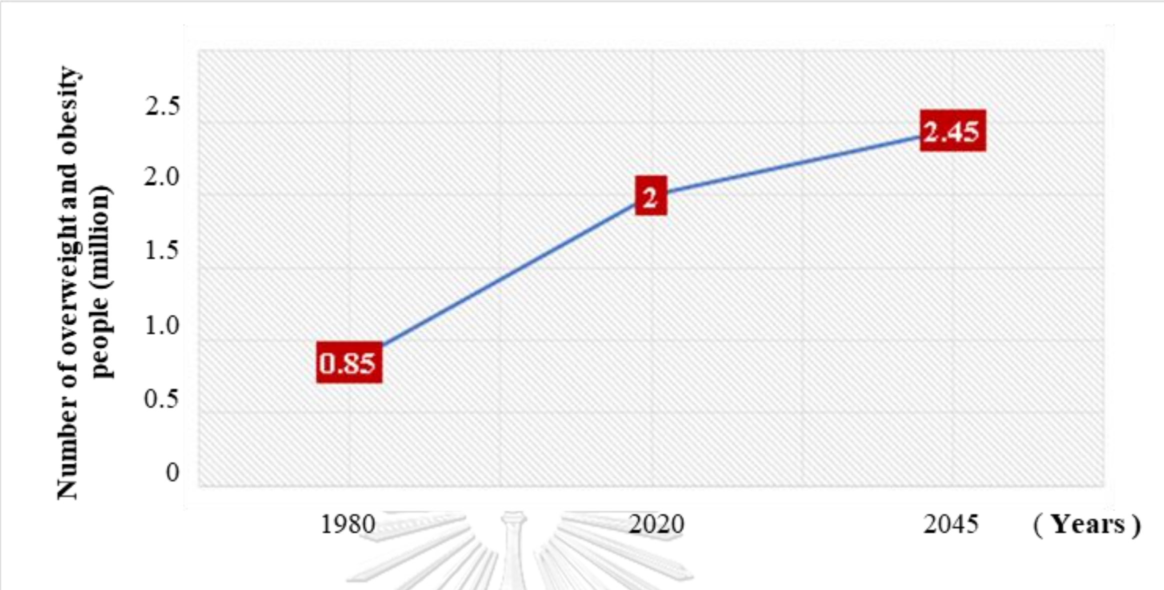
Body fat (%) = (0.29669 X sum of skinfolds, mm) – (0.00043 X sum of skinfolds, mm squared) + (0.02963 X age, years) + 1.4072

Table 3 Body fat percentage for male and female

Gender	Cut-Off Points (%)				
	Essential fat	Athletes	Fitness	Average	Obesity
Male	2-5	6-13	14-17	18-24	≥ 25
Female	10-13	14-20	21-24	25-31	≥ 32

2.1.4 Prevalence and public health problems of obesity

Currently, there is a global epidemic of obesity that is affecting people around the world. Between 1975 and 2020, the prevalence of obesity worldwide nearly tripled, and this trend is projected to continue in the future (Figure 1). This increase in obesity has been more pronounced among adults. In 2020, over 2 billion adults were classified as overweight, representing 39 percent of the global adult population. Among these adults, more than 600 million were considered obese (38), accounting for approximately 13% of the world's adult population. Additionally, there were 124 million cases of obesity among children and adolescents worldwide. The prevalence is reported to be higher in both male and female across the globe, affecting individuals in both developed and developing countries (39, 40).



Source: World Health Organizsation, 2020

Figure 1 Worldwide prevalence of obesity

In Thailand, a similar pattern of prevalence and trends in obesity is observed. Over the past decade, there has been a rapid and consistent rise in the prevalence of obesity in Thailand (41). According to a cross-sectional study conducted in a rural community in Thailand in 2018, this prevalence is most commonly observed among individuals aged 30 to 59 years, regardless of gender (Figure 2) (4). High BMI is associated with increased mortality rates (42) due to its wide range of complications that affect various aspects of physiology. Obesity is linked to a heightened risk or co-occurrence of nearly every chronic health condition. Therefore, obesity represents a significant public health epidemic that has been steadily worsening, leading to an increasing economic burden on the entire country. In the United States, for instance, it is estimated that over 700 billion US dollars are spent on obesity-related healthcare annually (43). In the case of Thailand, the estimated healthcare cost of obesity is approximately 12,142 million baht, equivalent to 725.3 million US dollars (41).

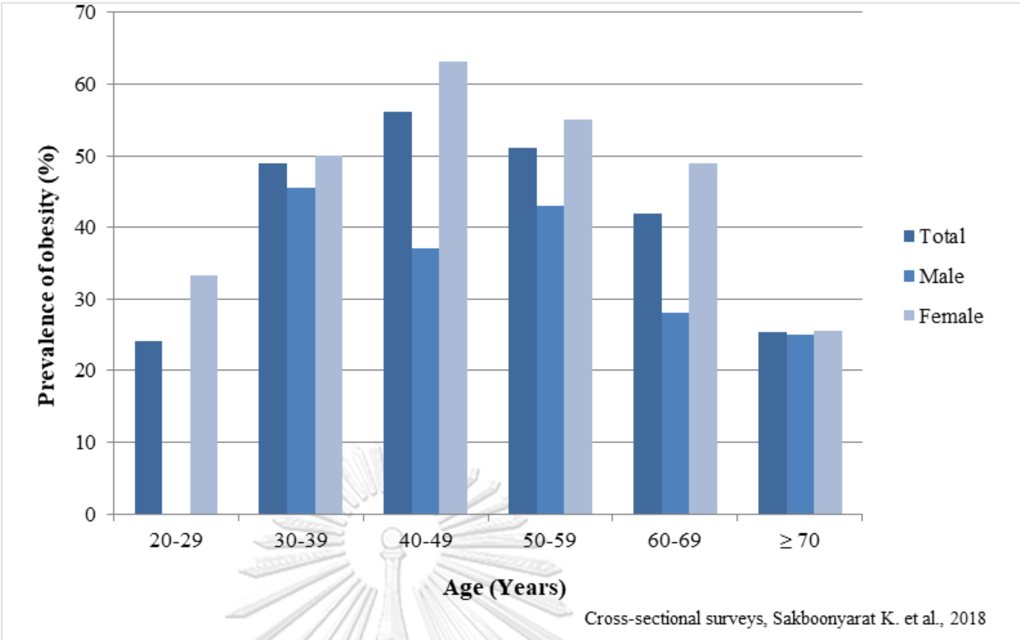
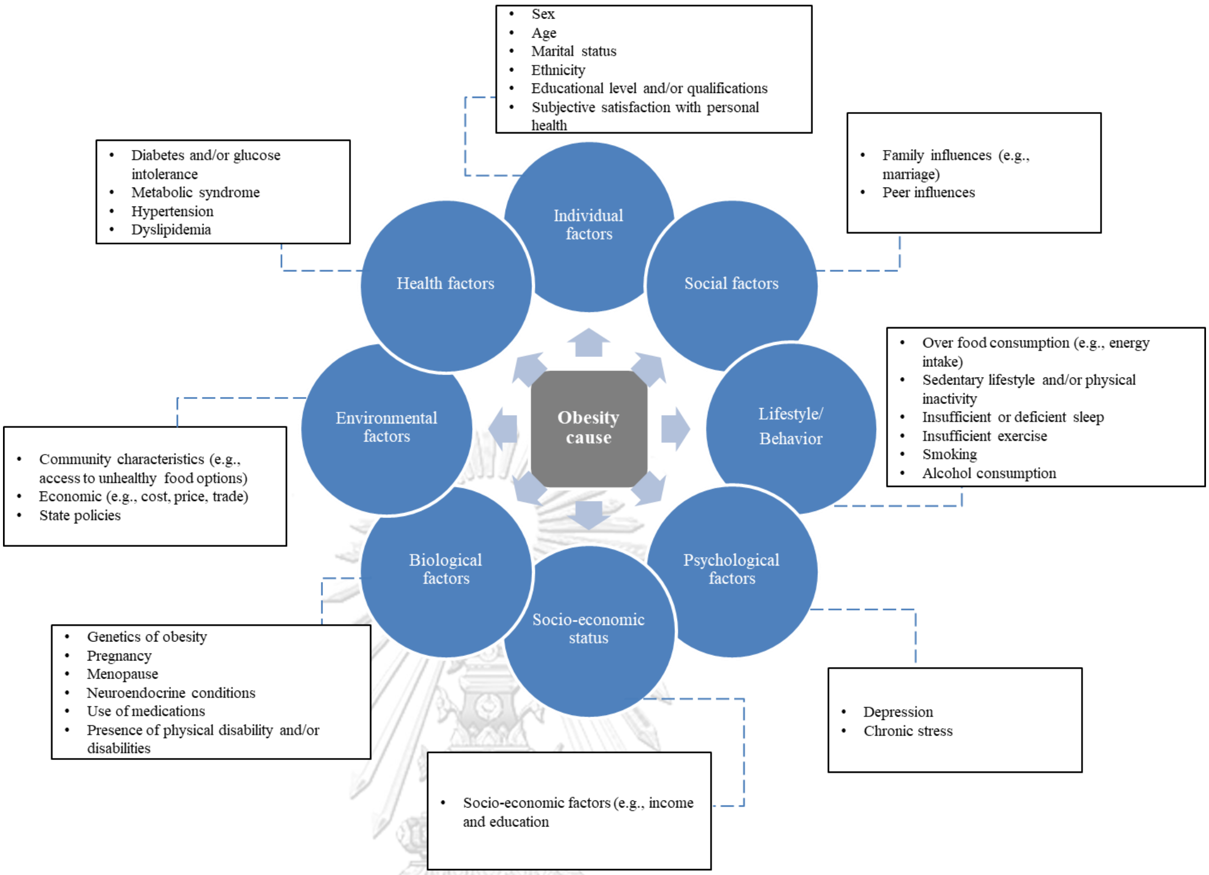


Figure 2 Prevalence of obesity among adults in in Thailand by age groups in 2018

2.1.5 Cause of adult obesity

A high BMI in adults has been demonstrated to significantly increase the risk of various diseases. Understanding the root causes of this condition is vital, as it can inform the development of strategies and policies aimed at addressing this global epidemic (44). Obesity is a multifaceted health issue that results from a combination of causes and individual factors, with external factors such as unhealthy habits (such as excessive drinking, smoking, lack of exercise, and overeating) playing a significant role. Moreover, obesity is influenced by a variety of contributing factors. Figure 3 illustrates some of these influential factors that contribute to overweightness or obesity in adults, as reported in a systematic literature review (27).



Modified from Safaei M. et al., 2021

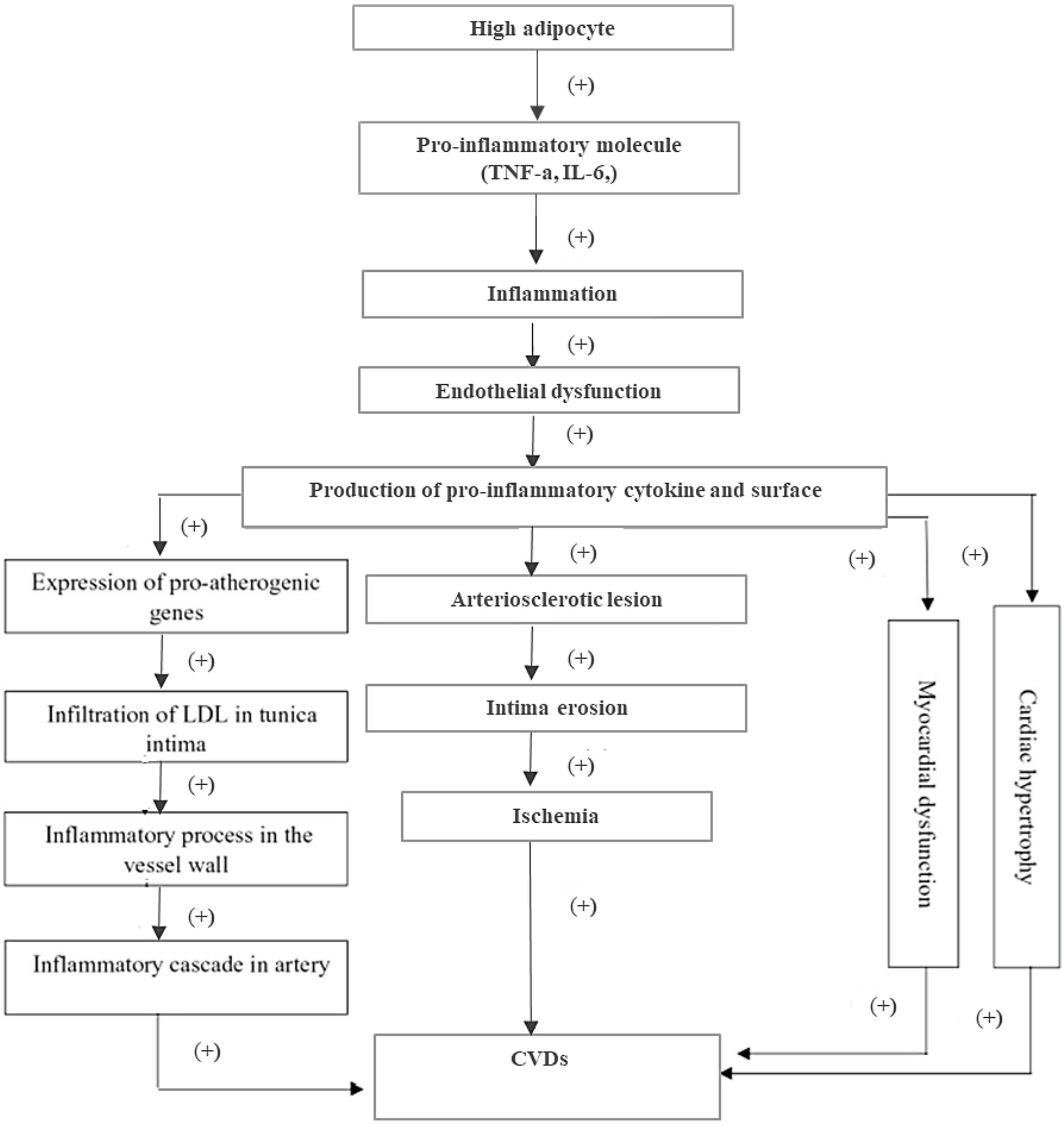
Figure 3 Potential factor that influence and/or cause adult obesity

2.1.6 Medical complication of obesity

The overabundance of adipocytes in obesity plays a central role in the pathophysiology of other NCDs, also referred to as chronic diseases (5). These NCDs encompass a range of conditions, including cardiovascular diseases, chronic respiratory diseases, diabetes mellitus, cancers, and others, collectively responsible for causing 41 million deaths each year, accounting for 71 percent of all fatalities (6). Excessive adipocytes contribute significantly to metabolic and organ dysfunction, affecting cardiac, liver, pulmonary, endocrine, and reproductive functions. They also lead to immune dysfunction due to the secretion of inflammatory adipokines and represent a major risk factor for numerous types of cancer(45). Furthermore, obesity increases the risk of severe symptoms and mortality associated with coronavirus (COVID-19) (46, 47). Each of these health impairments caused by obesity will be detailed below.

2.1.6.1 Cardiovascular diseases

Cardiovascular diseases (CVD) represent a general term encompassing conditions that affect the heart or blood vessels, and they hold a prominent position in the global landscape of disability and mortality (48). There is a clear association between obesity and an increased risk of developing CVD, including vascular diseases, heart disease, and stroke. The mechanism by which obesity heightens the risk of CVD involves changes in body composition that can impact hemodynamics (blood circulation) and alter the structure of the heart (49). In obesity, adipocytes can synthesize elevated levels of inflammatory molecules such as tumor necrosis factor-alpha (TNF-alpha) and several interleukins (IL), particularly IL-1b and IL-6, resulting in increased circulating concentrations of TNF-alpha and IL-6 (50). These cytokines play a significant role in the formation of atherosclerotic plaques within the tunica intima of artery walls (51, 52, 53). These inflammatory molecules contribute to tissue damage, ultimately leading to inflammation. Consequently, the formation of atherosclerotic plaques is promoted, and such plaques or lesions induce endothelial dysfunction, disrupting the normal functioning of endothelial cells and initiating the early stages of the atherosclerotic process (48). The heightened release of cytokines also stimulates the expression of pro-atherogenic genes (54), and provokes damage to the walls of blood vessels (51). Additionally, the infiltration of low-density lipoprotein (LDL) further exacerbates inflammation within the arteries (55). Moreover, an increase in body fat can directly contribute to heart disease by causing cardiac enlargement (56). Collectively, these effects culminate in the formation of cardiovascular lesions (Figure 4)



(+; increased)

Modified from Amin MN., 2020

Figure 4 Mechanism of CVDs induced by inflammation

2.1.6.2 Chronic respiratory diseases

Obesity impacts respiratory function through multiple mechanisms, including both direct mechanical changes stemming from the accumulation of adipose tissue on the chest wall, abdomen, visceral cavity, and upper airway, as well as systemic inflammation (57). These effects can lead to the development of chronic respiratory diseases (CRDs) (58). In normal respiration, the diaphragm contracts, pushing the abdominal contents downward and forward.

Simultaneously, the contraction of the external intercostal muscles raises and expands the ribs (59). However, in obese individuals, this mechanism becomes abnormal due to the excess body fat around the chest and abdominal regions, which limits the functioning of respiratory muscles. These structural changes restrict the mobility of the diaphragm and chest wall, altering the dynamics of the respiratory system and reducing its compliance. As a result, there is a mechanical impairment of the respiratory muscles (60), often leading to exertional dyspnea in obese adults (61). Furthermore, obesity can affect neural control of breathing and increase thoracic blood volume due to fat accumulation in the chest, which can also alter pulmonary function parameters (62). Numerous studies have reported that obesity significantly interferes with respiratory function by reducing lung volume, particularly the expiratory reserve volume (ERV) and functional residual capacity (FRC) (63, 64, 65). These changes are consistent with relative air trapping in obesity (66). A decrease in lung compliance can also stem from factors such as an increase in pulmonary blood volume, closure of dependent airways with the formation of small areas of atelectasis, or elevated alveolar surface tension due to a reduction in FRC (57, 65). The compression of fat mass can contribute to restrictive pulmonary damage (67) (Figure 5). Structural modifications in obesity (decline of total lung capacity) to humoral alterations, inflammatory state have demonstrated obesity-obstructive pulmonary disease associations, including, including asthma, chronic obstructive pulmonary disease (COPD) and obstructive sleep apnea (OSA) (68), are more prevalent in obese than in normal weights (69, 70). Having elucidated positive relation between adipokines (adiposity related inflammatory mediators) and asthma (71). The study reported that a pro-inflammatory state may be associated with increased risk of asthma in obesity (72), and developing to OSA (73). Moreover obesity may raise risk of COPD (74).

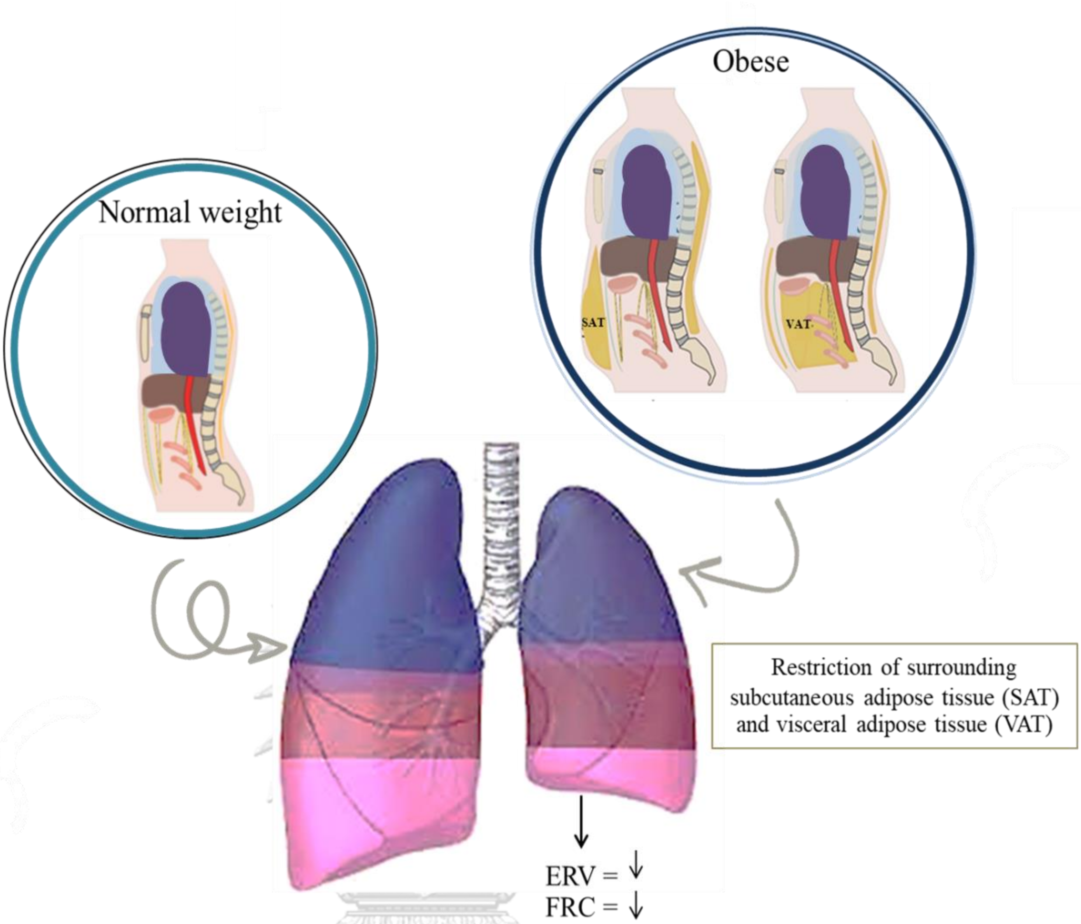


Figure 5 Obesity induced lung restriction contributing to deranged respiratory mechanics

2.1.6.3 Diabetes mellitus

In fact, obesity stands as the most significant risk factor for the development of diabetes mellitus (DM). Over time, the rates of both obesity and DM have continued to rise in parallel, contributing to increased mortality among affected individuals (75). It's worth noting that the majority of patients diagnosed with DM are either overweight or obese (76). According to the World Health Organization (WHO), overweight and obesity are responsible for approximately 44% of DM cases (77, 78). Elevated BMI significantly heightens the risk of developing type 2 DM when compared to individuals with a normal weight (79, 80). Consequently, the American Diabetes Association recommends that physicians screen for DM type 2 and assess the risk of future DM in people with obesity (81). DM type 2 is characterized by a combination of mechanisms, including a reduced level of insulin production from beta cells (a type of cell in pancreatic islets responsible for synthesizing and secreting insulin) and peripheral insulin resistance (82) These factors result in elevated levels of fatty acids in the bloodstream, leading to reduced glucose transport into muscle cells, increased fat breakdown, and heightened glucose production by the liver. It is important to note that DM type 2 occurs when insulin resistance and dysfunction of pancreatic beta-cells coexist (83). Beta-cell dysfunction plays a pivotal role in abnormal glucose tolerance, and elevated blood glucose levels can trigger vascular complications (84).

2.1.6.4 Cancer

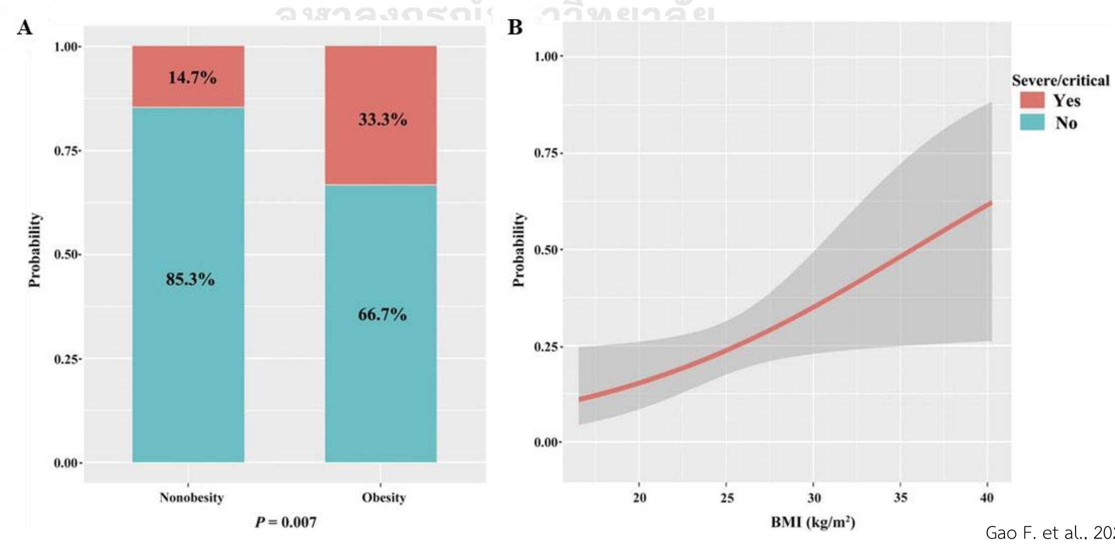
As obesity rates continue to rise, it is anticipated that the burden of cancer will also increase in the future (85). Evidence from a meta-analysis of observational studies has consistently shown a statistically significant and positive association between obesity and cancer risk. When comparing obese individuals to those who are not obese, both men and women with obesity face a significantly elevated risk of developing cancer (86). Obesity is recognized as a risk factor for over 10 different types of cancer (85) , including esophageal, colon, pancreatic, breast, endometrial, kidney, gallbladder, liver, ovarian, prostate, and leukemia (87), gallbladder (88), liver (89), ovaries (90), prostate (91), and leukemia (92). Many of these cancers are hormonally driven and are linked to increased cancer incidence and morbidity. Obesity-related dysfunctions can contribute to cancer pathogenesis and resistance to treatment through various mechanisms. Additionally, alterations in adipose tissue in obesity can impact tumor vascularity and promote inflammation within tumors, which can further stimulate tumor growth and development (85).

2.1.6.5 Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) disease (COVID-19)

The coronavirus disease (COVID-19), caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has emerged as the prevailing global health crisis of our time (93). It has become evident that patients with preexisting chronic medical conditions, which include CVDs, CRDs, DM, various cancers, and obesity, are particularly susceptible to severe cases of COVID-19. Current available data indicates that obesity is prevalent among patients with COVID-19 and firmly establishes that individuals with obesity face a significantly higher risk of experiencing severe illness as a result of COVID-19 (94, 95). The combination of immune and metabolic dysfunctions mediated by adipose tissue may play a pivotal role in the pathophysiology that leads to severe COVID-19 (12, 96, 97).

2.1.7 Obesity related to severe morbidity and death

Obesity is well-known for impairing organ function and disrupting the immune system (98, 99), making it a significant risk factor for several NCDs (76). When patients with obesity require hospitalization, their risk of complications, such as the accumulation of secretions, respiratory muscle weakness, lung atelectasis, and abnormal breathing patterns, is heightened. These complications can result in impaired gas exchange, ultimately leading to insufficient tissue oxygenation despite adequate hemodynamics and oxygen delivery to organ cells. Research has shown that obese patients, when compared to non-obese individuals, face higher in-hospital mortality rates and an elevated risk of major complications (100). A meta-analysis on obesity and its impact on healthcare outcomes revealed that obesity is associated with higher rates of complications, tends to lead to longer durations of mechanical ventilation, extended hospital stays, and increased odds of mortality. These findings held true even when injury severity was equivalent between obese and non-obese patients (101). Moreover, a study investigating the relationship between obesity and the severity of COVID-19 illness among patients found that obesity was linked to longer hospital stays and an increased risk of severe COVID-19 illness compared to non-obese patients (Figure 6A). There was a clear correlation between increasing BMI values and the proportion of patients experiencing severe COVID-19 (102), as shown in Figure 6B.



Gao F. et al., 2020

Figure 6 Prevalence of COVID-19 severities in patients with and without obesity (A) and association between increasing BMI values and COVID-19 severity (B)

2.2 Hemodynamics

2.2.1 Basic concepts of hemodynamics

Hemodynamics, which encompasses the circulation of blood throughout the body, plays a pivotal role in facilitating the transport of nutrients, hormones, metabolic waste, oxygen, and carbon dioxide. This circulation is essential for maintaining cellular metabolism, regulating pH levels, managing osmotic pressure, and controlling overall body temperature. Hemodynamics is a physics-based process, governed by the homeostatic mechanisms of auto-regulation. The study of hemodynamics involves the analysis of pressure distribution (where pressure refers to hydrostatic pressure) and the flow of fluids within the circulatory system. Pressure represents the internal mechanical energy per unit volume. The pumping action of the heart pressurizes blood, providing it with the necessary internal energy to propel it through the circulatory system. The term 'flow' pertains to the movement of fluids, such as blood (103).

2.2.2 Hemodynamics monitoring

Hemodynamic monitoring, also known as physiological monitoring, is an indispensable aspect of medicine. Its primary purpose is to assess, monitor, and provide ongoing care to patients, ensuring the adequate delivery of oxygen to tissues and organs. Hemodynamics plays a critical role in diagnosing the specific type of circulatory disorder based on the underlying pathophysiological processes, thereby enabling effective patient management (104). The advantages of hemodynamic monitoring allow the healthcare physician to review the information below:

- Enough blood
- Structural problems
- Suitable parameter

2.2.2.1 Hemodynamic parameters

Hemodynamic parameters utilized to evaluate a patient's health status, these parameters can be categorized into primary and advanced categories, as demonstrated in Table 4 (105, 106, 107, 108, 109).

Table 4 Primary and advanced hemodynamic parameters

Parameters	Definition	Normal range
Primary		
Heart rate (HR)	Number of heart beats per unit of time	60 - 100 beats/min
Systolic blood pressure (SBP)	Maximum pressure in the aorta at the end of systole	< 120 mm Hg
Diastolic blood pressure (DBP)	Minimum pressure in the aorta at the end of diastole	< 80 mm Hg
Mean arterial pressure (MAP)	Average arterial pressure throughout one cardiac cycle MAP = (SBP + 2DBP) / 3	70 - 105 mm Hg
Advance		
Stroke volume (SV)	Amount of blood the left ventricle ejects in one beat SV = EDV - ESV	60 - 100 ml/beat
Stroke volume index (SVI)	Amount of blood the left ventricle ejects in one beat dividing by the body surface area (BSA) CI / HR	33 - 47 $ml/m^2/beat$
Cardiac output (CO)	Amount of blood the ventricle pumps through the circulatory system in a minute CO = SV x HR	4.0 - 8.0 L/min
Cardiac index (CI)	Amount of blood the ventricle pumps through the circulatory system in a minute dividing by the body surface area $CI = CO / BSA (m^2)$	2.5 - 4.0 $L/min/m^2$
Systemic vascular resistance (SVR)	Vascular resistance to the systemic circulation SVR = [(MAP – RAP) / CO]	800 - 1200 $dynes/sec/cm^5$
Systematic vascular resistance index	Vascular resistance to the systemic circulation dividing by the body surface area	1,970 - 2,390 $dynes/sec/cm^5/$

(SVRI)	SVRI = [(MAP – RAP) / CI]	m^2
Ejection fraction (EF)	Fraction of blood ejected with each contraction of the ventricle EF = (SV / EDV) * 100	50-70%
End systolic volume (ESV)	Volume of blood in the ventricle at the end of contraction EDV - SV	50 - 100 ml
End diastolic volume (EDV)	Volume of blood in the ventricle at the end of filling SV / EF	100 - 160 ml

2.2.2.1 Methods of hemodynamic monitoring

Over the past few decades, several methods have been developed to measure hemodynamics, particularly crucial parameters like CO. These methods can be broadly categorized as invasive, less-invasive, and non-invasive.

Invasive methods

The Pulmonary Artery Catheter (PAC) is considered the gold standard for measuring CO. This diagnostic procedure involves the insertion of a flow-directed catheter through an access point in a central vein (110, 111). The PAC not only enables the measurement of CO but also provides several derived parameters, including SVR, pulmonary vascular resistance (PVR), left and right ventricular stroke work, and the oxygen extraction ratio. However, it's important to note that this measurement is not continuous but rather an average over the last 5 minutes. Moreover, it cannot immediately assess changes in CO during alterations in preload or afterload. The PAC is typically most indicated for patients with right ventricular heart failure or pulmonary hypertension since no other monitoring device can directly measure right heart pressures and pulmonary circulation (110).

Less-invasive methods

Several less-invasive procedures, such as pulse contour and pulse pressure analysis, aim to estimate CO using information about HR and BP. These devices also involve estimating the pressure-volume relationship of the aorta. Most of the techniques currently in use are based on a three-element model that integrates aortic characteristic impedance, arterial compliance, and SVR. While these models generally work well for stable patients, they may lack accuracy in unstable patients or when vasoactive drugs are administered (112). Another less-invasive method is partial CO_2 rebreathing, which uses a partial rebreathing approach to measure CO. This system combines a CO and airflow sensor with a pulse oximeter while monitoring CO_2 production. It calculates CO by assuming stability in both normal and rebreathing conditions and utilizes the difference between normal and rebreathing ratios to calculate CO. However, the use of this device is dependent on stable ventilation and can only be employed in fully sedated patients under volume-controlled ventilation (110). Transesophageal echocardiography (TEE) is a valuable diagnostic tool in cardiovascular assessment during perioperative and critical care situations. It employs ultrasound to provide real-time images of cardiac structures and blood flow. TEE can help identify pathophysiological abnormalities in patients with wall motion abnormalities, pericardial effusions, pulmonary hypertension, valvulopathy, and other conditions when used in conjunction with other monitoring techniques. There is a relatively low risk of oropharyngeal bleeding and endotracheal tube dislocation with TEE, but it should be used with caution in cases of esophageal pathologies and severe coagulation abnormalities (110).

Non-invasive methods

CO can be assessed using non-invasive techniques, with one such method being transthoracic echocardiogram (TTE). TTE provides static or moving images of the heart's internal structures, and measurements can be taken at various locations, including the mitral valve annulus, ascending aorta, pulmonary artery, and right ventricular outflow tract (RVOT). Accurate CO measurements can be obtained from the RVOT location, provided there is no interference due to pulmonary arterial hypertension (110). Another non-invasive method is bioimpedance, which involves applying a small electrical current. Voltage changes across the circuit occur due to variations in impedance and/or the volume of conducting tissues. Blood has relatively low resistivity, and changes in intrathoracic blood volume significantly impact impedance. Therefore, changes in thoracic impedance are primarily influenced by three components: base impedance (indirectly proportional to chest fluid volume), changes in intrathoracic blood volume due to respiration, and minor changes associated with the cardiac cycle. These changes, particularly in aortic volume, can be used to estimate SV and CO. However, bioimpedance has limitations in patients with lung edema and/or pleural effusions (113, 114). Signal morphology-based impedance cardiography is another technique that employs a low-magnitude, high-frequency alternating current transmitted through the chest. This method measures the baseline impedance and variations induced by respiration and cardiac flow. The 'PhysioFlow®' tool is an example of such a system, offering sensitive measurements even in challenging conditions and difficult patients. It pushes the boundaries of non-invasive hemodynamic monitoring, with CO measurement based on a formula incorporating heart rate (HR), stroke volume index (SVI), and body surface area (BSA). It does not require the distance between the sensing electrode and blood resistivity. PhysioFlow® can provide continuous, accurate, reproducible, and sensitive measurements of various parameters, including contractility index, HR, ventricular ejection time, early diastolic filling ratios, SV, SVI, CO, CI, SVR, SVRI, estimated EF, and estimated EDV. Notably, this tool is the only non-invasive CO monitor approved by the United States Food and Drug Administration (USFDA). It has demonstrated non-inferiority to the gold standard predicate device (thermodilution and Swan-Ganz catheter) and superiority to standard impedance cardiography. PhysioFlow® has been proven effective in a wide range of measurement conditions, including maximal exercise, highly instrumented intensive care units (ICUs), difficult patients (pulmonary edema, emphysema, obese, etc.) (115, 116).

2.2.3 Factors related to hemodynamics

Hemodynamic parameters are influenced by various internal and external factors.

Internal factors

Internal factors that influence hemodynamics are numerous, including blood characteristics. One key blood characteristic affecting hemodynamics is plasma viscosity, which relates to the internal friction of fluid. There exists an inverse relationship between flow and viscosity, meaning that higher viscosity results in greater internal friction, increased resistance to flow, and subsequently, elevated BP. Another significant internal factor is blood volume, which refers to the amount of blood circulating throughout the body. Higher total blood volume is associated with increased BP and CO. Blood vessels also play a pivotal role in hemodynamics. Their primary attributes, resistance and compliance, can be influenced by irregularities within the vessels. These irregularities can lead to increased resistance and/or decreased compliance, resulting in elevated SVR and BP. Furthermore, abnormalities in resistance and compliance can alter the type of blood flow from laminar to turbulent (Figure 7) (117).

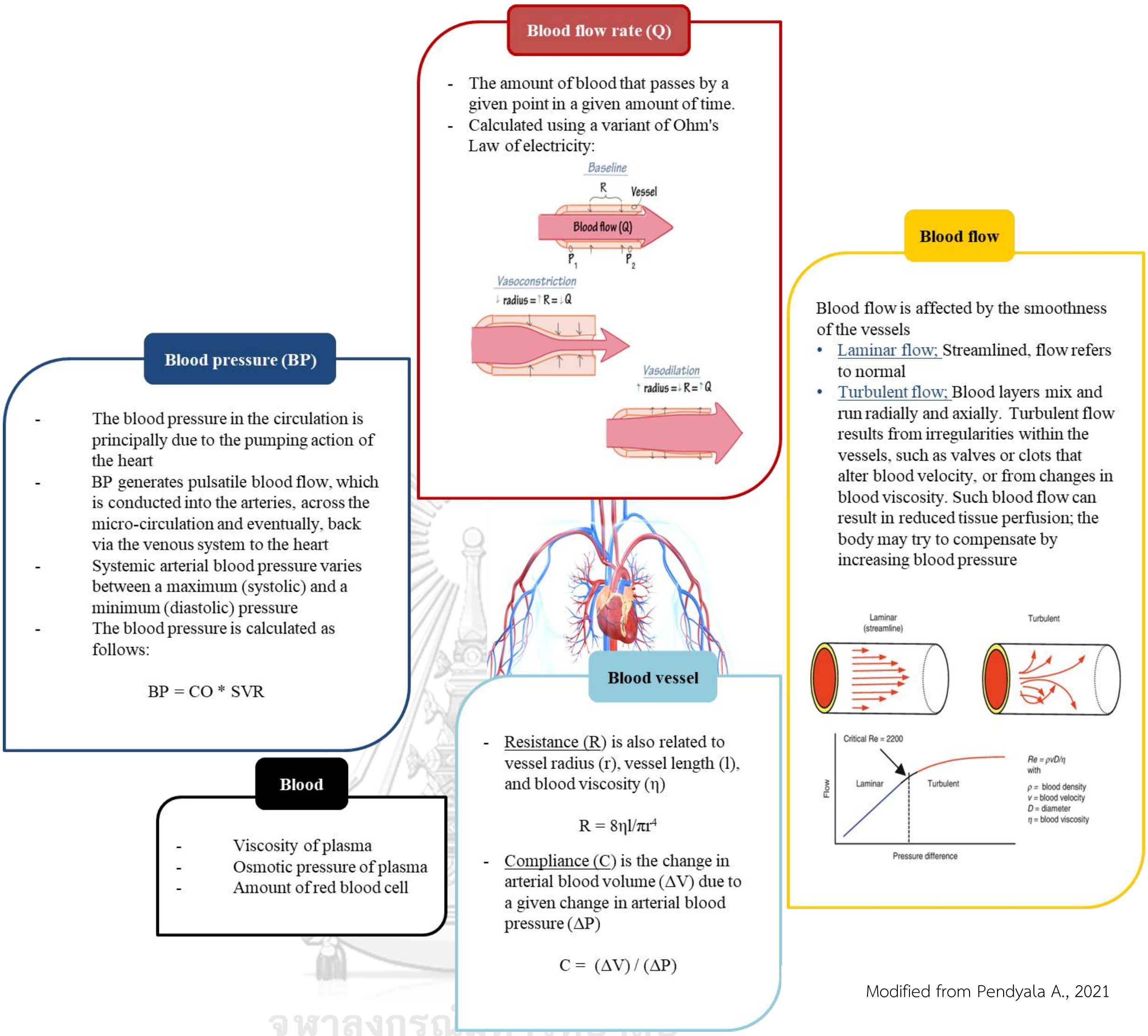


Figure 7 Internal factors affecting hemodynamics

External factors

Factors	Description
Age	Hemodynamic parameters are influenced by the aging process. As individuals grow older, there are noticeable changes in maximal CO and cardiac filling pressures, which differ from those observed in younger individuals (118, 119, 120). These findings align with previous research indicating that CO and SV tend to decrease with age in healthy subjects (121). This decline in CO and SV can be attributed to changes in left ventricular (LV) geometry, with younger individuals typically having more spherical LVs that tend to become more elliptical as they age (121, 122). Additionally, aging is associated with arterial wall stiffening, resulting in increased vascular stiffness (afterload). This age-related vascular stiffness can contribute to conditions such as basal septal hypertrophy (BSH), which is commonly observed in patients with systemic hypertension and has been linked to a reduction in SV.
Gender	Previous studies have explored the influence of gender on CO and SV in healthy adults, revealing significant differences between women and men (121). The findings indicate that CO and SV are notably lower in women compared to men, and this contrast can be attributed to differences in left ventricle (LV) volumes, left ventricular mass, and left atrial volumes between the two genders (122). These results are consistent with another study that reported differences in BP values between men and women within similar age ranges. Specifically, men exhibited higher BP levels than women in adulthood. However, following menopause, women's BP tends to be higher than that of men, which may be associated with estrogen loss (123).
BMI	A high BMI can lead to various hemodynamic changes, potentially affecting cardiac morphology and increasing the risk of left and right ventricular dysfunction (145). A study examined the relationship between BMI and hemodynamic parameters in patients of different body sizes. As BMI increases, there is often an associated rise in total blood volume, leading to the dilation and hypertrophy of the LV (121, 124). Notably, a BMI is greater than 30 kg/m^2

	linked to potential abnormalities in cardiovascular hemodynamics, cardiac morphology, and ventricular function (145). Prior research has established a positive linear relationship between BMI and both CO and SV. The findings indicate that for each 1 kg/m^2 increase in BMI, there is an associated increase of 0.08 L/min in CO and 1.35 mL in SV. However, it is essential to note that these small hemodynamic differences are unlikely to complicate clinical management. Similarly, another study observed that patients with BMIs below normal tended to have CO and SV values at the lower limits of normal, while very obese patients exhibited CO and SV values at the upper limits of normal. Nevertheless, these relationships are generally not clinically significant in most hemodynamic monitoring scenarios.
Fat distribution and waist hip ratio (WHR)	Elevated abdominal fat distribution has been linked to an increased risk of high blood pressure and cardiovascular issues (125). A previous study investigated hemodynamic changes in various forms of fat distribution, including subcutaneous adipose tissue (SAT, associated with general obesity) and visceral adipose tissue (VAT, linked to abdominal obesity). The study employed linear regressions to evaluate the impact of VAT and SAT on cardiac function. The findings indicated that SAT and VAT are associated with distinct cardiovascular characteristics. Specifically, VAT was linked to a smaller EDV, suggesting that VAT may have a more significant influence compared to SAT in LV remodeling, resulting in reduced LV dimensions (7). These results align with WHR, which reflects central fat levels and has been correlated with high BP and elevated cardiovascular risk (126).
Physical activity/Exercise	Insufficient physical activity is recognized as a leading risk factor for CVDs (127, 128). Regular physical activity is widely acknowledged as a vital component in preventing CVD (127). It offers significant benefits for hemodynamic functions, as research studies have shown that individuals with high levels of physical activity tend to have lower BP and increased CO (129). Consequently, exercise is considered a key contributor to favorable hemodynamic states. Previous meta-analyses have provided insights into the effects of exercise

	training. Both aerobic and resistance exercises have been shown to significantly decrease BP and enhance cardiac function (130).

2.3 Respiration

2.3.1 Basic concepts of respiration

Respiration is a fundamental physiological process that initiates with the intake of oxygen necessary for metabolism through inhalation and culminates in the removal of carbon dioxide from the body through exhalation (131). It plays a crucial role in facilitating gas exchange, a process in which oxygen and carbon dioxide are exchanged between the alveolar air in the lungs and the blood circulating in the pulmonary capillaries. Respiration represents one component of the cardiorespiratory system, which operates harmoniously to ensure the efficient delivery of oxygen to the body's tissues and organs. Any impairment or anomaly within these interconnected systems can result in the failure to provide adequate oxygen delivery, leading to conditions such as metabolic acidosis, hypoxic-ischemic injury, organ dysfunction, and ultimately failure.

2.3.2 Respiration monitoring

Besides hemodynamics, one of the fascinating physiological variables is respiration. Monitoring respiration is a crucial indicator of an individual's health (132). Information about breathing patterns is valuable for assessing one's health condition (133). It aids in the diagnosis of respiratory disorders like asthma, sleep apnea, and chronic obstructive pulmonary diseases (134). Moreover, respiration monitoring is employed during treatments and for patient surveillance. Access to respiration data can be instrumental in devising preventive measures or planning treatments for various ailments.

2.3.2.1 Respiration parameters

Respiration relies on both ventilation and oxygenation, which serve as essential indicators for assessing an individual's health condition. These parameters are outlined in Table 5 (108, 135, 136, 137, 138).

Table 5 Respiration and oxygenation parameters

Parameters	Definition	Normal range
Respiratory frequency (R_f)	Number of breaths a person takes per minute	12-20 breaths/min
Alveolar ventilation (V_A)	Flow of air into and out of the alveoli $V_A = RR * (V_T - V_D)$	
Minute ventilation (V_E)	Volume of gas inhaled or exhaled from the lungs per minute $V_E = V_T * RR$	
Tidal volume (V_T)	Amount of air that moves in or out of the lungs with each respiratory cycle	~ 500 ml in male ~ 400 ml in female
Dead space ventilation (V_D)	Volume of ventilated air that does not participate in gas exchange VD = VD (physiologic dead space) x RR	0.2 - 0.35 L/min
Oxygen Consumption (VO_2)	$(C(a - v)O_2) * CO * 10$	200 - 250 ml/min
Carbon dioxide production (VCO_2)	Volume of carbon dioxide that breathe out after transporting oxygen through the body	~ 200 ml/min
Partial pressure of arterial oxygen (PaO_2)	Pressure of oxygen dissolved in the blood	80 - 100 mm Hg
Partial pressure of arterial carbon dioxide ($PaCO_2$)	Pressure of carbon dioxide dissolved in the blood	35 - 45 mm Hg
Arterial oxygen saturation (SaO_2)	Percentage of oxyhemoglobin (oxygen-bound hemoglobin) in the blood	95 - 100%
Mixed Venous Saturation (SvO_2)	Percentage of oxygen bound to hemoglobin in blood returning to the right side of the heart.	60 - 80%
Arterial Oxygen Content (CaO_2)	$(0.0138 * Hgb * SaO_2) + 0.0031 * PaO_2$	17 - 20 ml/dl

2.3.2.2 Methods of respiration monitoring

One of the gold standards for monitoring respiration is cardiopulmonary exercise testing (CPET). CPET has become an indispensable tool in clinical practice, offering a non-invasive technique that enhances disease diagnosis and quality assessment (139). It allows for the comprehensive measurement of respiratory variables, aiding in the identification of specific pathophysiological conditions and the monitoring of their progression and response to treatment. CPET encompasses the measurement of respiratory oxygen uptake (VO_2), carbon dioxide production (VCO_2), and ventilatory parameters both at rest and during exercise (140).

2.3.3 Factors related to respiration

Internal factors

1. Airway resistance

Airway resistance (R) represents the resistance encountered by the respiratory tract during the inhalation and exhalation of air. It encompasses the conducting zone for air passage, including structures such as the trachea, main bronchi, segmental bronchi, and bronchioles. The calculation of R takes into account both the diameter of the airways and the properties of the airflow. Below is the equation used to calculate R.

$$R = 8 \eta l / \pi r^4$$

η = Gas viscosity

l = Airway length

r = Radius of airway

2. Airway diameter

The diameter of the airway is a critical parameter influencing respiration. The relationship between airway radius and R is inversely proportional.

3. Flow of air

Airflow can manifest as either laminar or turbulent flow. Laminar flow is characterized by an orderly and centralized distribution of air particles, typically occurring in small airways and associated with low resistance. On the other hand, turbulent flow is characterized by a disorganized distribution of air layers, often observed in large airways, branched airways, and associated with higher R.

4. Surface tension in the lung

Surface tension refers to the force exerted by water molecules on the lung tissue's surface. Since the air within the lungs is moist, surface tension within the lung tissue is prevalent. Alveoli in the lungs possess high compliance, meaning they do not counteract surface tension. This characteristic is the reason alveoli tend to collapse when air is expelled during exhalation.

5. Pulmonary surfactant

Pulmonary surfactant is a monomolecular layer that forms between the alveolar epithelium and the air within the lungs. Its primary function is to mitigate the effects of surface tension exerted by water molecules on lung tissue.

6. Lungs compliance

Compliance refers to the measure of the lungs' expandability or their ability to expand easily. Factors that reduce this compliance are outlined below.

- Reduced natural elasticity due to scar tissue or fibrosis
- Blockage of small respiratory passages by mucus or fluid
- Decreased production of surfactant

External factors

Factors	Description
Age	Gas exchange in the elderly is impaired, as indicated by an increase in the alveolar-arterial difference for oxygen and a reduction in the partial pressure of oxygen (141). This rise in the alveolar-arterial difference for oxygen is attributed to an increase in ventilation-perfusion heterogeneity, which signifies a decrease in gas exchange efficiency with advancing age (142). Additionally, aging is linked to an increase in closing volume (143) and alterations in the distribution of ventilation (144, 145). These changes encompass various anatomical, physiological, and immunological transformations associated with aging (146).
Gender	Male and female exhibit anatomical differences, which may have clinical implications. Male generally have larger airways, lung volumes, maximum expiratory flow rates, and diffusion surfaces compared to female. These differences extend to the size and resistance of the airways, with male typically having a greater cross-sectional area of airways than female (147). The cross-sectional area of airway in male is greater than in female (148). Furthermore, male have larger lungs than female (149). However, it is important to note that the number of alveoli per unit area does not differ between male and female.
BMI and fat distribution	Respiratory alterations involve mechanical changes caused by the accumulation of adipose tissue and the influence of various cytokines in individuals with high BMI. Obesity significantly impacts respiratory function by reducing lung volume, particularly the expiratory reserve volume and functional residual capacity. This results in weakened respiratory muscle strength and reduced resistance. These factors lead to increased respiratory effort, VO_2, and energy expenditure during respiration. Furthermore, the distribution of body fat significantly affects respiration due to the direct mechanical effects of fat accumulation in the chest and abdominal regions (69). Indeed, these factors can lead to various respiratory issues, including small airway dysfunction, limitations in airflow, and abnormalities in respiratory mechanics, reduced lung compliance, and impaired pulmonary gas exchange (65, 150).
Physical activity/exercise	Respiration responds to changes in activity levels almost immediately, and there are also some long-term effects of exercise on respiratory function.

	Exercise has a positive impact on the diaphragm and intercostal muscles, and regular exercise can help strengthen these respiratory muscles (151). This, in turn, leads to an increase in the overall efficiency of respiration. Individuals who exercise regularly tend to develop an improved ability for gas exchange. Research indicates that regular exercise can increase the number of capillaries around the alveoli. Furthermore, it can enhance the dilation of capillaries, facilitating more efficient gas exchange (152).

2.4 Therapeutic body positions

2.4.1 Basic concepts of body positions

Therapeutic body positioning involves the alignment of body parts and encompasses complex interactions among various organ systems. It is an important clinical intervention that physical therapists use to simulate specific postures based on individual patient needs. The choice of posture is determined by the patient's condition, as altering the body's position can have a significant impact on physiological functions (153). Various positions are commonly employed in clinical practice, including the fowler's, lateral, supine, and prone positions. This therapeutic intervention is non-invasive, cost-effective, and can be implemented either at home or in a healthcare setting.

2.4.2 Indications for therapeutic body positions intervention

Proper positioning is crucial for all patients who spend extended periods in bed or are bedridden. This includes patients with limited mobility, individuals at risk of impaired gas exchange, and those susceptible to lung atelectasis. The appropriate positioning of these patients can significantly impact their comfort, safety, and overall health outcomes.

2.4.3 Purpose and consideration of therapeutic body positions

- Therapeutic body positions can facilitate normal physiological functions of the cardiovascular and pulmonary systems, improving oxygen transport.
- Proper positioning can help prevent complications associated with hospitalization, including excess secretions, respiratory muscle weakness, and lung atelectasis.
- Patients often find therapeutic body positions more comfortable, enhancing their overall experience.
- These positions can also help alleviate stress on the hemodynamic and respiratory functions, contributing to better patient outcomes.

2.4.4 The influence of therapeutic body positions

2.4.4.1 Hemodynamics

Numerous studies have demonstrated that therapeutic body positions can have a pronounced effect on physiological function (153). Positional changes, both in the vertical and horizontal orientations of the human body, have been shown to influence hemodynamics related to gas exchange. The evidence suggests that cardiac volumes, including CO, are higher in the supine position compared to sitting and Fowler's positions (15, 17, 18, 154, 155) and SV because of gravity (17, 18, 155). In the supine position, gravitational forces are evenly distributed across the thorax, abdomen, and lower extremities, as these compartments lie in the same horizontal plane (18, 155, 156), correspond with an increase in HR and SVR in fowler’s position when compared with supine position (157). In Fowler's position, MAP did not change within 10 minutes of transitioning from the supine position. This change in posture leads to a gravity-induced shift of blood to the lower body, resulting in reduced cardiac preload and, consequently, a decrease in CO. To compensate for the initial drop in blood pressure, the baroreflex increases vasomotor tone through heightened sympathetic output, thereby elevating SVR and accelerating HR to maintain MAP (16, 158). Conversely, another study reported an increase in MAP one minute after changing from the supine position to Fowler's position (157). This could be due to a delayed response of the blood pressure control mechanisms. When comparing the transition from supine position to the left lateral position, it was observed that CO and SV were smaller in the supine position. This could be attributed to improved venous return, as hydrostatic pressure gradients between the caval veins and the heart are likely higher when lying on one's side compared to lying on the back (159).

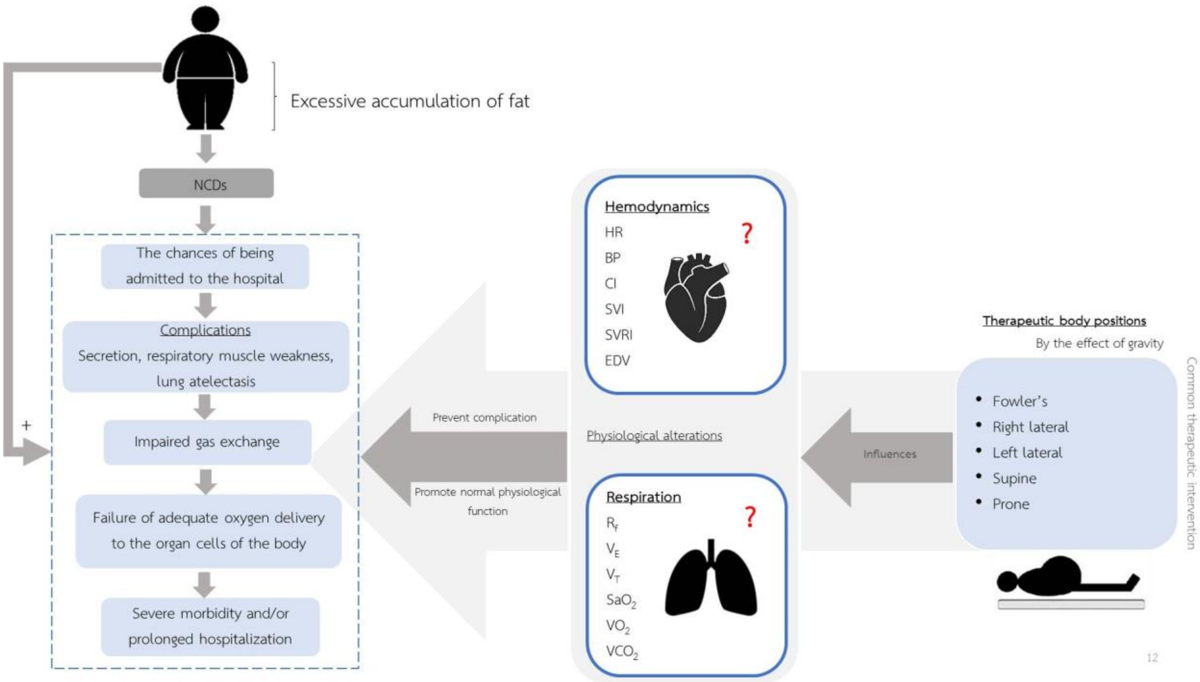
2.4.4.2 Respiration

Previous studies have examined the effects of different body positions on respiratory parameters and have reported various findings. It was observed that V_A was greater in the supine position compared to the prone position (160). This difference in V_A can be attributed to variations in lung shape between postures, with a larger lung volume in the supine position compared to the prone position (161). Additionally, transitioning from the supine position to Fowler's position resulted in a decrease in the frequency of breathing and total respiratory resistance (Rrs) (162). Similarly, transitioning from the supine position to sitting and left lateral positions led to decreased Rrs and lung resistance. These findings are consistent with previous research that showed a reduction in functional residual capacity when in the supine position compared to the left lateral and sitting positions (163, 164, 165). On the other hand, resistance of the diaphragm and abdomen increased when changing from the supine position to the left lateral and sitting positions. This increase in resistance may be related to the relative displacement of the rib cage and diaphragm-abdomen in these positions during diaphragm contraction (162).

2.4.5 The influence of therapeutic body positions in COVID-19 patients

Ineffective gas exchange is a common issue seen in patients with COVID-19, and the management of these patients has brought therapeutic body positions into the realm of clinical management (166). Therapeutic body positions are a conventional method used to enhance oxygenation in patients (167), and it has been proven that gas exchange is significantly more beneficial in the prone position compared to the supine position. In the supine position, the heart and adjacent structures are more likely to compress the central posterior parts of the lung. However, in the prone position, the central anterior parts of the lung are compressed, which results in improvements in CO and increased pulmonary ventilation (168). Following this principle, patients with ineffective gas exchange can benefit from the prone position, especially when early intervention is performed and the positioning is maintained for relatively long sessions (167). Moreover, the prone position has been shown to reduce mortality rates among patients. From a physiological perspective, the prone position leads to more homogeneous ventilation by reducing ventral alveolar expansion and dorsal alveolar collapse. This, in turn, reduces the difference between dorsal and ventral transpulmonary pressures, minimizes lung compression, enhances perfusion, and improves ventilation-perfusion matching (169).

2.5 Conceptual framework



CHAPTER 3 Research methodologies

In this research, three studies were conducted. The first study was a systematic review and meta-analysis aimed at reviewing the influence of therapeutic body positions on hemodynamics and respiration in healthy adults. The second study was an experimental study aimed at assessing and comparing the influence of therapeutic body positions on hemodynamics in adults with and without obesity. The final study was aimed at assessing and comparing the influence of therapeutic body positions on respiration in adults with and without obesity.

3.1 Study 1: A Systematic review and meta-analysis

3.1.1 Study design

The systematic review and meta-analysis would be performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (170) guidelines (171). The protocol would be registered with the International Prospective Registry of Systematic Reviews (PROSPERO).

3.1.2. Search strategy

We would perform a computerized, systematic search of PubMed, ProQuest, Scopus, Web of Science, and ScienceDirect (data base insertion up to August 2021), using combinations of the following search term: ("body position" or "body posture" or "supine" or "lying" or "lateral" or "recumbent" "prone" or "leaning" or "fowler" or "Trendelenburg" or "sitting" or "standing") and ("cardiac output" or "blood flow rate" or "ventilation" or "gas exchange" or "respiration" or "perfusion" or "gas diffusion" or "respiratory resistance" or "respiratory diameter" or "respiratory compliance" or "airway diameter" or "airway resistance" or "airway compliance". All records would be collected into Endnote library in order to delete duplicated articles. The process would be conducted by two independent reviewers (RS and SC), and then reviewers would recheck search results.

3.1.3 Study selection

First, RS and SC would independently screen articles based on titles and abstracts. Second, the two reviewers would obtain the full texts of the relevant studies and independently evaluate each study using the inclusion criteria. The inclusion criteria would be English full-text articles that meet PICO (population, interventions, comparators, outcomes) as follows:

P: Healthy adult aged 18-59 years, male and female, no smoking or no ex-smoking

I: Performed body positions during quiet breathing

C: Compared with other body positions

O:Cardiac output (CO), systolic blood pressure (SBP), diastolic blood pressure (DBP), systematic vascular resistance (SVR), oxygen saturation (SpO_2), alveolar ventilation (V_A), perfusion (Q), oxygen consumption (VO_2), and resistance of total respiratory (Rrs)

The articles would be excluded when they investigated non-human, participants with co-morbidities and/or medical treatment. Moreover, we would exclude abstracts, conference proceedings, books, letters, and single case reports. Discrepancies between reviewers (RS, SC) would be resolved by discussion. If there is disagreement between the reviewers, then a third reviewer (TK) will make the decision process.

3.1.4 Data Extraction

Data would be independently extracted by two reviewers (RS and SC). For each article, the data would be extracted according to authors, year of publications, study designs, number of participants, characteristic of participants, body positions, outcomes, and the main results. The third reviewer (TK) would be consulted if disagreement between the two authors (RS and SC).

3.1.5 Risk of bias in individual study

Two reviewers (RS and SC) would independently assess the quality of the included studies using Downs and Black checklist, which evaluates several domains of bias, including reporting, external validity, internal validity-bias, internal-confounding, and power (172, 173). This study would select the items that are suitable for experimental trials, 18 of the 27 items Downs and Black checklists. 9 items that related to the observational study would be excluded, including 8, 9, 13, 14, 15, 16, 19, 25, and 26 (11, 24). Downs and Black full score are 19, which score in each item start from 0 (no or unable to determine) to 1 (yes), except item 5 including 0 (no), 1 (partial), and 2 (yes). The scores of articles with greater or equal 50% (or ≥ 10 points) indicated high quality of methodology (172, 173).

3.1.6 Data analysis

A meta-analysis would analyze using Review Manager (RevMan 5.4). The overall effect of body position would be performed by pooling the estimated mean of each outcome. The data would be reported with 95 percent confidence interval (CI). A standard deviation will be obtained from the standard error of a mean by multiplying by the square root of the sample size. GetData graph digitizer 2.26 software (RIPE Network coordination centre, Russian Federation) would be used to estimate the mean ± SD if an article did not present mean ± SD. A random-effect model would be conducted. The I^2 statistic would be used to assess heterogeneity. Publication bias would be assessed by examining the asymmetry of a funnel plot. Forest plots would be generated to present the pooled estimates where there are two or more experiments. If the data are not quantified for meta-analysis, the effects of body position would be reported in qualitative analysis.

Reviewers would use Grading of Recommendations, Assessment, Development and Evaluations (GRADE) to evaluate the overall quality of evidence. The quality of evidence would be categorized into high, moderate, low, and very low. Assessment would begin with high-quality evidence and then addresses five reasons to possibly rate down the quality of evidence. Subsequent sections of the data would address each domain (174, 175).

- Limitations in the study design could be downgraded if > 25% of the participants were from high risk of bias article.
- Inconsistency could be downgraded if the data represented heterogeneity ($p < 0.1$)
- Indirectness could be downgraded if participants, interventions, comparisons, and outcomes differ from the objective of this study.
- Imprecision could be downgraded if the number of total sample size for each outcome was less than 400.
- Publication bias could be downgraded if the funnel plot was show asymmetry.

3.2 Study 2 and 3: Hemodynamic and respiratory responses during therapeutic body positions in adults with and without abdominal obesity

3.2.1 Study participants

This experimental design study will recruit participants from general population who stay in Bangkok through brochures, announcement board, acquaintance, and social media including Facebook, Instagram, TikTok, and Twitter. All participants will be divided into 2 groups consisting of normal weight and abdominal obesity group. The participants will be recruited into this study as the following:

3.2.1.2 Inclusion criteria

1. Male aged 30-59 years old
2. Normal weight group; BMI 18.5-22.9 Kg/m^2, WC < 90 cm, WHR ≤ 0.95 and abdominal obesity group; BMI ≥ 25 Kg/m^2, WC ≥ 90 cm, WHR > 0.95 (1, 32, 33, 34, 176)
3. Overall physical activity in sedentary range (Baecke habitual physical activity questionnaire score of < 6) (177)
4. Voluntary who agree to participate in the research program

3.2.1.3 Exclusion criteria

1. There is a history of acute or chronic cardiovascular, respiratory, renal, endocrine, and neurological disorders
2. There is being currently on any drug that might potentially stimulate/depress the cardiovascular and respiratory system
3. There is smoking and/or drinking
4. There is an abnormal chest shape and no postoperative chest wound
5. There is a disability such as vision, movement, communication, hearing, etc.
6. There is illness on the day of the test such as headache, nausea, vomiting, etc.
7. Unable to listen speak read and write in Thai language
8. Prefer to discontinue the test

3.2.2 Research procedure

An experimental study would be conducted in the laboratory of the Department of Physical Therapy, Faculty of Allied Health Science, Chulalongkorn University. 52 male participants would be explained about the detail and process of research. They would be asked to sign an informed consent before participate the research project, and they would be prefer to discontinue the test at any time. Research project would be divided in to two procedures, including volunteer screening, base line assessment, and outcome assessment. Both volunteer screening and assessment would be performed on the same day. Only eligible participants who met the criteria would move to the assessment procedure. Before participating in the research project, all participants need getting enough sleep (more than 6 hours). Heavy meals for at least 4 hours, caffeine-containing products for at least 12 hours prior to the assessment would be avoided. All data would be collected in a temperature control laboratory (in a room with an ambient temperature of 25 °C). The overall time used for assessment estimates about 5 hours. Research procedure would be performed in the following sequence.

3.2.3 Volunteer screening

The screening process would be performed according to the inclusion and exclusion criteria as follows:

1. General information and clinical history taking

All volunteers fill out the screening form about general information and clinical history. Eligible research participants would be male, aged 30-59 years old. There is no history of chronic cardiovascular, respiratory, renal, endocrine, and neurological disorders. There is no taking any drug that might potentially stimulate/depress the cardiovascular and respiratory system, as well as no smoking and drinking.

2. Physical activity assessment

After fill out general information and clinical history, all volunteers would fill out physical activity in screening form. Overall physical activity assessment of eligible research participants would be sedentary range, based on an average Beacke habitual physical activity score of less than 6 (177).

3. Vital sign

After 10 minutes of sitting (or stable vital sign), the vital sign assessment would be assessed. Heart rate (HR) and arterial blood pressure (systolic arterial blood pressure; SABP, diastolic arterial blood pressure; DABP) would be measure in a brachial artery by an autonomic digital blood pressure monitor (Yuwell,YE670D). Respiratory frequency assesses by counting the number of breaths taken over the course of one minute. And SaO_2 would be obtained by use pulse oximeter (ChoiceMMedTM, MD300C1). Eligible research participants would have normal range of HR (60-120 beats/min), BP (SABP<140 mmHg and DABP < 90 mmHg), R_f (12-20 breaths/min), and SaO_2 (95-100%).

4. Anthropometric measurement

Weight would be measure using stadiometer. Height would be measured the distance from the floor to the vertex using height indicator tape. Body mass index (BMI) would be calculated as weight in kilograms (kg) divided by square of height in meters (m^2). And, waist circumference (WC) and hip circumference (HC) would be determined by tape for calculated waist to hip ratio (WHR) (WC divided by HC). All eligible research participants would be classified into normal weight and abdominal obesity groups according to BMI and WHR. Eligible research participants in normal weight group would have BMI between 18.5-22.9 Kg/m^2, WC < 90 cm, and WHR ≤ 0.95. Eligible research participants in abdominal obesity group would have BMI ≥ 25 Kg/m^2, WC ≥ 90 cm, and WHR > 0.95

3.2.4 Base line assessments

Eligible participants would be collected baseline data.

1. Body composition

Percentage of body fat (% BF), visceral fat, and subcutaneous fat would be assessed by bioelectrical impedance (Karada scan: OMRON, Model HBF-375).

2. Skinfold thickness

Adipose tissue or fat would be measure in millimeters (mm) using digital outside skinfold caliper (Digital Caliper Gauge, EDC-A1150). The Participants would be assessed in standing position. The measurement of skinfolds include chest; which is a diagonal fold half way between top of axillary and the nipple, mid-axillary; which is the point where a vertical line from the mid axilla intersects with a horizontal line level with the bottom edge of the xiphoid process, subscapular; which is 2 centimeters below the inferior angle of scapular, suprailiac; which is the point above iliac crest in the mid axillary line, and abdomen; which is 5 centimeters to the right of umbilicus.

3. Lung function test

The test would be done in sitting position using spirometry (MGC, Ultima CPX™). The participants sit on a chair, and then put on a mouthpiece and nose clip (Figure 8). After that, they would be asked to breath 5 times at tidal volume. And, the participants would asked to take a maximal inspiration and then to forcefully expel air for as long and as quickly as possible.

Figure 8 Lung function test

3.2.5 Participant preparations

Before launching a measurement, to ensure a stable signal and proper data acquisition, Electrode of physioFlow (Manatec Biomedical, Paris, France) and equipment of CPET would be setting up in sitting position as following:

1. Clean off the sites for six physioFlow electrode with an alcohol prep pad and dry with a paper towel (chest hair at the electrode site would be removed)
2. Connect the appropriately colored PhysioFlow probes on the participant cables to the six PhysioFlow electrodes (Figure 9) including:
   - Z1: Left lateral aspect of the neck
   - Z2: Below Z1
   - Z3: Xiphisternum
   - EKG1: Near sternal body at right side
   - EKG2: Mid axillary line at Z3 level
   - Z4+EKG3: Near the xiphisternum at right side

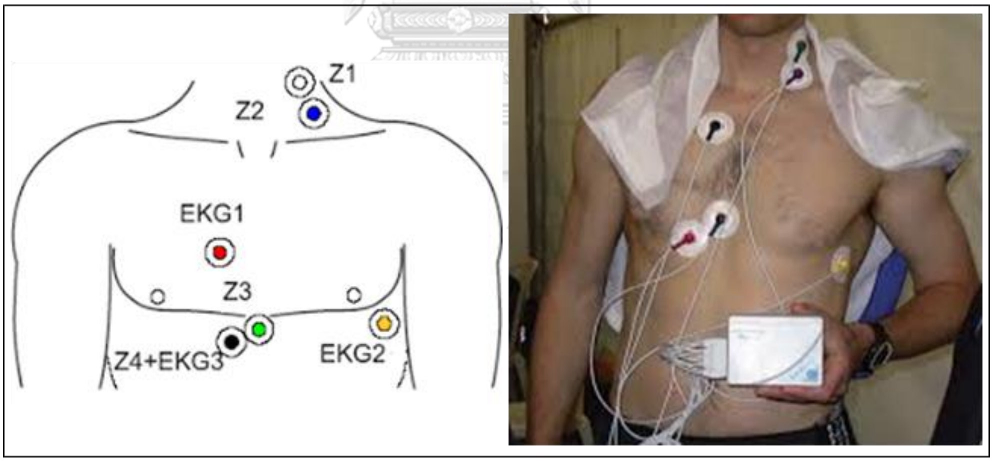


Figure 9 Electrode positions of physioFlow®

3. The participants would wear a mask (MGC, Ultima CPX™) for respiration assessment (Figure 10).

Figure 10 Participants with MGC mask

3.2.6 Outcome assessments

The main outcome measurements are hemodynamics and respiration parameters.

1. Hemodynamics

Change in impedance cardiograph during cardiac cycle would be recorded using trans-thoracic bio impedance; Physio Flow® (Manatec Biomedical, Paris, France) to determine hemodynamics parameters. Measurement of the parameters using Physio Flow® involves placing six electrodes on the chest which would be connected to an electronic processing unit, which is in turn connected to a laptop computer running on Microsoft Windows for acquisition and analysis of data. Before analysis of the data, the calibration phase is done over 30 heart cycle and subsequent continuous measurements can be taken. For the Systolic arterial blood pressure (SABP) and diastolic arterial blood pressure (DABP) would be obtained by use of an autonomic blood pressure monitor (Yuwell, YE670D). The cuff around upper arm will be kept alongside the body.

2. Respiration

Ventilation and oxygenation would be recorded by cardiopulmonary exercise test (PET) (MGC, Ultima CPX™). During the assessment in each position, participants would be assessed on the system, using a breath-by-breath analysis. Which CPET would be calibrated before the test. Arterial oxygen saturation (SaO_2) would be obtained by use pulse oximeter (ChoiceMMed^{TM}, MD300C1)

3.2.7 Therapeutic body positions

After set up the equipment, 52 participants would be performed five therapeutic body positions including fowler's (upright 90 degrees), right lateral, left lateral, supine, and prone position. The participants would start with supine position followed by fowler's, right lateral, left lateral, and prone positions, respectively. Each therapeutic body position would be performed once for 40 minutes. After finish in each position, hemodynamics and respiratory data would be recorded for 1 minute, as well as BP, R_f, and SaO_2 would be recorded three times to calculate the average. Between each therapeutic body position the participants can rest, taking a nap, going restroom and drinking water for 10 minutes. The details regarding five therapeutic body positions are described as below.

1. Fowler's position

Participants sit on the bed with back rest, with 90 degrees of trunk inclination. Hip position is flexion at 90 degree. Hip abduction is less than 10 degrees, with straightened knee (Figure 11).

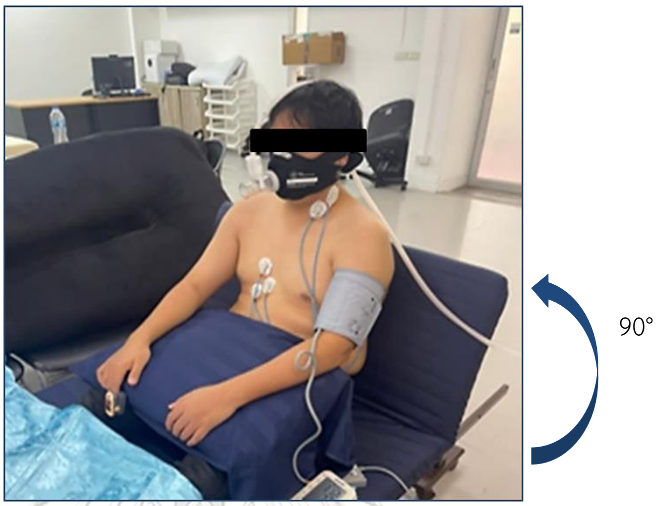


Figure 11 Fowler's position

2. Right lateral position

Participants lie on right side. The knees are slightly flexed, with support of a pillow (Figure 12).

Figure 12 Right lateral position

3. Left lateral position

Participants lie on left side. The knees are slightly flexed, with support of a pillow (Figure 13).

Figure 13 Left lateral position

4. Supine position

Participants lie on the back. Head and neck position are in a neutral position, and support by a pillow. Hip and knee slightly flexed (about 15 degrees), with support of a pillow (Figure 14).

Figure 14 Supine position

5. Prone position

Participants lie on their abdomen with support from a pillow that has a gap at the chest area, and they keep their head and neck in a neutral position (Figure 15).

Figure 15 Prone position

3.2.8 Data analysis

For statistical analysis, data would be analyzed with statistics software (SPSS version 22.0, Chicago, IL, USA). The result would be expressed as mean ± one standard deviation. Komokorov-Sminov test would be used to verify normal distribution of the data. Comparison of baseline characteristics between normal weight group and abdominal obesity group would use Independent samples t-test if the variable is normally distributed, or use Mann-Withney U-test if the variable is non-normal distribution data. We would use two-way mixed ANOVA with Bonferroni post hoc analyses to compare the differences among groups and between groups (normal weight and abdominal obesity group) in normal distribution data, or use Kruskal–Wallis Test in non-normal distribution data. Statistical significance would be set at $p < 0.05$.

3.2.9 Sample size calculation

The sample size was estimated using G Power 3.1.9.7, considering a 0.05 significance level and an 80% statistical power. The main objectives of this study aim to determine the influence of therapeutic body positions on hemodynamics and respiration in adults, both with and without abdominal obesity. Therefore, a pilot study was conducted with 10 males (5 normal weight, 5 abdominal obese) to compute the effect size. With the most conservative estimate (effect size = 0.40), the total sample size calculated is 52 participants (26 normal weight, 26 abdominal obese). The sample size calculation is shown in figure 16.

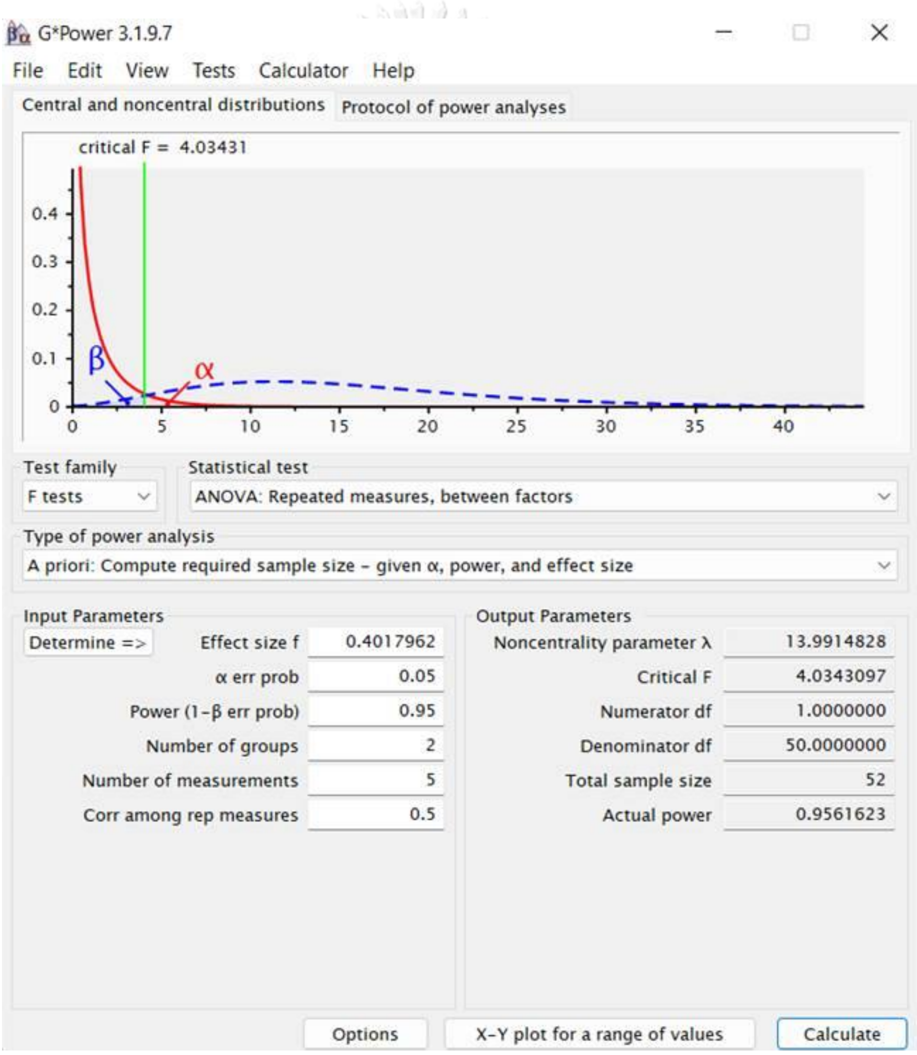


Figure 16 Sample size calculation

CHAPTER 4 Study 1 - A systematic review and meta-analysis

Objective:

To conduct a systematic review of the influence of therapeutic body positions on hemodynamics and respiration in healthy adults

Paper 1: The Influence of Body Positions on Hemodynamics and Respiration in Healthy Adults: A Systematic Review and Meta-Analysis

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4.1 Abstract

Background: Different body positions can exert both positive and negative physiological effects on hemodynamics and respiration. This study aimed to conduct a literature review and examine the impact of various body positions on hemodynamic and respiratory variables.

Methods: The study protocol was registered with the International Prospective Registry of Systematic Reviews (register no. CRD42021291464). Two independent reviewers evaluated the methodological quality of all included studies using the Down and Black checklist, while the quality of evidence was evaluated using the Grading of Recommendations, Assessment, Development, and Evaluations approach. The overall effects of different body positions are reported from random effects meta-analysis.

Results: Ten with low risk of bias and three with high risk of bias met the eligibility criteria. The supine resulted in the highest cardiac output compared to the 70 deg head-up tilt, sitting, and standing positions (very low- to low-quality evidences) and the lowest systemic vascular resistance compared to the 70 deg head-up tilt, and standing positions (very low-quality evidence). Additionally, the supine was associated with the highest total respiratory resistance compared to the 70 deg head-up tilt, left lateral, and standing positions (low-quality evidence) and higher alveolar ventilation than the prone (low-quality evidence).

Conclusions: The results demonstrated that the supine position had the most positive influence on hemodynamic variables, resulting in the highest cardiac output and the lowest systemic vascular resistance. The upright positions (70 deg head-up tilt and standing positions) had the most positive influence on the respiratory variables, resulting in the lowest total respiratory resistance.

Key Words

Body position; Cardiac output; Systemic vascular resistance; Alveolar ventilation, Total respiratory resistance

4.2 Introduction

Cellular well-being and regulation require homeostasis, which involves various physiological system interactions; in particular, the physics-based flow of blood circulation called hemodynamics works together with respiration to facilitate the gaseous exchange at the respiratory membrane and the target organ cell to maintain optimal survival. Therefore, hemodynamic and respiratory variable monitoring is absolutely necessary for medicine, with the purpose of evaluation, surveillance, and follow-up care in patients. Several hemodynamic variables are used to assess the health status, such as cardiac output (CO), blood pressure (BP), and systemic vascular resistance (SVR), and the variables that reflect respiration, such as alveolar ventilation (V_A), perfusion (Q), oxygen saturation (SpO_2), oxygen consumption (VO_2), and total respiratory resistance (Rrs). Despite the routine use of these variables to assess health status, it should be known that these variables depend upon many factors such as age, sex, body mass index, fat distribution, physical activity levels, and pathophysiological conditions (124, 144, 150, 151, 152, 178, 179, 180, 181). Furthermore, the body position commonly used in clinical settings is a factor that also has an effect on hemodynamics and respiration.

In general, body positions are used to prevent hospital-acquired complications and promote physiological function (14). However, previous studies demonstrated that different body positions modulate physiological effects. It is widely known that positional change from the supine to the upright position induces a reduced central blood volume with a simultaneous decrease in CO and related variables because of gravity (17, 18, 154, 155, 182, 183, 184), which has a direct effect on oxygen transportation in the bloodstream (185). Comparing the supine and the prone positions, we found BP was significantly higher in the prone (186) due to the prone reducing central blood, which may cause pooling and increased blood volume in peripheral vessels (128). Furthermore, some studies investigating respiratory variables found that the supine was typically associated with an increase in V_A compared to the prone (160), while Q was more uniformly distributed in the prone compared to the supine (187). This is due to the increased Q per alveolus in the gravitationally non-dependent regions of the lung in the prone position compared to the supine position (188). These two variables, V_A and Q, are important for gas exchange. Ideally, the V_A/Q ratio should be one for maximally efficient gas exchange. Previous studies reported that the prone position can improve ventilation/perfusion (V_A/Q) matching (189, 190, 191). This is the physiological rationale behind prone positioning in patients with coronavirus disease 2019 with acute respiratory distress syndrome. In addition, the supine was associated with significantly higher Rrs than the head-up tilt (HUT), left lateral, and sitting positions, and the supine had the highest Rrs compared to HUT and standing positions. That is probably because the supine position promotes airway closure in dependent lung regions (192).

Based on these preliminary findings, it appears that different body positions influence both positive and negative effects on hemodynamic and respiratory variables. At present, no systematic review or meta-analysis has reviewed these findings. This study aims to understand and analyze the effects of different body positions on hemodynamic and respiratory variables for optimal patient management.

4.3 Materials and Methods

4.3.1 Study registration and methodology

This systematic review and meta-analysis was performed according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines (171). The protocol was registered with the International Prospective Registry of Systematic Reviews (PROSPERO CRD42021291464) on August 1, 2021.

4.3.2 Search strategy

Five online databases were searched: PubMed, ProQuest, Scopus, Web of Science, and ScienceDirect. Studies published before June 2022 were included in the search. Keyword combinations were used as search terms: ("body position" or "body posture" or "supine" or "lying" or "lateral" or "recumbent" "prone" or "leaning" or "Fowler's or "Trendelenburg" or "sitting" or "standing") and ("cardiac output" or "blood flow rate" or "ventilation" or "gas exchange" or "respiration" or "perfusion" or "gas diffusion" or "respiratory resistance" or "respiratory diameter" or "respiratory compliance" or "airway diameter" or "airway resistance" or "airway compliance"). All records were collected into an Endnote library so that duplicated articles could be deleted. This process was conducted by two independent reviewers (Ruchada Sriamad; RS and Sirinut Chaiduang; SC), then rechecked the search results.

4.3.3 Study selection

First, two reviewers independently screened the article titles and abstracts from the search process. Second, the reviewers obtained the full texts of the relevant studies and independently evaluated each study. The full texts of the studies that passed this screening process were obtained and independently evaluated based on the inclusion criteria. Included studies had to be English full-text articles and meet the PICO model (P; population, I; interventions, C; comparators, O; outcomes) (193).

P: Non-smoking healthy adults aged between 18-59 years, male and/or female

I: Performed body positions (supine, Fowler's, HUT, head down tilt (HDT), sitting, and standing positions)

C: Compared between body positions

O: Cardiac output (CO), systolic blood pressure (SBP), diastolic blood pressure (DBP), systemic vascular resistance (SVR), oxygen saturation (SpO_2), alveolar ventilation (V_A), perfusion (Q), oxygen consumption (VO_2), and total respiratory resistance (Rrs)

Articles were excluded if they investigated non-human participants, participants with co-morbidities, or participants receiving medical treatment. Abstract-only texts, conference proceedings, books, letters, and single case reports were also excluded. Discrepancies between the two reviewers were resolved by discussion. If a disagreement could not be resolved, a third reviewer (Thaniya Klinsophon; TK) would make the decision.

4.3.4 Data extraction

Data extraction was carried out independently by the two reviewers. Several study characteristics were reported: author (s), year of publication, study design, number of participants, age mean, body positions, primary outcome, and main finding. The third reviewer was consulted if a disagreement about data extraction between the two reviewers could not be resolved.

4.3.5 Bias risk in individual studies

The two reviewers independently assessed the quality of the included studies using the Downs and Black checklist, which evaluates several domains of bias, including reporting bias, external validity, internal validity, selection bias, and power (172, 194). The eighteen checklist items that were relevant for experimental trials were used, while the nine items (items 8, 9, 13, 14, 15, 16, 19, 25, and 26) that were relevant for observational studies were excluded. The highest score the studies included in this review could receive was nineteen, with each item either being scored as 0 (no or unable to determine) or 1 (yes), except item 5, which could be scored as 0 (no), 1 (partial), or 2 (yes). Scores equal to or over 50% of the total possible score (≥ 10 points) indicated that the study was of high methodological quality (172, 194).

4.3.6 Data analysis

This systematic review and meta-analysis was analyzed using the Review Manager (RevMan 5.4). The overall effects of different body positions were determined by pooling the estimated mean of each outcome. A 95% confidence interval (CI) was used. For articles that only reported the standard error (SE) of a mean, the standard deviation was obtained by multiplying the square root of the sample size by the SE. For articles that did not report the mean ± SD, the GetData graph digitizer 2.26 software (RIPE Network Coordination Center, Russian Federation) was used to estimate it. A random-effects model was used, and the I^2 statistic was used to assess heterogeneity across studies. Publication bias was assessed by examining the asymmetry of a funnel plot. Forest plots were generated to present pooled estimates for each outcome where there were one or more studies compared to the supine. For data that did not demonstrate meta-analysis (i.e., studies did not compare to the supine or the data could not be used), qualitative analysis was used to determine the effects of body positions.

The Grading of Recommendation Assessment, Development, and Evaluation (GRADE) approach was used to evaluate the quality of the evidence. Evidence quality was categorized as high, moderate, low, or very low. Randomized controlled trials (RCTs) and experimental trials are considered to provide high-quality evidence, while observational studies are considered to provide low-quality evidence (174, 175, 195). As this study only included experimental trials, a high-quality evidence baseline was applied to all studies. Evidence quality was then downgraded based on five domains: study design limitations, inconsistency, indirectness, imprecision, and publication bias.

- Study design limitations: evidence quality could be downgraded by > 25% if the participants were at a high risk of bias.
- Inconsistency: evidence quality could be downgraded if the data were heterogeneous ($p < 0.1$) or if the data had only one study.
- Indirectness: evidence quality could be downgraded if the participants, interventions, comparisons, or outcomes differed from the objective of the current study.
- Imprecision: evidence quality could be downgraded if the total sample size for each outcome was less than 400.
- Publication bias: evidence quality could be downgraded if the funnel plot demonstrated asymmetry.

3.3.7 Sensitivity analysis

A sensitivity analysis was performed to assess how sensitive the results of the review were in relation to the way it was conducted. For the results of the qualitative analysis (using the GRADE approach), the low-quality studies (the total scores < 50%) were excluded from the analysis.

4.4 Results

4.4.1 Search strategy

In total, 17,607 English publications were identified during the initial search. Following duplicate removal and screening of titles and abstracts for eligibility, nineteen full-text articles were selected for assessment. Of those, thirteen met the eligibility criteria and were included for methodological quality evaluation and data extraction (Figure 17).

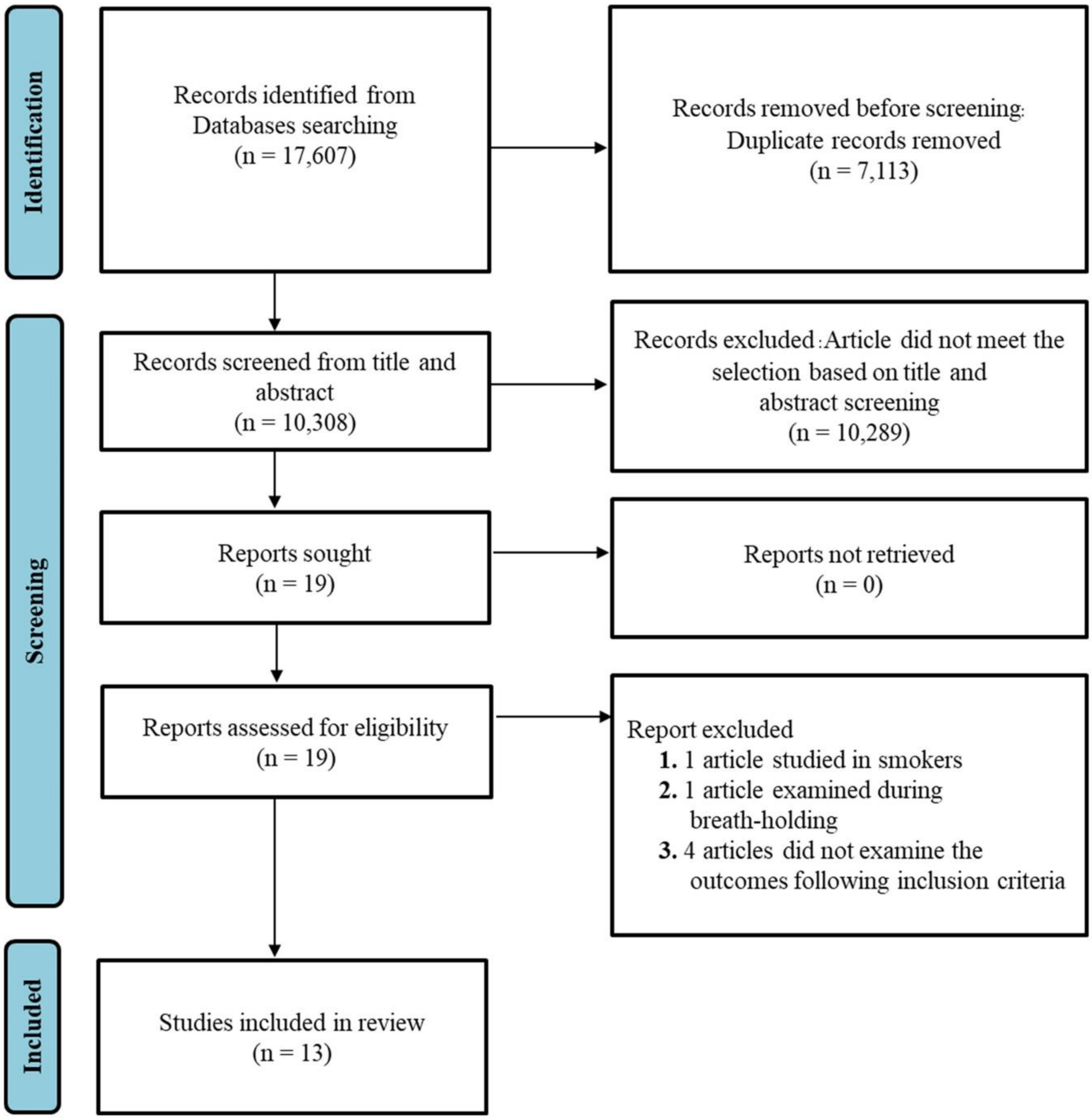


Figure 17 Flow diagram of the searching and screening process

4.4.2 Study characteristics

Overall, thirteen studies published between 1966 and 2018 were included in this study (17, 18, 154, 155, 160, 168, 182, 188, 192, 196, 197, 198, 199). In total, 116 adult participants (86 males and 17 females) were included in the studies (Table 6). One study did not provide the number of participants involved (199). The mean participant age was between 19 and 59 years; one study did not report the mean participant age (18). No participants had acute and/or chronic cardiovascular or respiratory diseases. Nine studies evaluated hemodynamic parameters, including CO, SBP, DBP, and SVR (17, 18, 154, 155, 182, 196, 197, 198, 199). However, different hemodynamic assessment methods were utilized. Three studies used the CO_2 rebreathing method (17, 182, 198), two used transthoracic echocardiography (196, 197), while others used thermodilution (154), pulse contour (18), dye dilution (155), and impedance cardiography device methods (198). Regarding respiration, seven studies evaluated respiration parameters, including V_A, Q, SpO_2, VO_2, and Rrs (154, 160, 168, 182, 198). Different methods of respiration assessment were employed. For example, one study used ASL-specific ventilation imaging (160), while another used the pulmonary diffusing capacity maneuver (198). For the assessment of Q, one study used a two-dimensional ASL-FAIRER sequence with a half-Fourier acquisition single-shot turbo spin-echo (HASTE) imaging scheme (168), while another only used two-dimensional ASL (160). All studies recorded data while participants were in different body positions. The body positions used across the included studies were supine, Fowler's, HUT (30, 60, and 70 deg), HDT (5, 10, 20, and 30 deg), left lateral, prone, sitting, and standing positions. In four of the studies, participants stayed in the reported positions for 5 minutes (182, 188, 197, 198), while in three studies, they stayed in the positions for 10 minutes (17, 154, 196). Six studies did not include information on the time participants spent in each position (18, 155, 160, 168, 192, 199). Most of the studies compared the supine position with other positions. However, one study compared Fowler's in different deg (197), one study compared the HUT (lying on the back) and HUT with left lateral (lying on the left side) positions (196), while another only evaluated the HUT, HDT, and left lateral positions (192).

Table 6 Characteristics of the included studies

Study, Y.	Study designs	No. participants	Age, mean ± SD Y.	Body positions	Outcomes	Main findings
Lundin G, Thomson D. 1966	Experimental (within subject)	N =8 (…)	26.8 ± …	Supine versus sitting	CO	Supine > sitting*
Kawakami Y, et al. 1980	Experimental (within subject)	N =5 (…)	22.0 ± …	Supine versus fowler's	CO	Supine >sitting*
Barnas GM, et al. 1993	Experimental (within subject)	N =7 (6 male, 1 female)	33.57 ± …	Supine versus 30 deg HUT Supine versus left lateral Supine versus sitting Supine versus 30 deg HDT Sitting versus 30 deg HUT Sitting versus left lateral Sitting versus 30 deg HDT HUT versus left lateral HUT versus 30 deg HDT Left lateral versus 30 deg HDT	Rrs	Supine -- 30 deg HUT Supine > left Lateral* Supine > sitting* Supine -- 30 deg HDT Sitting -- 30 deg HUT Sitting --left Lateral Sitting < 30 deg HDT* HUT > left Lateral* HUT-- 30 deg HDT Left lateral < 30 deg HDT*
Harms MP, et al. 2003	Experimental (within subject)	N =9 (8 male, 1 female)	29 ± …	Supine versus 30 deg HUT Supine versus 70 deg HUT Supine versus 5 deg HDT Supine versus 10 deg HDT Supine versus 20 deg HDT	CO SVR SpO_2 VO_2	Supine -- 30 deg HUT, supine > 70 deg HUT*, supine -- 5 deg HDT, supine –10 deg HDT, supine -- 20 deg HDT Supine -- 30 deg HUT, supine < 70 deg HUT*, supine -- 20 deg HDT Supine -- 5 deg HDT, supine -- 10 deg HDT, supine -- 20 deg HDT Supine < 70 deg HUT*, supine -- 20 deg HDT
Gisolf J, et al. 2004	Experimental (within subject)	N =8 (6 male, 2 female)	24 ± …	Supine versus standing	CO VO_2	Supine > standing* Supine -- standing
Peces-Barba G, et al. 2004	Experimental (within subject)	N =14 (7 male, 7 female)	37.5 ± …	Supine versus prone	CO	Supine > sitting*, supine > prone*

Chang AT, et al. 2005	Experimental (within subject)	N =20 (20 male)	28.3 ± 4.8	Supine versus 70 deg HUT Supine versus standing	VO_2 Rrs	Supine < 70 deg HUT*, supine < standing* Supine > 70 deg HUT*, supine > standing*
Prisk GK., et al. 2007	Experimental (within subject)	N =6 (4 male, 2 female)	25.0 ± 1.0	Supine versus prone	Q SpO_2	Supine < prone* Supine -- prone
Zhang H, Li JK. 2008	Experimental (within subject)	N ... = (...)	25.0 ± ...	Supine versus sitting	CO	Supine > sitting*
Van den Bogaard B, et al. 2011	Experimental (within subject)	N =10 (9 male, 1 female)	...	Supine versus 30 deg HUT Supine versus 70 deg HUT Supine versus standing	CO SBP DBP SVR	Supine -- 30 deg HUT, supine > 70 deg HUT*, supine > standing* Supine -- 30 deg HUT, supine -- 70 deg HUT, supine -- standing Supine < 30 deg HUT*, supine < 70 deg HUT*, supine < standing* Supine < 30 deg HUT*, supine < 70 deg HUT*, supine < standing*
Henderson AC, et al. 2013	Experimental (within subject)	N =7 (4 male, 3 female)	29.4 ± 7.4	Supine*prone	VO_2 SpO_2 V_A Q	Supine -- prone Supine -- prone Supine > prone Supine -- prone
Kubota S, et al. 2015	Experimental (within subject)	N =10 (10 male)	20.7 ± 0.5	30°Fowler's*60°Fowler's	SBP DBP CO SVR	30 deg Fowler's -- 60 deg Fowler's 30 deg Fowler's -- 60 deg Fowler's 30 deg Fowler's -- 60 deg Fowler's 30 deg Fowler's -- 60 deg Fowler's
Kölegård R, et al. 2018	Experimental (within subject)	N =12 (12 male)	29.0 ± 4.1	Supine*left lateral 60°HUT*60°HUT with left lateral	SBP DBP CO	Supine --left lateral, 60 deg HUT --60 deg HUT with left lateral Supine --left lateral, 60 deg HUT -- 60 deg HUT with left lateral Supine < left lateral*, 60 deg HUT < 60 deg HUT with left lateral*

* Significant (*P* < .05)

>; Greater

<; Lesser,

--; No difference

HUT; head up tilt, HDT; head down tilt, CO; cardiac output, SBP; systolic blood pressure, DBP; diastolic blood pressure, SVR; systemic vascular resistance, SpO_2; oxygen saturation, V_A; alveolar ventilation, Q; perfusion, VO_2; oxygen consumption

4.4.3 Methodological quality of the studies

Regarding the Downs and Black checklist scores, scores for individual studies ranged between seven and fourteen. Ten studies had high methodological quality (17, 18, 154, 155, 160, 168, 182, 188, 192, 196, 197, 198, 199), three studies had low quality (17, 155, 199). All studies clearly described their hypotheses, interventions, and main findings. Eleven studies did not report the population source (17, 18, 154, 155, 160, 168, 182, 192, 196, 198, 199), while for two studies, it could not be determined whether the participants were representative of the entire population (188, 197). The participants in the studies were recruited from the same population. However, no studies reported the period over which participants were recruited. Only two studies randomized the order of interventions (188, 197). No studies reported a power analysis (Table 7).

Table 7 Quality assessment of the included studies

Study, Y.	Reporting bias (8)								External validity (2)		Internal validity (7)							Power (1)	Total scores (19)	Quality of studies
	*	†	‡	§	||	¶	**	††	‡‡	§§	||||	¶¶	***	†††	‡‡‡	§§§	||||||	¶¶¶		
Lundin G, Thomson D. 1966	1	1	0	1	0	1	0	0	0	U	0	U	1	1	U	0	0	U	6	Low
Kawakami Y, et al. 1980	1	1	0	1	0	1	1	0	0	U	1	U	1	1	U	0	0	U	8	Low
Barnas GM, et al. 1993	1	1	1	1	0	1	1	0	0	U	1	1	1	1	U	0	0	U	10	High
Harms MP, et al. 2003	1	1	1	1	0	1	1	0	0	U	1	1	1	1	U	U	U	U	10	High
Gisolf J, et al. 2004	1	1	0	1	0	1	1	1	0	U	1	1	1	1	U	0	0	U	10	High
Peces-Barba G, et al. 2004	1	1	1	1	0	1	1	0	0	U	1	1	1	1	U	U	U	U	10	High
Chang AT, et al. 2005	1	0	1	1	0	1	1	1	U	U	1	1	1	1	U	1	U	U	11	High
Prisk GK., et al. 2007	1	1	0	1	0	1	1	1	0	U	1	1	1	1	U	U	U	U	10	High
Zhang H, Li JK. 2008	1	1	0	1	0	1	0	0	0	U	0	1	1	1	U	0	0	U	7	Low
Van den Bogaard B, et al. 2011	1	1	1	1	0	1	1	1	0	U	1	1	1	1	U	0	0	U	11	High
Henderson AC, et al. 2013	1	1	1	1	0	1	1	1	0	U	1	1	1	1	U	0	0	U	11	High
Kubota S, et al. 2015	1	1	1	1	0	1	1	1	U	U	1	1	1	1	U	1	U	U	12	High
Kölegård R, et al. 2018	1	1	1	1	0	1	1	1	0	U	1	1	1	1	U	0	0	U	11	High

All items which adopted from Down and Black checklist in this study were as followed (33).

[*]: Is the hypothesis, aim, objective of the study clearly described?

[†]: Are the main outcomes to be measured clearly described in the introduction or methods section?

[‡]: Are the characteristics of the patients included in the study clearly described?

[§]: Are the interventions of interest clearly described?

[||]: Are the distributions of principal confounders in each group of subjects to be compared clearly described?

[¶]: Are the main findings of the study clearly described?

[**]: Does the study provide estimates of the random variability in the data for the main outcomes?

[††]: Have actual probability values been reported (eg, .035 rather than .05) for the main outcomes except when the probability value is .001?

[‡‡]: Were the subjects asked to participate in the study representative of the entire population from which they were recruited?

[§§]: Were those subjects who were prepared to participate representative of the entire population from which they were recruited?

[||||]: Any of the results of the study were based on "data dredging, "was this made clear?

[¶¶]: Were the statistical tests used to assess the main outcomes appropriate?

[***]: Were the main outcome measures used accurate (valid and reliable)?

[†††]: Were the patients in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited from the same population?

[‡‡‡]: Were study subjects in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited over the same period of time?

[§§§]: Were study subjects randomized to intervention groups?

[||||||]: Was the randomized intervention assignment concealed from both subjects and health-care staff until recruitment was complete and irrevocable?

[¶¶¶]: Did the study have sufficient power to detect a clinically important effect where the probability value for a difference being due to chance is %5?

1: Yes (1 score)

1: Partial of item e (1 score)

0: No (0 score)

U: Unable to determine (0 score)

4.4.4 Influence of body positions on hemodynamics

The meta-analysis revealed very low to moderate quality evidence regarding the effects of the supine, Fowler's, HUT, HUT with left lateral, HDT, left lateral, prone, sitting, and standing positions on CO (17, 154, 155, 182, 196, 197, 198, 199). Qualitative synthesis revealed low-quality evidence regarding the effects of the supine, Fowler's, HUT, HUT with left lateral, left lateral, and standing positions on SBP and DBP (18, 196, 197). The quality of the evidence regarding the effects of the supine, Fowler's, HUT, HDT, and standing positions on SVR was very low (18, 154, 197) (Table 8).

Table 8 Summary of evidence for the influence of body positions

Outcomes	Comparators (positions)	Mean differences (95% CI)	No. participants	No. studies	Quality of evidences (GRADE)
CO	Supine versus 30 deg HUT	0.49 (-0.17, 1.15)	19	2	⊕⊕⊕◯ (Moderate [†])
	Supine versus 70 deg HUT	0.95 (0.43, 1.48)	19	2	⊕⊕◯◯ (Low [*,†])
	Supine versus left lateral	-1.10 (-2.35, 0.15)	12	1	⊕⊕◯◯ (Low [*,†])
	Supine versus prone	0.30 (-0.53, 1.13)	10	1	⊕⊕◯◯ (Low [*,†])
	Supine versus sitting	0.86 (0.33, 1.38)	23	3	⊕◯◯◯ (Very low [*,†,‡])
	Supine versus standing	1.78 (0.41, 3.15)	18	2	⊕⊕◯◯ (Low [*,†])
	Supine versus 5 deg HDT	0.20 (-0.44, 0.84)	9	1	⊕⊕◯◯ (Low [*,†])
	Supine versus 10 deg HDT	0.00 (-0.74, 0.74)	9	1	⊕⊕◯◯ (Low [*,†])
	Supine versus 20 deg HDT	-0.10 (-0.77, 0.57)	9	1	⊕⊕◯◯ (Low [*,†])
	30 deg Fowler's versus 60 deg Fowler's	-0.10 (-0.51, 0.31)	10	1	⊕⊕◯◯ (Low [*,†])
	60 deg HUT versus 60 deg HUT with left lateral (saddle-supported tilt)	-0.90 (-2.07, 0.27)	12	1	⊕⊕◯◯ (Low [*,†])
	60 deg HUT versus 60 deg HUT with left lateral (footboard-supported tilt)	-0.90 (-1.87, 0.07)	12	1	⊕⊕◯◯ (Low [*,†])
SBP	Supine versus 30 deg HUT	1.30 (-8.44, 11.04)	10	1	⊕⊕◯◯ (Low [*,†])
	Supine versus 70 deg HUT	3.30 (-4.84, 11.44)	10	1	⊕⊕◯◯ (Low [*,†])
	Supine versus left lateral	4.00 (-5.28, 13.28)	12	1	⊕⊕◯◯ (Low [*,†])
	Supine versus standing	1.30 (-7.64, 10.24)	10	1	⊕⊕◯◯ (Low [*,†])
	30 deg Fowler's versus 60 deg Fowler's	-2.80 (-13.34, 7.74)	10	1	⊕⊕◯◯ (Low [*,†])
	60 deg HUT versus 60 deg HUT with left lateral (saddle-supported tilt)	-5.00 (-14.21, 4.21)	12	1	⊕⊕◯◯ (Low [*,†])

	60 deg HUT versus 60 deg HUT with left lateral (footboard-supported tilt)	0.00 (-8.84, 8.84)	12	1	⊕⊕◯◯ (Low *, †)
DBP	Supine versus 30 deg HUT	-8.00 (-20.53, 4.53)	10	1	⊕⊕◯◯ (Low *, †)
	Supine versus 70 deg HUT	-10.30 (-22.80, 2.20)	10	1	⊕⊕◯◯ (Low *, †)
	Supine versus left lateral	2.00 (-4.91, 8.91)	12	1	⊕⊕◯◯ (Low *, †)
	Supine versus standing	-9.70 (-22.12, 2.72)	10	1	⊕⊕◯◯ (Low *, †)
	30 deg Fowler's versus 60 deg Fowler's	-3.30 (-11.57, 4.97)	10	1	⊕⊕◯◯ (Low *, †)
	60 deg HUT versus 60 deg HUT with left lateral (saddle-supported tilt)	-2.00 (-8.12, 4.12)	12	1	⊕⊕◯◯ (Low *, †)
	60 deg HUT versus 60 deg HUT with left lateral (footboard-supported tilt)	1.00 (-3.80, 5.80)	12	1	⊕⊕◯◯ (Low *, †)
SVR	Supine versus 30 deg HUT	-175.33 (-354.77, 4.11)	19	2	⊕◯◯◯ (Very low *, †, ‡)
	Supine versus 70 deg HUT	-380.84 (-623.86, -137.82)	19	2	⊕◯◯◯ (Very low *, †, ‡)
	Supine versus 20 deg HDT	-31.00 (-159.06, 97.06)	9	1	⊕◯◯◯ (Very low *, †, ‡)
	Supine versus standing	-481.00 (-546.24, -415.76)	10	1	⊕◯◯◯ (Very low *, †, ‡)
	30 deg Fowler's versus 60 deg Fowler's	-30.90 (-143.92, 82.12)	10	1	⊕◯◯◯ (Very low *, †, ‡)
SpO_2	Supine versus prone	-0.10 (-0.94, 0.74)	13	2	⊕⊕◯◯ (Low *, †)
	Supine versus 5 deg HDT	0.20 (-0.49, 0.89)	9	1	⊕⊕◯◯ (Low *, †)
	Supine versus 10 deg HDT	0.20 (-0.45, 0.85)	9	1	⊕⊕◯◯ (Low *, †)
	Supine versus 20 deg HDT	0.00 (-0.65, 0.65)	9	1	⊕⊕◯◯ (Low *, †)
V_A	Supine versus prone	0.55 (0.17, 0.93)	7	1	⊕⊕◯◯ (Low *, †)
Q	Supine versus prone	-0.32 (-0.92, 0.28)	13	2	⊕⊕⊕◯ (Moderate †)
VO_2	Supine versus 70 deg HUT	-0.02 (-0.05, 0.01)	29	2	⊕⊕⊕◯ (Moderate †)

	Supine versus prone	-0.01 (-0.06, 0.04)	7	1	⊕⊕◯◯ (Low *,†)
	Supine versus standing	-0.03 (-0.06, -0.00)	28	2	⊕⊕⊕◯ (Moderate †)
	Supine versus 20 deg HDT	0.00 (-0.05, 0.05)	9	1	⊕⊕◯◯ (Low *,†)
Rrs	Supine versus 30 deg HUT	0.90 (-1.33, 3.13)	7	1	⊕⊕◯◯ (Low *,†)
	Supine versus 70 deg HUT	0.90 (0.83, 0.97)	20	1	⊕⊕◯◯ (Low *,†)
	Supine versus left lateral	2.40 (0.32, 4.48)	7	1	⊕⊕◯◯ (Low *,†)
	Supine versus sitting	1.90 (-0.37, 4.17)	7	1	⊕⊕◯◯ (Low *,†)
	Supine versus 30 deg HDT	0.50 (-1.89, 2.89)	7	1	⊕⊕◯◯ (Low *,†)
	Supine versus standing	0.50 (0.20, 0.80)	20	1	⊕⊕◯◯ (Low *,†)
	Sitting versus 30 deg HUT	-1.00 (-3.23, 1.23)	7	1	⊕⊕◯◯ (Low *,†)
	Sitting versus left lateral	0.50 (-1.58, 2.58)	7	1	⊕⊕◯◯ (Low *,†)
	Sitting versus 30 deg HDT	-1.40 (-3.79, 0.99)	7	1	⊕⊕◯◯ (Low *,†)
	30 deg HUT versus left lateral	1.50 (-0.86, 3.86)	7	1	⊕⊕◯◯ (Low *,†)
	30 deg HUT versus 30 deg HDT	-0.40 (-3.04, 2.24)	7	1	⊕⊕◯◯ (Low *,†)
	Left lateral versus 30 deg HDT	-1.90 (-4.41, 0.61)	7	1	⊕⊕◯◯ (Low *,†)

* Serious inconsistency (eg, significant heterogeneity between the trials; $P < 0.1$ or not applicable heterogeneity)

† Serious imprecision (eg, total sample size of < 400)

‡ Publication bias (eg, funnel plot shows asymmetry)

⊕◯◯◯ = Very low evidence

⊕⊕◯◯ = Low evidence

⊕⊕⊕◯ = Moderate evidence

Cardiac output (CO)

The supine resulted in significantly higher CO compared to 70 deg HUT, sitting, and standing positions ($p < 0.05$) based on low-quality evidence (two studies; N = 19; limitations of inconsistency and imprecision), very low-quality evidence (three studies; N = 23; limitations of inconsistency, imprecision, and publication bias), and low-quality evidence (two studies; N = 18; limitations of inconsistency and imprecision) (17, 18, 154, 182), respectively (Figure 18).

Systolic blood pressure (SBP)

Low-quality evidence suggests that body positions do not have a significant impact on SBP (Figure 19).

Diastolic blood pressure (DBP)

The data from the meta-analysis showed no significant differences in how the body positions impacted DBP, based on low-quality evidence (Figure 20). However, one included study reported that the HUT (30 and 70 deg) and standing positions resulted in significantly higher DBP than the supine position (Table 6) (192).

Systemic vascular resistance (SVR)

The supine resulted in significantly lesser SVR compared to 70 deg HUT and standing positions ($p < 0.01$) based on very low-quality evidence (two studies; N = 19; limitations of inconsistency, imprecision, and publication bias) (18, 154), and very low-quality evidence (one study; N = 10; limitations of inconsistency, imprecision, and publication bias) (18), respectively (Figure 21).

4.4.5 Influence of body positions on respiration

The meta-analysis revealed low-quality evidence regarding the effects of the supine, HDT, and prone positions on SpO_2, low-quality evidence regarding the effects of the supine and prone positions on V_A, and moderate-quality evidence regarding the effects of the supine and prone positions on Q. Furthermore, low- to moderate-quality evidence was found on the effects of the supine, HUT, HDT, prone, and standing positions on VO_2, while low-quality evidence was reported regarding the effects of the supine, HUT, HDT, left lateral, sitting, and standing positions on Rrs (Table 8).

Oxygen saturation (SaO_2)

There were no significant differences based on low-quality evidence in how the body positions impacted SpO_2 (Figure 22).

Alveolar ventilation (V_A)

The supine was associated with significantly higher V_A compared to the prone based on low-quality evidence ($p < 0.01$) (one study; N = 7; limitation of inconsistency and imprecision) (160) (Figure 23).

Perfusion (Q)

The meta-analysis shows no significant differences based on moderate-quality evidence in how the body positions impacted Q (Figure 24). However, one included study reported that the prone position resulted in a significantly higher Q than the supine position (Table 6) (168).

Oxygen consumption (VO_2)

According to the data from the meta-analysis, there were no significant differences regarding the effects of the different body positions on VO_2 based on low- to moderate-quality evidence (Figure 25). However, one included study reported that the 70 deg HUT and standing positions resulted in significantly higher VO_2 than the supine position (188).

Total respiratory resistance (Rrs)

The supine was associated with significantly higher Rrs compared to the 70 deg HUT, left lateral, and standing positions ($p < 0.05$) based on low-quality evidence (one study; N = 20; limitations of inconsistency and imprecision) (188), low-quality evidence (one study; N = 7; limitations of inconsistency and imprecision) (192), low-quality evidence (one study; N = 20; limitations of inconsistency and imprecision) (188), respectively (Figure 26).

4.4.6 Sensitivity analysis

The sensitivity analysis of the synthesized results was assessed by excluding low-quality studies. The studies published in 1966 (17) and 1980 (155) had low-quality assessments. These two studies evaluated the effect of supine and sitting positions on CO. Excluding low-quality studies would not change the quality of the evidence (Figure 27)

Study or Subgroup	Supine position Mean	SD	Total	Other positions Mean	SD	Total	Weight	Mean Difference IV, Random, 95% CI	Year
2.1.1 Supine position vs 30 deg HUT position									
Harm 2003	6.1	0.85	9	5.3	1.18	9	6.7%	0.80 [-0.15, 1.75]	2003
Van Den Bogaard 2011	5.1	1.14	10	4.9	0.95	10	6.9%	0.20 [-0.72, 1.12]	2011
Subtotal (95% CI)			19			19	13.7%	0.49 [-0.17, 1.15]	
Heterogeneity: Tau² = 0.00; Chi² = 0.79, df = 1 (P = 0.37); I² = 0%									
Test for overall effect: Z = 1.45 (P = 0.15)									
2.1.2 Supine position vs 70 deg HUT position									
Harm 2003	6.1	0.85	9	5.2	0.8	9	8.0%	0.90 [0.14, 1.66]	2003
Van Den Bogaard 2011	5.1	1.14	10	4.1	0.26	10	8.2%	1.00 [0.28, 1.72]	2011
Subtotal (95% CI)			19			19	16.2%	0.95 [0.43, 1.48]	
Heterogeneity: Tau² = 0.00; Chi² = 0.03, df = 1 (P = 0.85); I² = 0%									
Test for overall effect: Z = 3.55 (P = 0.0004)									
2.1.3 Supine position vs left lateral position									
Kölegård 2018	5.6	1.4	12	6.7	1.7	12	5.1%	-1.10 [-2.35, 0.15]	2018
Subtotal (95% CI)			12			12	5.1%	-1.10 [-2.35, 0.15]	
Heterogeneity: Not applicable									
Test for overall effect: Z = 1.73 (P = 0.08)									
2.1.4 Supine position vs prone position									
Peces-Barba 2004	6.2	0.95	10	5.9	0.95	10	7.5%	0.30 [-0.53, 1.13]	2004
Subtotal (95% CI)			10			10	7.5%	0.30 [-0.53, 1.13]	
Heterogeneity: Not applicable									
Test for overall effect: Z = 0.71 (P = 0.48)									
2.1.5 Supine position vs sitting position									
Lundin 1966	4.33	1.05	8	3.46	0.65	8	7.3%	0.87 [0.01, 1.73]	1966
Kawakami 1980	8.46	1.61	5	7.16	1.92	5	2.3%	1.30 [-0.90, 3.50]	1980
Peces-Barba 2004	6.2	0.95	10	5.4	0.63	10	8.4%	0.80 [0.09, 1.51]	2004
Subtotal (95% CI)			23			23	18.0%	0.86 [0.33, 1.38]	
Heterogeneity: Tau² = 0.00; Chi² = 0.18, df = 2 (P = 0.91); I² = 0%									
Test for overall effect: Z = 3.17 (P = 0.002)									
2.1.6 Supine position vs standing position									
Gisolf 2004	6.5	1.1	8	4	0.9	8	6.5%	2.50 [1.52, 3.48]	2004
Van Den Bogaard 2011	5.1	1.14	10	4	0.76	10	7.4%	1.10 [0.25, 1.95]	2011
Subtotal (95% CI)			18			18	13.9%	1.78 [0.41, 3.15]	
Heterogeneity: Tau² = 0.76; Chi² = 4.45, df = 1 (P = 0.03); I² = 78%									
Test for overall effect: Z = 2.54 (P = 0.01)									
2.1.7 Supine position vs 5 deg HDT position									
Harm 2003	6.1	0.85	9	5.9	0.48	9	8.8%	0.20 [-0.44, 0.84]	2003
Subtotal (95% CI)			9			9	8.8%	0.20 [-0.44, 0.84]	
Heterogeneity: Not applicable									
Test for overall effect: Z = 0.61 (P = 0.54)									
2.1.8 Supine position vs 10 deg HDT position									
Harm 2003	6.1	0.85	9	6.1	0.75	9	8.1%	0.00 [-0.74, 0.74]	2003
Subtotal (95% CI)			9			9	8.1%	0.00 [-0.74, 0.74]	
Heterogeneity: Not applicable									
Test for overall effect: Z = 0.00 (P = 1.00)									
2.1.9 Supine position vs 20 deg HDT position									
Harm 2003	6.1	0.85	9	6.2	0.58	9	8.6%	-0.10 [-0.77, 0.57]	2003
Subtotal (95% CI)			9			9	8.6%	-0.10 [-0.77, 0.57]	
Heterogeneity: Not applicable									
Test for overall effect: Z = 0.29 (P = 0.77)									
Total (95% CI)			128			128	100.0%	0.60 [0.23, 0.98]	
Heterogeneity: Tau² = 0.31; Chi² = 35.16, df = 13 (P = 0.0008); I² = 63%									
Test for overall effect: Z = 3.15 (P = 0.002)									
Test for subgroup differences: Chi² = 20.03, df = 8 (P = 0.01), I² = 60.1%									

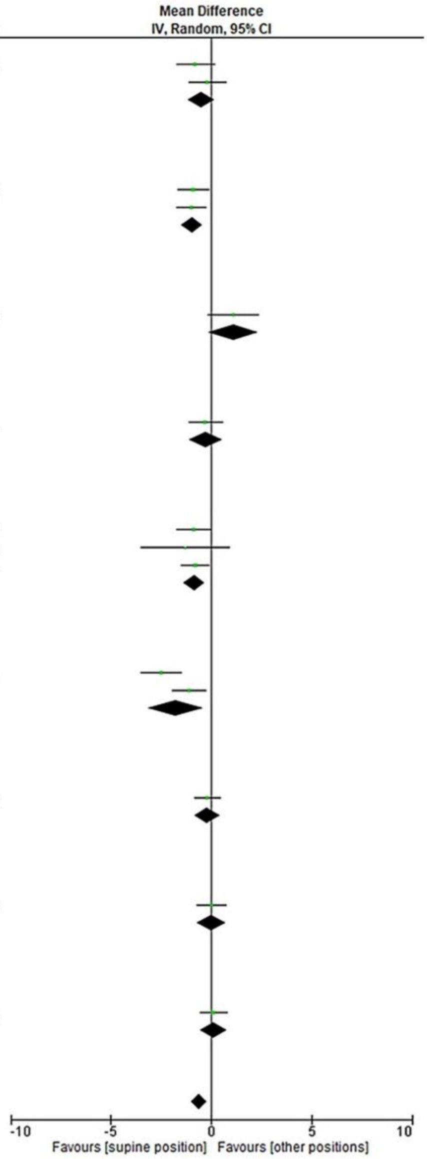


Figure 18 Meta-analysis of the results of the effects of body positions on CO

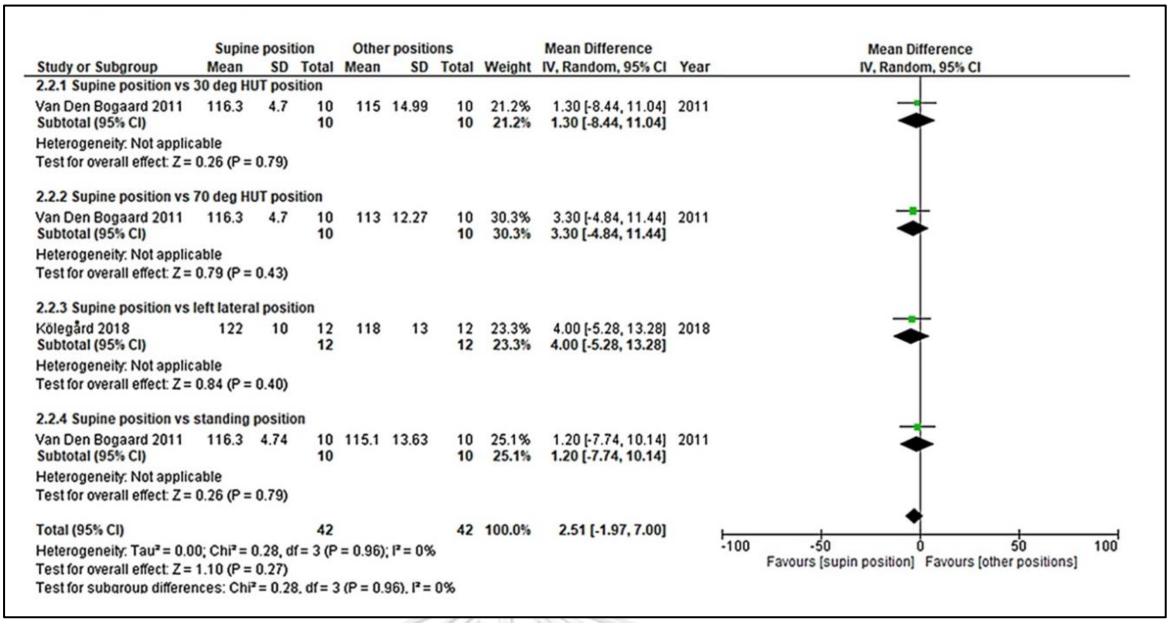


Figure 19 Meta-analysis of the results of the effects of body positions on SBP

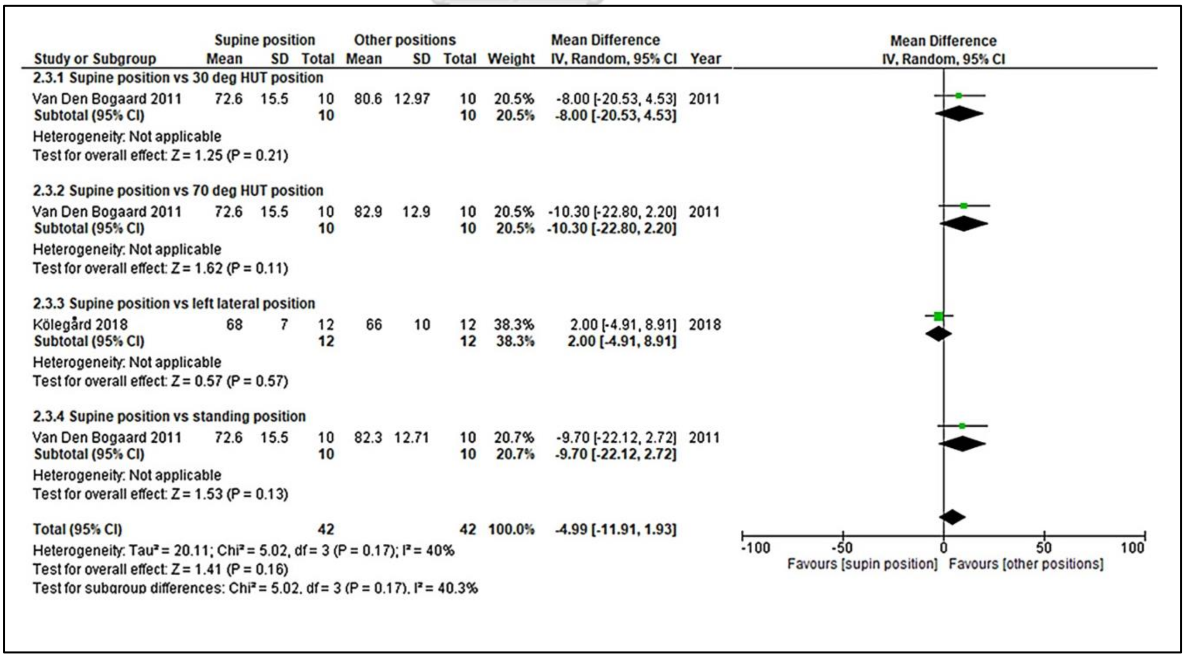


Figure 20 Meta-analysis of the results of the effects of body positions on DBP

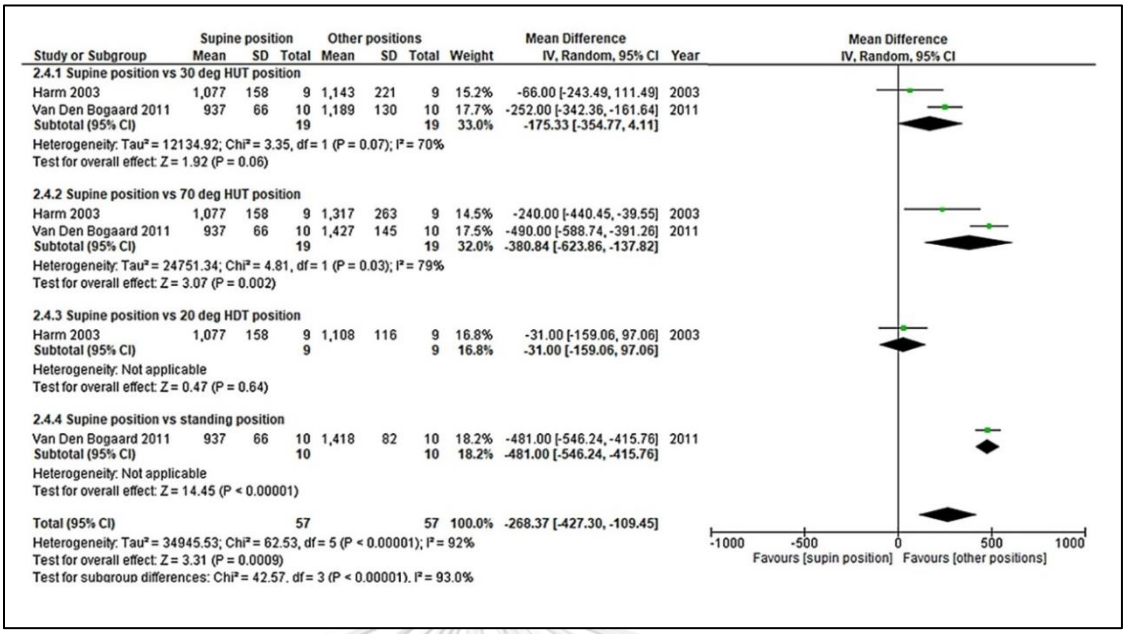


Figure 21 Meta-analysis of the results of the effects of body positions on SVR

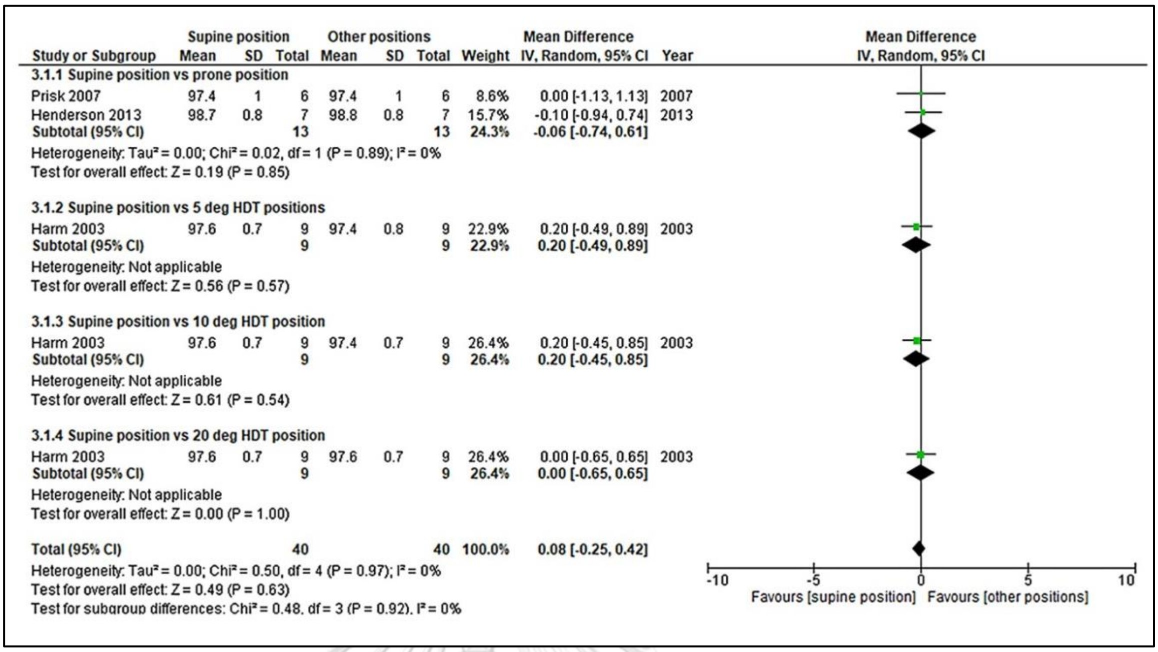


Figure 22 Meta-analysis of the results of the effects of body positions on SaO_2

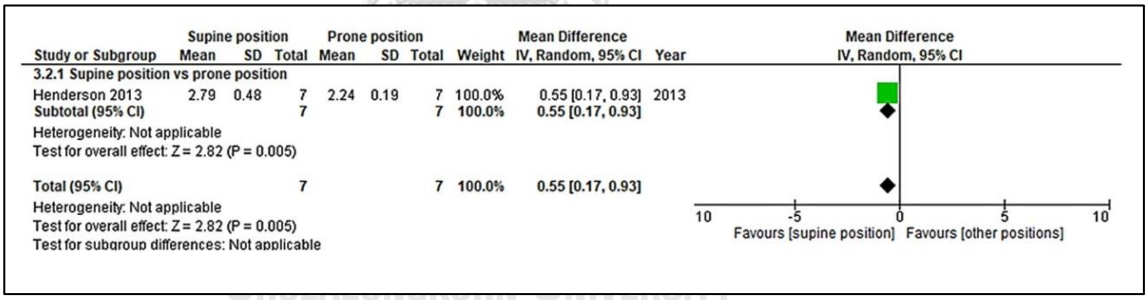


Figure 23 Meta-analysis of the results of the effects of body positions on V_A

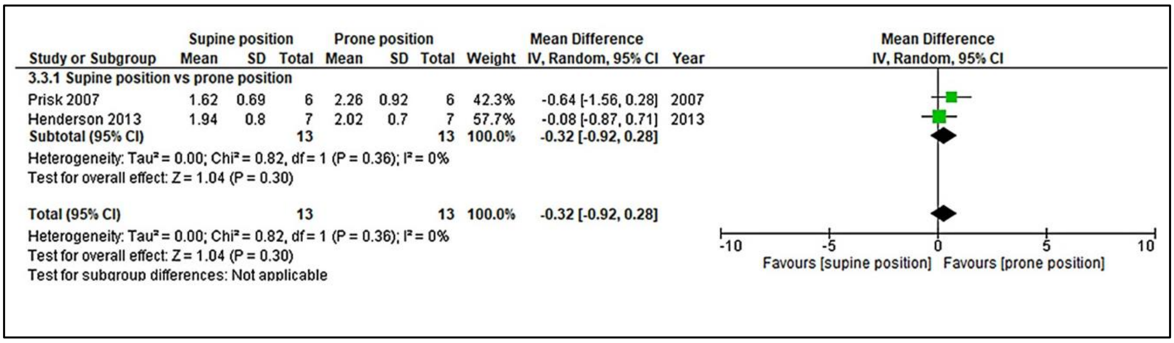


Figure 24 Meta-analysis of the results of the effects of body positions on Q

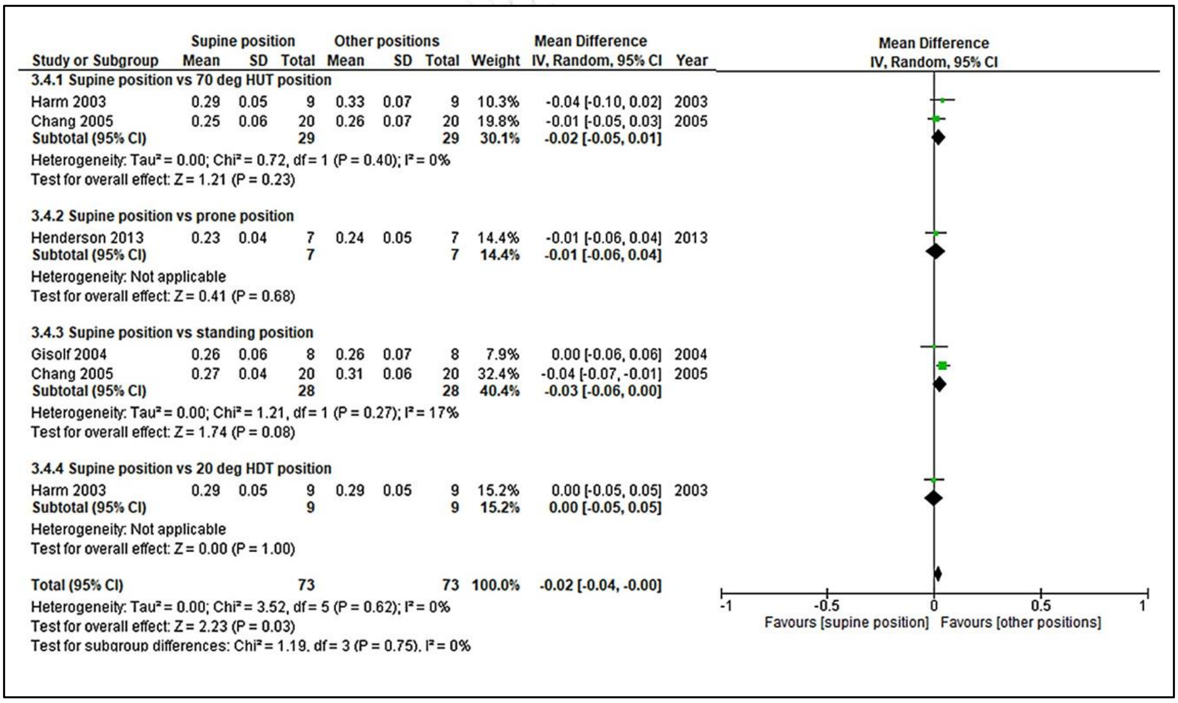


Figure 25 Meta-analysis of the results of the effects of body positions on VO_2

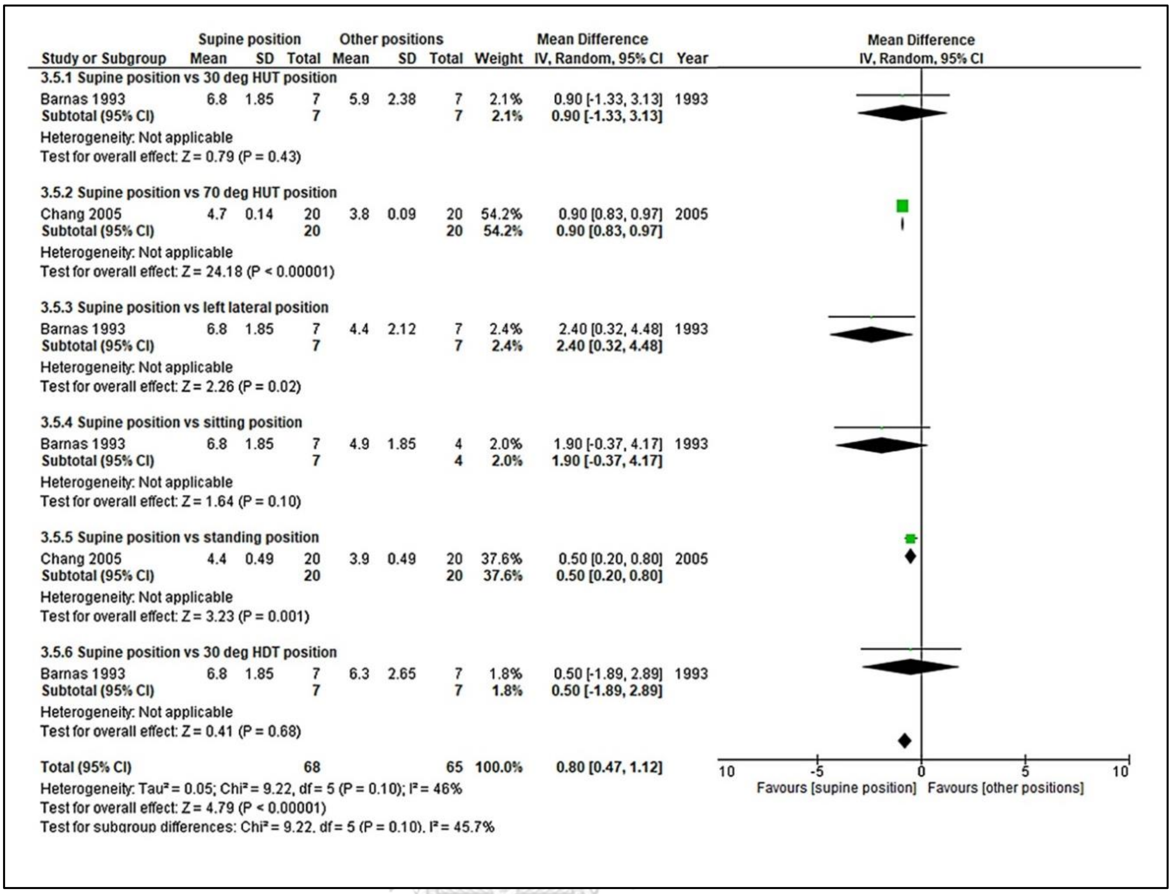


Figure 26 Meta-analysis of the results of the effects of body positions on Rrs

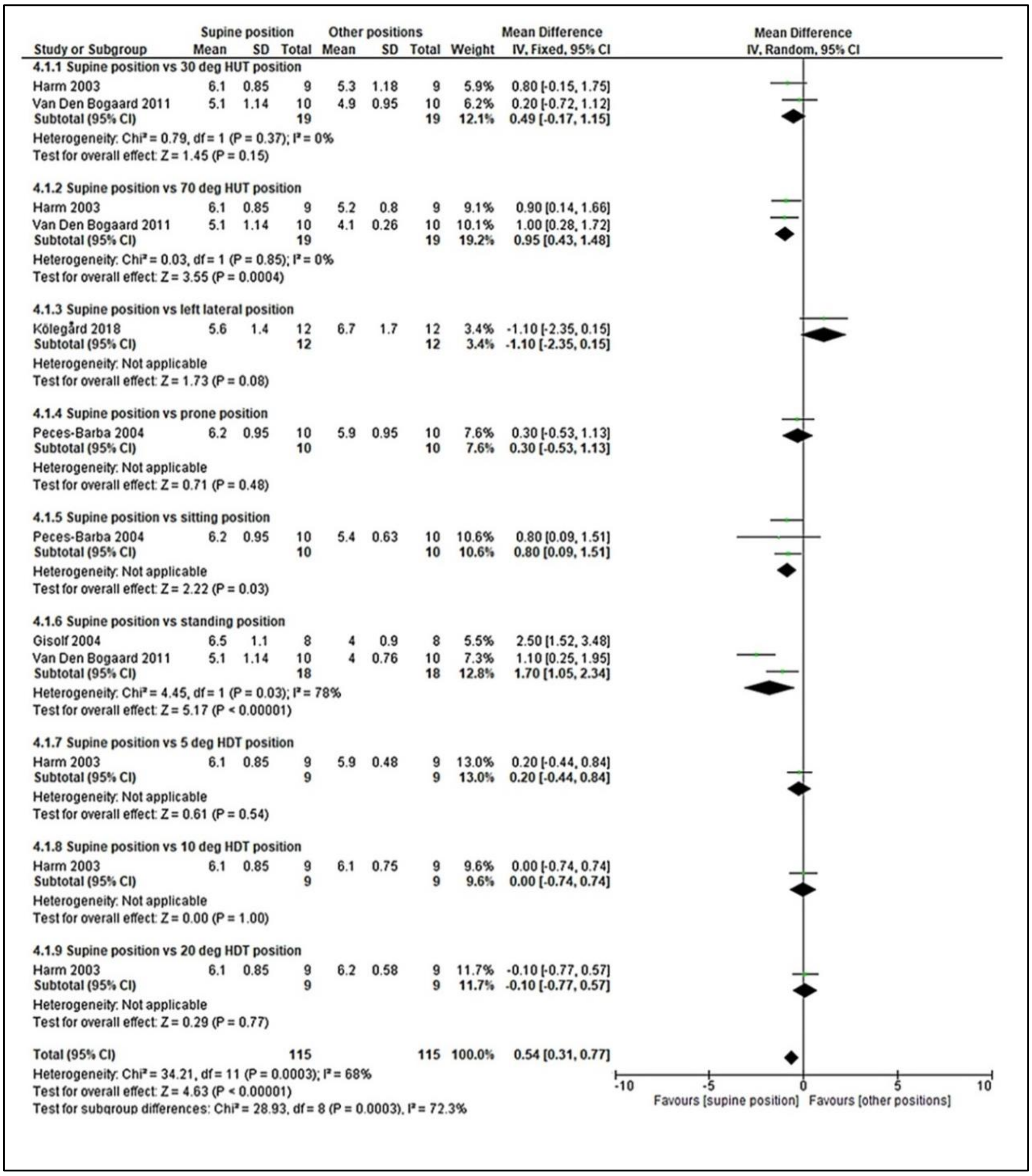


Figure 27 Meta-analysis of the results of the effects of body positions on CO (sensitivity analysis)

4.5 Discussion

Body positioning is a treatment typically used in hospitals. The current systematic review and meta-analysis of thirteen studies showed that different body positions influence hemodynamic and respiratory variables. Across the included studies, nine different body positions were examined: supine, Fowler's, HUT (30, 60, and 70 deg), 60 deg HUT with left lateral, HDT (5, 10, 20, and 30 deg), left lateral, prone, sitting, and standing positions. Data analysis demonstrated very low to moderate evidence quality. The supine was associated with the highest CO and the lowest SVR. Moreover, the supine position was associated with the highest V_A and Rrs. The results of the included studies exemplified the impact of different body positions on physiological functions associated with gravitational force. However, the evidence did not show significant differences between the impact of different body positions on SBP, DBP, SpO_2, Q, and VO_2.

4.5.1 Study characteristics

All thirteen studies included in this review involved both female and male participants. One study reported that CO and SV were significantly lower in females compared to males (121), which is likely explained by the smaller left ventricular (LV) volume and mass and left atrial volume in females (122). Regarding respiration, males have larger airway diameters, lung volumes, maximum expiratory flows, and diffusion surface characteristics compared to females, resulting in respiratory parameter differences (179). In this review, female subjects in each study were very rare, and neither study identified causality. It might be because the study design is difficult to implement for females. The participants included in the thirteen studies were of mixed ages, which is a known factor that affects hemodynamics and respiration. Previous studies have reported that hemodynamic variables are affected by increasing age. CO and SV have been found to decrease with age in healthy individuals due to changes in LV geometry, which tend to be more spherical in younger individuals and more elliptical in older individuals (121, 122). However, as the participants in the included studies were all adults, this effect may have been minimal. Furthermore, one of the included studies did not report the number of participants or their age range (18).

The pooled data estimates of the included studies indicated data heterogeneity. Therefore, a random-effects model was used to adjust for data variation to reduce heterogeneity. The included studies used different methods. However, all methods were valid and reliable for evaluating hemodynamics and respiratory variables. In several studies, the participants remained in each body position for 5 minutes (182, 188, 197, 198) or 10 minutes (17, 154, 192). However, six studies did not report the time participants spent in each position (18, 155, 168, 192, 199, 200). The difference in time spent in the different body positions is noteworthy. Hemodynamics and respiration are controlled by several cardiovascular and respiratory control systems, including the baroreceptor reflex, the renin-angiotensin system (RAS), the local vascular mechanisms, the chemoreceptor reflex, and the Hering-Breuer reflex (lung and upper airway receptors). These systems regulate these functions at various times, meaning differences in time spent in each position could impact the results gained. Although the exposure time to a specific posture varied depending on the studies, subgroup analyses are difficult due to the fact that the studies included in this meta-analysis have relatively small sample sizes.

Most of the studies compared the supine position with other positions. It is because hemodynamic assessments are generally made in the supine position. However, one study compared Fowler's in different deg (197), another study compared the HUT positions in different deg (196), and another only evaluated the HUT, HDT, and left lateral positions.(192) Future studies should look at comparing all body positions.

4.5.2. Methodological considerations

The thirteen studies were rated as having low- to high-quality methodologies. Ten studies were assessed as having a low risk of bias across all eighteen domains (18, 154, 160, 168, 182, 188, 192, 196, 197, 198). Only three studies were assessed as having a high risk of bias (17, 155, 199) (Table 7). Factors that impacted bias assessment included a lack of reporting on participant characteristics and population sources, participant selection, intervention assignment randomization, and power of analysis. Regarding important patient characteristics, some of the included studies did not report on smoking history (17, 18, 154, 168, 192, 197, 199), level of physical activity, (17, 160, 168, 188, 192, 197, 198, 199, 201) and medical history (17, 18, 160, 182, 192, 197, 198). Such characteristics can impact cardiovascular and respiratory responses, which could, therefore, impact results. Population sources went unreported in eleven studies (17, 18, 154, 155, 160, 168, 182, 192, 196, 198, 199), while in two other studies, it was unclear whether the participants recruited were representative of the source population (188, 197). Without reporting on population sources, results cannot be generalized to the wider population. Only two studies randomized the allocation of interventions (188, 197). Randomization should be performed to minimize selection bias. Furthermore, the lack of experimental randomization may have affected the estimated effects of the results. No studies performed a power analysis, which is necessary to ascertain the smallest possible sample size that can be used to detect an effect at a given significance level. Therefore, not doing this analysis can lead to imprecise results. These factors are all important for establishing internal and external validity, which should also be reported on to minimize selection bias.

4.5.3 Influence of body positions on hemodynamics

The supine was found to result in a significantly higher CO compared to the 70 deg HUT, sitting, and standing positions, but the evidence supporting this is of very low- to low-quality evidences. This discovery is in agreement with previous studies that explained the effects of gravity on the heart and surrounding body structure when aligned horizontally in the supine, leading to increased blood flow from the heart and central blood volume, resulting in higher CO (183, 184, 185). Adequate CO is essential for blood circulation to supply oxygen-rich blood to vital organs throughout the body, as it is a crucial factor in determining oxygen delivery.

On the other hand, a research study reported that the left lateral position resulted in a greater increase in CO compared to the supine position (196). Additionally, the study showed that lying on the left side at 60 deg HUT resulted in significantly higher CO compared to lying on the back at 60 deg HUT (Table 6). This suggests that the left lateral position may lead to an increased venous return, possibly due to the hydrostatic pressure gradients between the caval veins and the heart.

There were no differences in SBP and DBP between the supine and upright positions (30 deg HUT, 70 deg HUT, standing), as the upright positions result in blood shifting to the lower body (lower extremities). This causes a decrease in cardiac preload to counteract the initial drop in BP, and the baroreceptor reflex increases vasomotor tone via an increase in sympathetic activity to maintain BP (154). However, a study reported that DBP increased in the upright positions (30 deg HUT, 70 deg HUT, standing) compared to the supine position with low-quality evidence (18). This change is likely due to the BP control mechanism increasing sympathetic adrenergic nerve activation in the blood vessels and alpha-adrenoceptor agonists (alpha-agonists) binding to alpha-receptors on vascular smooth muscle cells, thereby inducing vasoconstriction (178, 202). This control mechanism regulates the peripheral blood supply, as the run-off of conductance vessels during left ventricular diastole results in increased DBP (203). This result is in line with the finding in this meta-analysis that the supine resulted in significantly less SVR compared to the 70 deg HUT and standing positions due to vasoconstriction based on very low-quality evidence (18).

4.5.4 Influence of body positions on respiration

There were no significant differences between the effects of different body positions on SpO_2, Q, and VO_2. Although SpO_2 values did not change between the body positions in this systematic review and meta-analysis, a previous study reported that the highest SpO_2 was achieved in the sitting position while the lowest was achieved in the supine position after each position had been held for ten minutes (204). Therefore, the time spent in positioning may impact SpO_2, and differences in time spent between studies may impact results. The evidence found that V_A in the supine was significantly higher than in the prone. In the supine position, more alveoli placed in the dependent lung have low trans-pulmonary pressures (PTP). These alveoli are small in size and highly compliant (more distensible), so they are capable of higher ventilation in the supine position compared to the prone position (160, 205). V_A is one of the key variables considered together with Q to indicate gas exchange efficiency (200). However, there were no significant differences in Q between the supine and prone positions among the included studies based on moderate evidence (160). These findings are inconsistent with the principles of Q, as Q is more uniformly distributed in the prone position compared to the supine position. This is due to the increased Q per alveolus in the gravitationally non-dependent regions of the lung in the prone position compared to the supine position (188). This evidence is represented by the two included studies. Nevertheless, one of them had a significantly higher Q in the prone position than in the supine position.

Although the evidence did not show changes in VO_2 in the 70 deg HUT, prone, 20 deg HDT, and standing positions compared to the supine, some studies reported increasing VO_2 in the 70 deg HUT (154, 188) and standing positions (188). This is due to these positions resulting in increased energy expenditure (188). These VO_2 results are associated with body positional changes in the sagittal plane; however, further studies are required to evaluate the effect of body position in the transverse plane. The HUT position resulted in significantly lower Rrs compared to the left lateral position because the functional residual capacity (FRC) is greater in the left lateral position because of the large mean airway diameter. Moreover, the 70 deg HUT and standing positions were associated with significantly lower Rrs than the supine position. The FRC is reduced in the supine position. FRC reductions promote airway closure (small mean airway diameter) in dependent lung regions (206, 207). It is tempting to speculate that the upright positions might be the best position for influencing Rrs.

4.5.5 Sensitivity analysis

In studies with low-quality assessments, it is possible that the effect size has a large variation in the data analysis, which might have influenced the level of evidence and potentially the results of this review. After excluding these studies, the results were not different from the previous analysis and did not affect the quality of the evidence. So, including the studies with low-quality assessments did not change the results.

4.6 Conclusion

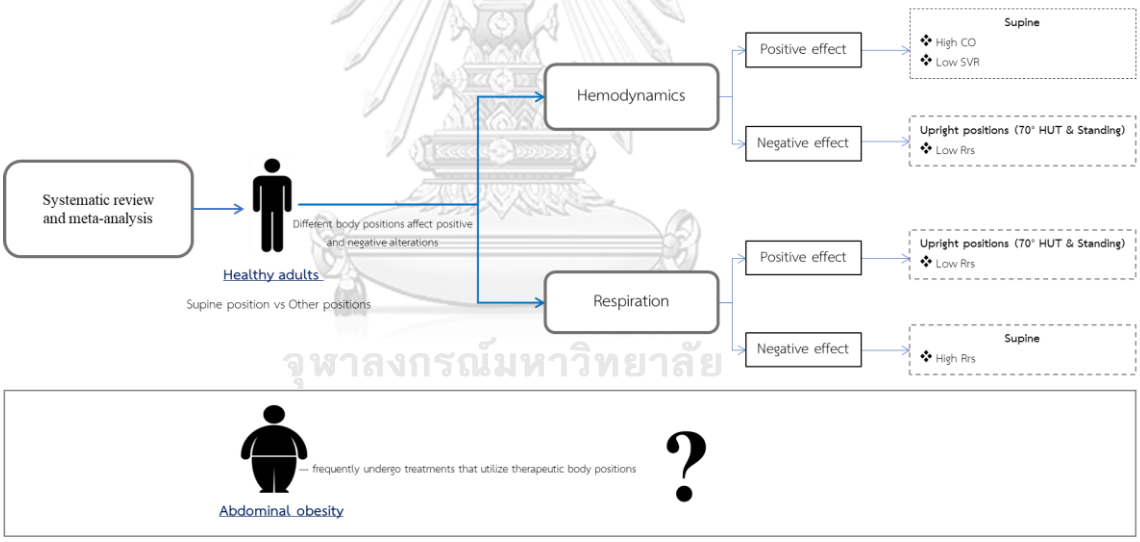
Different body positions result in different alignments of body parts that are involved in complex interactions within diverse organ systems. This systematic review and meta-analysis revealed that different body positions exert both positive and negative effects on the physiological functions of hemodynamics and respiration, as demonstrated in their variables. From the evidence, it appears that the supine position had the most positive influence on hemodynamic variables, resulting in the highest CO and the lowest SVR compared to other positions. SBP and DBP did not differ between supine and other positions due to the responsibility of the reflex to control BP. Regarding respiration, the upright positions (70 deg HUT and standing positions) had the most positive influence on the respiratory variables, resulting in the lowest Rrs compared to the supine. The supine had the highest Rrs. Although the supine has a negative effect on Rrs, the V_A was higher in the supine than in the prone.

Acknowledgements

The authors would like to thank Dr. Rattanaporn Sonpeayung for suggestions.

Summary

This study conducted a review of existing research to offer insights into how various body positions can have both advantageous and disadvantageous effects on these physiological aspects. The findings of this review can be valuable for medical professionals in comprehending the physiological repercussions of different body positions. However, it is important to note that these results are primarily applicable to healthy individuals, and many of the studies compared the effects of various positions to the supine position. Therefore, it is essential to assess hemodynamic and respiratory variables in patient-specific conditions, particularly in obesity cases, with regard to all therapeutic body positions, including Fowler's, right lateral, left lateral, supine, and prone positions.



CHAPTER 5 Study 2 - Hemodynamic responses during therapeutic body positions in adults with and without abdominal obesity

Objective:

To compare hemodynamic responses during therapeutic body positions within and between groups of adults with and without abdominal obesity

Paper 2: Hemodynamic responses during therapeutic body positions in adults with and without abdominal obesity

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5.1 Abstract

Background: Excess adipocytes in abdominal obesity induce adverse hemodynamics, increasing patients' risk of illness. Body positioning serves as a treatment for these individuals. However, evidence suggests that positioning can modulate positive and negative hemodynamics. This study examines hemodynamic responses to therapeutic body positions in adults with and without abdominal obesity.

Methods: 52 male (26 normal weight, 26 abdominal obesity), aged between 30 and 59 years, underwent 40 minutes of each position, including Fowler's, right lateral, left lateral, supine, and prone positions.

Results: In the prone position, heart rate exhibited the highest value ($p < 0.05$), whereas it resulted in the lowest cardiac index ($p < 0.05$). End-diastolic volume, contractility index, and stroke volume index were the highest in the supine position ($p < 0.05$). Blood pressures were lowest in the right lateral position ($p < 0.05$). These findings were consistent across both groups. Moreover, cardiac index and stroke volume index in abdominal obesity were lower than normal weight in the right lateral position ($p = 0.021$, $p = 0.028$, respectively). Contractility index and systolic blood pressure in abdominal obesity were higher than the normal weight group in the prone position ($p = 0.045$, $p = 0.047$, respectively).

Conclusions: Supine emerged as the most favorable for hemodynamics. However, for blood pressure, the optimal choice was found to be the right lateral position. The study advises against the prone position due to its potential negative effect on hemodynamics. The impact of this position could be even more pronounced in abdominal obesity.

Keywords: Therapeutic body positions, Hemodynamics, Cardiac output, Stroke volume, Blood pressure, Obesity

5.2 Introduction

Obesity can cause both morphological and functional changes in the heart. Excessive adipose tissue is linked to inflammation, deregulation of the immune system, and dysfunctions in multiple organs (99, 208). High adipose tissue also leads to an increase in total and central blood volume, which in turn predisposes to an increase in cardiac output (CO) (209, 210), as well as increased left ventricular end-diastolic volume (LVEDV) (211). These changes can lead to the development of cardiovascular disorders (212, 213). Particularly, in cases of abdominal obesity, excessive intra-abdominal adipose tissue can affect fluid retention, the sympathetic nervous system, and the renin-angiotensin-aldosterone system. These changes can impact hemodynamic alterations (214). Unsurprisingly, hospitalized patients with obesity exhibit higher levels of serious illness. Evidence has indicated an elevated risk of developing severity in patients with obesity (215). Furthermore, a meta-analysis has demonstrated that patients with obesity experience higher rates of hospital complications compared to non-obese patients, even when injury severity is equivalent(101). This may be attributed to the fact that obese patients are often bedridden.

During hospitalization, one of the standard treatments employed in hospitals is therapeutic body positions, including Fowler's, right lateral, left lateral, supine, and prone positions. These positions aim to enhance physiological functions and prevent complications that can arise during hospitalization. Therapeutic body positions not only facilitate effective treatments but also contribute to a decrease in mortality rates. Currently, therapeutic body positions are extensively employed due to their non-invasive nature, requiring no complex tools and incurring no additional charges. Moreover, these positions can be continued without any long-term adverse effects on patients, even after their discharge from the hospital. Consequently, therapeutic body positions are important as interventions within the clinical setting.

However, previous studies have consistently demonstrated the influence of therapeutic body positions on pressure and blood flow within the circulation, as evidenced by hemodynamic outcomes. It is widely acknowledged that alterations in body position along the longitudinal axis (z-axis) impact cardiovascular function. Extensive documentation supports that the upright position has been observed to cause a decrease in central blood volume, accompanied by a simultaneous reduction in mean arterial pressure (MAP), cardiac output (CO), and associated variables compared to lying down positions (184, 185). When comparing the positions along the y-axis, it was found that blood pressure (BP) and heart rate (HR) were notably higher in the prone position compared to the supine position. The prone position led to an elevation in HR and total peripheral vascular resistance (SVR), while stroke volume (SV) experienced a decrease (186). These findings have presented compelling evidence elucidating the significant impact of gravitational force on body organs and their physiological functions.

Based on previous studies, it can be inferred that therapeutic body positions can have both positive and negative effects on the physiological functions of hemodynamics. However, it is important to note that these results have been observed solely in healthy individuals. The effects of therapeutic body positions on obese individuals who undergo extended hospital stay due to debilitating diseases, and are often treated with such positions, are currently unknown. Furthermore, most existing studies have examined the effects of each body position for short durations, while therapeutic body positions are typically maintained for extended periods, often exceeding 30 minutes. This study aimed to investigate the impact of various therapeutic body positions, administered for 40 minutes, on hemodynamics in individuals with and without abdominal obesity. Additionally, the study aimed to determine the most optimal therapeutic body position based on its effects on hemodynamics in both groups. We hypothesized differences in hemodynamics among therapeutic body positions in individuals with and without abdominal obesity, and morphological alterations in the abdominal obesity group may result in differences from the normal weight group.

5.3 Materials and Methods

5.3.1 Study design and ethics considerations

This study received approval from the Research Ethics Review Committee for Research Involving Human Research Participants, Group I, Chulalongkorn University (RECCU) (certificate of approval number: 186/2021). The study was conducted at the laboratory of the Department of Physical Therapy, Faculty of Allied Health Science, Chulalongkorn University, located in Bangkok, Thailand. All participants were asked to sign an informed consent form before participating in this study.

5.3.2 Study participants

A pilot study was conducted with ten male participants, comprising five individuals with normal weight and five with abdominal obesity. The pilot study aimed to estimate the sample size using G*power software (version 3.1.9.7). The results indicated that 52 participants would be required to achieve 80% statistical power and detect any differences between the groups, assuming the most conservative effect size of 0.40. The eligibility criteria for participants encompassed adult males aged 30-59 years. These criteria were based on the acknowledgment that gender and age exert an influence on hemodynamic responses, attributed to the anatomical distinctions within cardiovascular organs (216, 217). The participants were classified as either normal weight or abdominal obesity. For the normal weight group, the criteria were a BMI of 18.5-22.9 Kg/m^2, waist circumference (WC) < 90 cm, waist-to-hip ratio (WHR) ≤ 0.95. For the abdominal obesity group, the criteria were a BMI ≥ 25 Kg/m^2, WC ≥ 90 cm, and WHR > 0.95 (1, 32, 33, 176, 218). All participants were non-smokers and non-alcohol-drinkers. All of them had overall physical activity in the sedentary range (Baecke questionnaire score of < 6), HR 60–100 beats/min, SBP < 140 mmHg, diastolic blood pressure (DBP) < 90 mmHg, respiratory frequency (R_f) 12-20 breaths/min, and oxygen saturation (SaO_2) 95-100%. Participants having any cardiovascular, respiratory, renal, endocrine, or neurological disorders and being treated with any drug that might potentially stimulate or depress the cardiovascular system were excluded. Participants who have abnormal chest shapes and/or postoperative chest wounds were also excluded.

5.3.3 Research procedure

Before participating in the experimental study, all participants were required to ensure they had sufficient sleep of more than six hours. They were also instructed to avoid consuming heavy meals for at least four hours and abstain from consuming caffeine-containing products for at least 12 hours. All data were collected in a temperature-controlled laboratory (room temperature: 25 °C). The research procedure consisted of three distinct processes: participant screening, baseline assessment, and participant preparation, and main outcome assessments. These processes are visually represented in Figure 28.

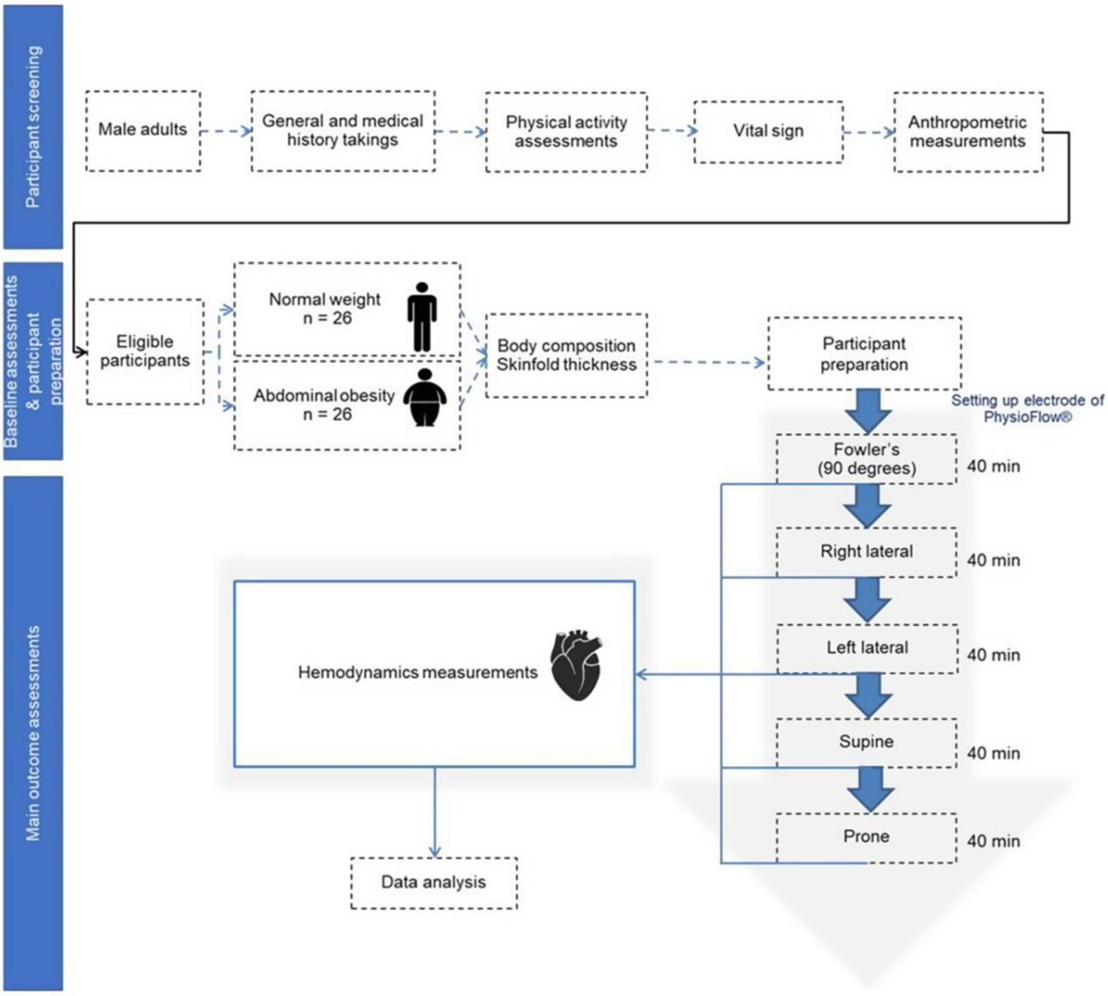

Figure 28 Research procedure

Participants screening

All participants were asked to complete the general information and medical history screening form. And they were asked to answer the Baecke questionnaire to assess physiological activity (177). The vital signs were assessed after the ten-minute rest in a sitting position (or until stable vital signs). An autonomic digital blood pressure monitor assessed HR, SBP, and DBP in a brachial artery (Yuwell, YE670D). R_f was assessed by counting the number of breaths taken over one minute. And SaO_2 was obtained by using a pulse oximeter (ChoiceMMedTM, MD300C1). All the assessed vital signs needed to be stable. Then, weight was measured using a stadiometer. Using a height indicator tape, the height was measured as the distance from the floor to the vertex. BMI was calculated as weight in kilograms (kg) divided by the square of height in meters

(m^2) (219). WC and hip circumference (HC) were determined by tape for the calculated WHR (220).

Baseline assessments and participant preparation

Eligible participants were measured for body composition, including the percentage of body fat (% BF), visceral fat, and subcutaneous fat, by bioelectrical impedance (Karada scan: OMRON, Model HBF-375), and skinfold thickness using a digital outside skinfold caliper (Digital Caliper Gauge, EDC-A1150). Skinfold thickness was measured three times to determine an average at five sites in standing position, including: 1) Chest, a diagonal fold halfway between the top of the axillary and the nipple. 2) Mid-axillary is where a vertical line from the mid-axilla intersects with a horizontal line level with the bottom edge of the xiphoid process. 3) Subscapular, which is 2 cm below the inferior angle of the scapular. 4) Suprailiac, which is the point above the iliac crest in the mid-axillary line. 5) Abdomen, which is five centimeters to the right of the umbilicus. Afterward, all participants removed their shirts to set up electrodes for PhysioFlow® (Manatec Biomedical, Paris, France). The electrode placement protocol was performed as previously described (221). After setting up the equipment, participants performed five therapeutic body positions, starting with Fowler's (upright 90°), followed by supine, right lateral, left lateral, and prone positions. The details regarding five therapeutic body positions are described below.

Fowler's: Sitting on the bed with backrest at 90° trunk inclination. Hips flexed about 90° with slightly abducted (about 10°) and straightened knees.

Right lateral: Lying on the right side. Right leg straightened. Left leg placed on a pillow.

Left lateral: Lying on the left side. Left leg straightened. Right leg placed on a pillow.

Supine: Lying on the back. Head and neck kept in the neutral position, with support of a pillow.

Hip and knee slightly flexed (about 15°), with support of a pillow.

Prone: Lying on the abdomen. Head and neck kept in the neutral position, with support of a U-shaped pillow (with a gap at the chest area).

Main outcome assessments

After maintaining each position for 40 minutes, hemodynamic data were collected using the trans-thoracic bio-impedance principle of Physio Flow® to determine HR, end-diastolic volume (EDV), contractility index (CTi), stroke volume index (SVI), cardiac index (CI), and systemic vascular resistance index (SVRI). These measurements were normalized based on body surface area (BSA) to account for individual variations. Before collecting the data, a calibration phase was conducted over 30 heart cycles. All of these hemodynamic outcomes were recorded for 1 minute. The SBP and DBP were recorded three times using an autonomic blood pressure monitor (Yuwell YE670D). Finally, all participants were asked about their comfort scores in each therapeutic body position.

5.3.4 Data analysis

For statistical analysis, the data were analyzed with statistical software (SPSS version 22.0, Chicago, IL, USA). The results were expressed as the mean ± standard deviation. The Komokorov-Sminov test was used to verify the normal distribution of the data. Comparison of baseline characteristics between the normal weight group and the abdominal obesity group used the independent samples t-test. We used two-way mixed ANOVA with Bonferroni post hoc analyses to evaluate the differences between adults with and without abdominal obesity, considering different therapeutic body positions. The statistical differences were considered to be significant at $p < 0.05$.

5.4 Results

5.4.1 Baseline characteristics of participants

The baseline characteristics of participants, consisting of normal weight and abdominal obesity groups, are presented in Table 9. The results showed that body weight, BMI, WC, HC, and WHR in the abdominal obesity group were significantly higher than the normal weight group ($p < 0.001$). Furthermore, body fat, visceral fat, subcutaneous fat, and all the sites of skinfold thickness in the abdominal obesity group were significantly higher than in the normal weight group ($p < 0.001$).

Table 9 Baseline characteristics of study participants

characteristics	Mean ± SD		*p*-value
	Normal weight (N = 26)	Abdominal obesity (N = 26)	
Age (y)	41.96 ± 8.55	41.31 ± 7.44	0.385
Body weight (kg)	63.03 ± 6.64	80.02 ± 9.20	<0.001*
Height	169.33 ± 7.26	168.73 ± 6.54	0.379
BMI (kg/m^2)	21.95 ± 1.29	28.07 ± 2.44	<0.001*
WC	83.98 ± 4.78	97.91 ± 5.42	<0.001*
HC	95.65 ± 4.85	100.69 ± 4.58	<0.001*
WHR	0.88 ± 0.05	0.97 ± 0.03	<0.001*
Physical activity	5.50 ± 0.42	5.38 ± 0.49	0.394
HR (bpm)	72.35 ± 10.45	75.38 ± 8.97	0.133
SBP (mmHg)	121.81 ± 10.32	125.58 ± 10.18	0.096
DBP (mmHg)	82.08 ± 9.02	82.85 ± 7.35	0.369
MAP (mmHg)	95.32 ± 8.66	97.09 ± 7.70	0.220
R_f (bpm)	14.46 ± 3.40	15.46 ± 2.83	0.127
SaO_2 (%)	98.00 ± 0.69	97.92 ± 0.89	0.905
Body compositions	.	.	
Body fat (%)	22.05 ± 4.22	27.35 ± 3.55	< 0.001*
Visceral fat (%)	7.69 ± 3.07	13.48 ± 2.67	< 0.001*
Subcutaneous fat (%)	15.97 ± 4.19	19.98 ± 3.81	< 0.001*
Skinfold thickness	.	.	
Chest (mm)	10.49 ± 4.21	17.38 ± 6.55	< 0.001*
Mid axillary (mm)	8.65 ± 3.64	16.97 ± 7.87	< 0.001*
Subscapular (mm)	13.67 ± 5.00	25.38 ± 7.72	< 0.001*
Suprailiac (mm)	16.28 ± 6.58	23.85 ± 7.81	< 0.001*
Abdomen (mm)	16.71 ± 5.82	27.56 ± 7.43	< 0.001*
Sum skinfold thickness (mm)	65.80 ± 20.96	111.14 ± 30.37	< 0.001*

BMI, body mass index; WC, waist circumference; HC, hip circumference; WHR, waist to hip ratio; HR, heart rate; SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure; R_f, respiratory frequency; SaO_2, peripheral oxygen saturation. Data are represented as mean ± SD. All characteristics were tested by independent samples t-test. * represents $p < 0.001$ (significance of the difference between normal weight and abdominal obesity groups)

5.4.2 Effects of therapeutic body positions on hemodynamics

Heart rate (HR)

The results are presented in Table 10. HR was significantly highest when participants were prone, followed by Fowler's position ($p < 0.05$). In contrast, HR was significantly lowest in the left lateral position ($p < 0.05$). These findings were consistent across both groups. However, there were no significant differences in HR between groups within the same position.

End-diastolic volume (EDV)

The results revealed that EDV was significantly highest in the supine position for both groups ($p < 0.05$). However, there were no significant differences in EDV between groups within the same position (as shown in Table 10).

Contractility index (CTi)

According to the findings, the CTi in the normal weight group was significantly highest in the supine position and lowest in the prone position ($p < 0.05$). However, in the abdominal obesity group, there were no significant differences in CTi among the therapeutic body positions. Additionally, in the prone position, the CTi of the abdominal obesity group was significantly higher than the normal weight group ($p = 0.045$), as demonstrated in Table 10.

Stroke volume index (SVi)

SVi was significantly highest in the supine position, followed by Fowler's position in both groups ($p < 0.05$). Moreover, in the Fowler's and right lateral positions, SVi in the normal weight group was significantly higher than in the abdominal obesity group ($p = 0.029$ and $p = 0.028$, respectively), as presented in Table 10.

Cardiac index (CI)

Table 10 showed that in the normal weight group, the CI was significantly highest in the supine position, followed by Fowler's position, and lowest in the prone position ($p < 0.05$). However, in the abdominal obesity group, there were no significant differences in CI among the therapeutic body positions. Furthermore, in the right lateral position, the CI in the normal weight group was significantly higher than in the abdominal obesity group ($p = 0.021$).

Systemic vascular resistance index (SVRi)

There were no significant differences in SVRi among the therapeutic body positions in both groups. Additionally, there were no significant differences in SVRi between groups within the same position (Table 10).

Table 10 The influence of therapeutic body positions on hemodynamics

Parameters	Normal weight					Abdominal obesity					Interaction effect
	Fowler's (†)	Right lateral (‡)	Left lateral (§)	Supine (‖)	Prone (¶)	Fowler's (†)	Right lateral (‡)	Left lateral (§)	Supine (‖)	Prone (¶)	*p*-value
HR (bpm)	74.29 ± 14.01 [§,‖]	73.37 ± 20.99	65.96 ± 10.71 [†,¶]	67.23 ± 11.34 [†]	76.73 ± 19.15 [§]	77.01 ± 17.29 [‡,§,‖]	70.85 ± 11.14 [†,¶]	70.09 ± 16.68 [†,¶]	71.21 ± 21.35 [†,¶]	78.51 ± 13.18 [‡,§,‖]	0.002
EDV est (ml)	173.19 ± 78.52 [¶]	167.74 ± 81.99 [‖,¶]	168.28 ± 89.53 [‖,¶]	187.74 ± 110.89 [‡,§,¶]	141.17 ± 65.22 [†,‡,§,‖]	155.85 ± 54.10 [‖]	151.53 ± 43.34 [‖]	158.77 ± 72.55 [‖]	177.19 ± 89.59 [†,‡,§,¶]	154.38 ± 60.59 [‖]	0.020
CTi	150.34 ± 64.22 [¶]	150.75 ± 54.00 [¶]	125.35 ± 51.49 [‖]	172.78 ± 99.93 [§,¶]	108.57 ± 55.04 [†,‡,‖]	130.28 ± 72.21	123.42 ± 66.00	115.80 ± 42.27	142.79 ± 54.19	146.48 ± 92.03 [*]	0.038
SVi (ml/m²)	46.23 ±8.37 [¶]	45.74 ± 11.07 [¶]	44.05 ± 11.41 [‖]	51.81 ± 14.08 [§,¶]	38.05 ± 14.73 [†,‡,‖]	39.98 ± 10.60 [*,‖]	39.26 ± 9.78 [*,‖]	39.70 ± 10.19 [‖]	45.46 ± 11.21 [†,‡,§,¶]	39.32 ± 11.22 [‖]	<0.001
CI (l/min/m²)	3.42 ± 0.79 [¶]	3.27 ± 0.88 [§]	2.90 ± 0.79 [‖]	3.46 ± 1.01 [§,¶]	2.78 ± 0.92 [†,‖]	2.93 ± 0.63 [*]	2.75 ± 0.74 [*]	2.75 ± 0.95	3.09 ± 0.83	3.01 ± 0.78	0.002
SVRi (dyn.s/cm5.m²	1370.58 ± 481.41	1458.18 ± 488.64	1668.85 ± 575.99	1452.60 ± 575.84	1747.57 ± 682.19	1545.98 ± 403.85	1598.54 ± 442.74	1659.23 ± 438.85	1460.21 ± 399.43	1569.90 ± 480.99	0.052

HR, heart rate; EDV, end-diastolic volume; CTi, contractility index; SVi, stroke volume index; CI, cardiac index; SVRi, systemic vascular resistance index. Data are represented as mean ± SD.

All characteristics were tested by two-way mixed ANOVA with Bonferroni post hoc analyses. Data are represented as mean ± SD.

[*] Significant difference between normal weight and abdominal obesity in the same therapeutic body position ($p < 0.05$)

[†] Significance difference compared with Fowler's in the same group ($p < 0.05$)

[‡] Significance difference compared with right lateral in the same group ($p < 0.05$)

[§] Significance difference compared with left lateral in the same group ($p < 0.05$)

[‖] Significance difference compared with supine in the same group ($p < 0.05$)

[¶] Significance difference compared with prone in the same group ($p < 0.0$

Blood pressure (BP)

SBP, DBP, and MAP were significantly lowest in the right lateral position compared to other positions in both groups ($p < 0.05$). Furthermore, it was observed that in the prone position, SBP in the abdominal obesity group was significantly higher than in the normal weight group ($p = 0.047$). However, there were no significant differences in DBP and MAP between groups within the same position, as illustrated in Figure 29.

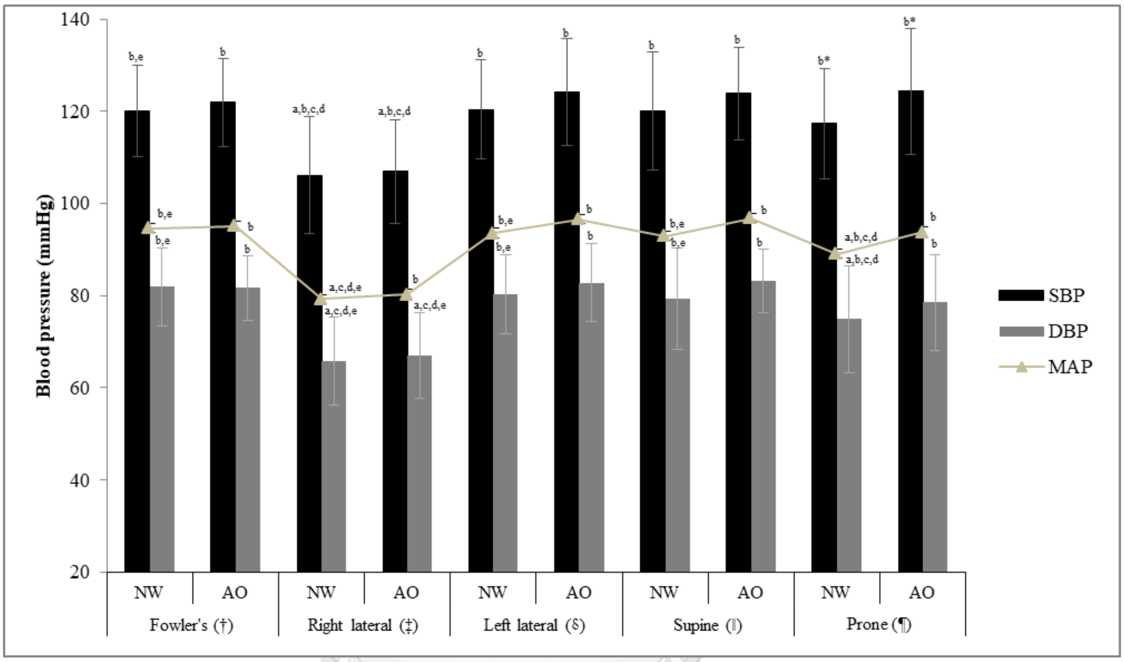

Figure 29 The influence of therapeutic body positions on BP

The data were tested by two-way mixed ANOVA with Bonferroni post hoc analyses. Data are represented as mean ± SD. NW, normal weight; AO, abdominal obesity; SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial blood pressure; *, significant difference between normal weight and abdominal obesity in the same therapeutic body position ($p < 0.05$); †, significance difference compared with Fowler's in the same group ($p < 0.05$); ‡, significance difference compared with right lateral in the same group ($p < 0.05$); §, significance difference compared with left lateral in the same group ($p < 0.05$); ‖, significance difference compared with supine in the same group ($p < 0.05$); ¶, significance difference compared with prone in the same group ($p < 0.05$).

5.4.3 Positioning comfort score

Figure 30 displays the results of the comfort scores for the different therapeutic body positions. The statistical analysis showed significant differences in comfort scores among the different positions. In both groups, the supine position was rated as the most comfortable, followed by the right lateral, left lateral, Fowler's, and prone positions (*p* < 0.01). This suggests that participants consistently rated the supine position as the most comfortable while the prone position was the least comfortable.

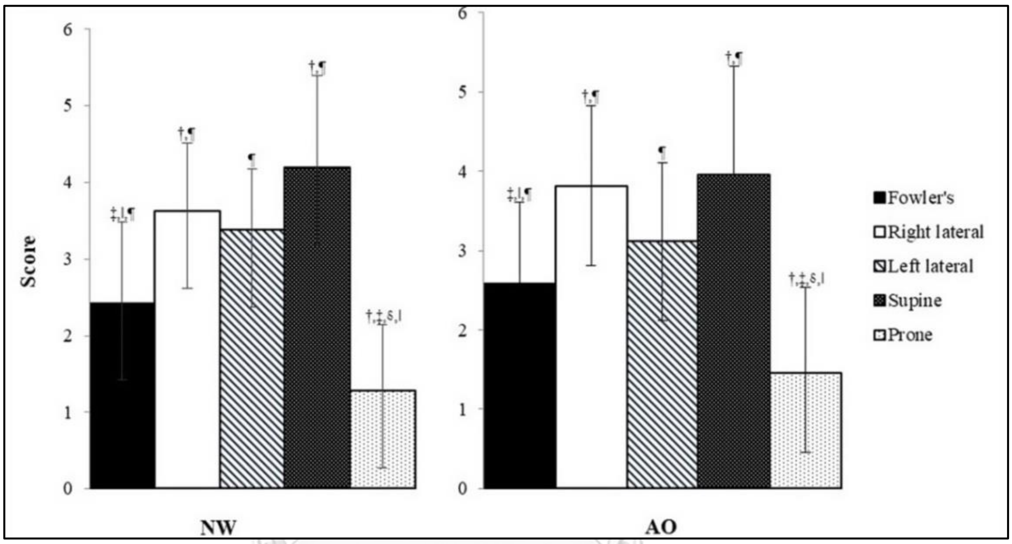

Figure 30 The positioning comfort score

The data were tested by two-way mixed ANOVA with Bonferroni post hoc analyses. Data are represented as mean ± SD. NW, normal weight; AO, abdominal obesity; † significance difference compared with Fowler's in the same group ($p < 0.01$); ‡ significance difference compared with right lateral in the same group ($p < 0.01$); § significance difference compared with left lateral in the same group ($p < 0.01$); ‖ significance difference compared with supine in the same group ($p < 0.01$); ¶ significance difference compared with prone in the same group ($p < 0.01$).

5.5 Discussion

This experimental study comprehensively compares the effects of various therapeutic body positions commonly utilized in clinical settings on hemodynamic outcomes. It also considers the differences between the normal weight group and the abdominal obesity group. The study's main findings highlight significant differences in hemodynamic outcomes attributed to the influence of therapeutic body positions. Moreover, CTi, SVi, CI, and SVRi were adjusted based on body surface area (BSA) to account for individual variations in size and determine hemodynamic performance. In comparisons among therapeutic body positions, the current results demonstrated that HR was the lowest in the left lateral position. At the same time, EDV and SVi were found to be highest in the supine position. These observations were consistent in both groups. In addition, the study revealed that in both groups, the right lateral position was associated with the lowest SBP, DBP, and MAP. When comparing the two groups, it was found that the normal weight group had higher SVI and CI than the abdominal obesity group in the Fowler's and right lateral positions. Conversely, in the prone position, the abdominal obesity group exhibited a higher CI than the normal weight group. These findings further support the study reporting that gravitational forces influence cardiovascular function. Gravitational changes in different therapeutic body positions influence systemic circulation and cardiac control through mechanical fluid shifts and autonomic effects (222). Consequently, these effects contribute to alterations in hemodynamic outcomes in both groups.

5.5.1 Effects of therapeutic body positions on hemodynamics

Heart rate (HR)

With five positions performed, HR in both groups was highest in the prone position, in agreement with previous findings comparing the supine position versus the prone position, which also reported higher HR in the prone position (186). The heart's contraction rate is normally affected by hormones and the nervous system. Prone position reduces venous flow (caused by inferior vena cava compression), inhibiting baroreflexes and subsequently increasing sympathetic nervous activity (223). HR in both groups was highest in Fowler’s position next to the prone position. Fowler's position is known to cause a gravitational redistribution of blood, leading to blood pooling in the lower body, estimated to be approximately 500-1000 ml (224). The subsequent reduction in BP decreases baroreceptor discharge. Then the signal is sent to the integrating center at the pressor and depressor areas in the medulla and compensated by baroreflex-mediated sympathetic activation and parasympathetic withdrawal. These adaptive mechanisms cause an increased HR (225). The study revealed that the left lateral position was associated with the lowest HR, consistent with a previous study reporting larger cardiac volumes in the left lateral position compared to the supine position (196). The increased cardiac volumes in the left lateral position may be attributed to enhanced venous return (226). The increased VR in this position may also modulate the atrial reflex, which further influences HR modulation.

End-diastolic volume (EDV)

This study found EDV in both normal weight and abdominal obesity groups was higher in the supine position than in other positions. This finding is consistent with a previous study that reported larger EDV and end-systolic volumes (ESV) in the supine position. The supine position, where the body and heart are aligned on the same horizontal plane, facilitates the distribution of venous blood volume and pressure throughout the body. This leads to increased VR, preload, and an elevated EDV (227).

Contractility index (CTi)

The study investigated the CTi, which represents the left ventricle's contractile function considering preload and afterload normalized by BSA. Although CTi in the abdominal obesity group showed no significant difference, CTi in the normal weight group was the highest in the supine position, consistent with the EDV data found in this study. During the supine position of the normal weight group, cardiac muscle has more ability to generate a force that is independent of any load or stretch applied. However, the data comparing hemodynamic responses in the same position between groups demonstrated that CTi in abdominal obesity was higher than in the normal weight group in the prone position. In the prone position, obese individuals may experience reduced VRdue to the pressure exerted on abdominal organs, which can impede blood flow back to the heart. In response to decreased VR, the body's compensatory mechanisms trigger sympathetic activation, crucial in regulating HR and CTi.

Stroke volume index (SVi)

SVi, the SV normalized by the BSA that indicates heart performance according to the size of the individual, was the highest in the supine position, followed by Fowler's position. Continuing from the mechanism described in the EDV section, EDV was increased in the supine position, leading to an increase in SVi because SV is equal to the difference between the left ventricular blood volume before the heart contraction, EDV, and ESV (228). Nonetheless, in the prone position, especially in abdominal obesity, there is an increase in intra-abdominal pressure. This increased pressure can compress the abdominal organs, including the inferior vena cava, leading to a reduced VR to the heart and subsequently affecting the EDV (229), leading to a decreased volume of blood pumped out of the left ventricle or a decrease in SVi. These correspond to the CTi data showing that the normal weight group was the highest in the supine position and the lowest in the prone position. SVi is determined by EDV (preload) and contractility (230). SVi in the abdominal obesity group was lower than the normal weight group in the right lateral and supine positions, consistent with CO and CI in the abdominal obesity were lower than the normal weight in the right lateral position. These contexts can describe the adverse effects of excessive adipose tissue in the abdominal cavity on the heart. In general, abdominal obesity increases adipose tissue in the abdomen called visceral fat. In the lying down position, visceral fat load on the heart and adjacent structures causes compressive vena cava, resulting in decreased SVi.

Cardiac index (CI)

CI, a hemodynamic parameter that relates the CO from the left ventricle in one minute to BSA, was the highest in the supine position and lowest in the prone position because CO is the product of SV (228). Although CI in abdominal obesity groups showed no significant difference among positions, CI tends to be the highest in the supine position. Similar to many studies, this result has been compared across the supine position versus other positions (182, 198, 199). CI in normal weight was higher than abdominal obesity in the right lateral position, consistent with the SVi mechanism contexts described previously.

Systemic vascular resistance index (SVRi)

The findings of the current study indicate that SVRi, which represents the left ventricular afterload normalized by BSA, was unaffected among therapeutic body positions because different positions do not result in changes in the factors that affect SVRi, such as vessel diameter, vessel length, and blood viscosity. This result is inconsistent with a previous study shown SVRi increases during the prone position. However, this previous study examined cardiovascular parameters over a period of nine hours (231).

Blood pressure (BP)

The decline of SBP, DBP, and MAP in both groups in the right lateral position compared to other positions occurred. The vena cava, located on the right side of the heart, was compressed when lying on the right side. This compression leads to a narrowing of the vena cava, reducing VR and subsequently decreasing CO as CO is directly related to arterial pressure, a decrease in CO results in lower SBP, DBP, and MAP. SBP in both groups was the highest in the left lateral position. High SBP is affected by the arm-measured BP, which is the left arm side being compressed in the left lateral position. According to the results, the study found SBP in abdominal obesity was higher than normal weight in the prone position due to more thorax compression, reducing LV relaxation and central arterial expansion, and then increasing SBP.

5.5.2 Effects of therapeutic body positions on comfortable score

Besides considering the patient's status, therapeutic body position plays a crucial role in promoting optimal physiological function and preventing complications in patients. It also has to take into account the comfort of patients. Hence, after completing five positions, participants rated their comfort level, revealing that the most comfortable position in both groups was the supine position, followed by the right lateral, left lateral, Fowler’s, and prone positions. The preference for the supine position as the most comfortable might be attributed to the minimal activation of muscles in this position. In contrast, the prone position resulted in compression of the thorax and abdomen, leading to discomfort and lower comfort scores.

5.6 Conclusion

In conclusion, even though the hemodynamic variables measured in all positions were normal range, the results unequivocally demonstrated that there are differences in hemodynamic responses during therapeutic body positions within and between groups of adults with and without abdominal obesity. It has been determined that the most effective position for enhancing blood distribution in both groups is the supine position compared to right lateral, left lateral, and prone positions. When focusing on optimizing BP, the right lateral position stands out as the preferred option compared to other positions. Conversely, the prone position should be avoided in cardiovascular patients, particularly those with abdominal obesity, as it appears to have an adverse effect on hemodynamics.

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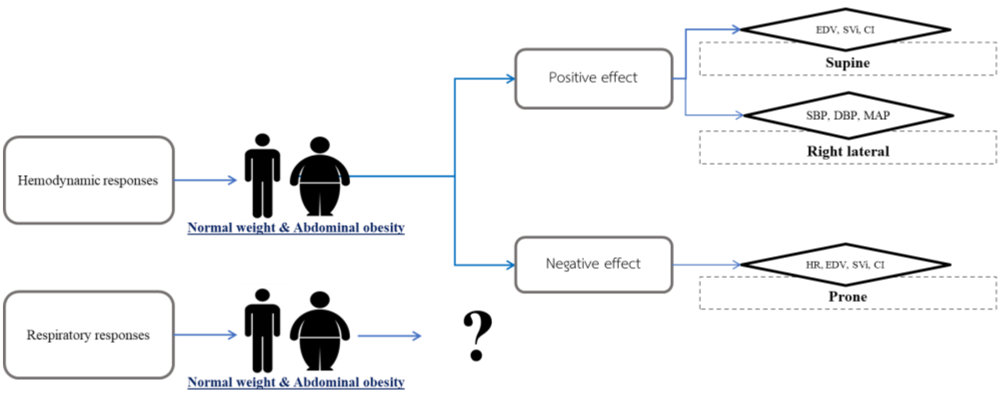
Summary

Therapeutic body position significantly affects changes in blood flow dynamics in individuals of both normal weight and those with abdominal obesity. Indeed, the summary highlights the recommended positions that can be beneficial and should be utilized for improving blood flow dynamics. It also underscores the postures that should be avoided due to their potential negative impact on hemodynamics. This study primarily concentrated on hemodynamic responses, which are crucial for supporting gas exchange. However, it's worth noting that respiratory responses are equally essential for gas exchange and warrant further investigation.



CHAPTER 6 Study 3 - Respiratory responses during therapeutic body positions in adults with and without abdominal obesity

Objective:

To compare respiratory responses during therapeutic body positions within and between groups of adults with and without abdominal obesity

Paper 3: Respiratory responses during therapeutic body positions assessed by Metabolic Stress Testing System (MGC, Ultima CPX ™) in adults with and without abdominal obesity

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6.1 Abstract

Background: Visceral adiposity has been associated with lung compliance and air passage disturbances, increasing the risk of respiratory disorders. Utilizing body positioning is a common approach for these patients. Nevertheless, it is unclear how different body positions impact the respiratory functions of individuals with abdominal obesity. This research examined respiratory responses during therapeutic body positions in obese and non-obese individuals.

Methods: A total of 52 males, including 26 individuals with normal weight and 26 with abdominal obesity, aged between 30 and 59 years, underwent five positions: Fowler's, right lateral, left lateral, supine, and prone positions.

Results: Ventilation: Tidal volume and minute ventilation were the highest during prone position in both groups ($p < 0.01$). Oxygenation: Oxygen consumption, carbon dioxide production, partial pressure of carbon dioxide estimation, and end-tidal carbon dioxide tension were also the highest in prone position in both groups ($p < 0.001$). Additionally, oxygen consumption and carbon dioxide production were higher in the abdominal obesity group compared to the normal weight group during prone position ($p = 0.016$, $p = 0.049$, respectively). Metabolic equivalent: It was the highest in prone position in both groups ($p < 0.01$). However, the abdominal obesity group exhibited lower metabolic equivalent than the normal weight group during right lateral, left lateral, and supine positions (p <0.010, p = 039, p = 0.013, respectively).

Conclusions: In both groups, prone position was the most effective for enhancing ventilation and oxygenation.

Keywords: Respiratory response, Body position, Ventilation, Oxygenation, Metabolic equivalent, Body mass index

6.2 Introduction

Abdominal obesity, also termed central or visceral obesity, refers to an excessive concentration of fat deposits in the mediastinum and the abdominal cavities to such an extent that it is likely to cause numerous complications. Abdominal obesity has been strongly linked to chronic respiratory illnesses that have impaired respiratory function (232) and is associated with morbidity and mortality (233). Many abdominal-obese patients suffer from respiratory symptoms and disease. The overall impact of abdominal obesity on respiratory function is multifactorial and related to mechanical and inflammatory aspects of obesity (234). Clinical studies have reported that obesity is associated with poor respiratory function (235). Excess fat is associated with reduced compliance of the lungs and chest wall movement (21, 236, 237, 238). It is likely to significantly affect airway narrowing and closure, leading to gas trapping and lung inhomogeneity (239). The impact of these factors can result in modifications to ventilation, oxygenation, and related variables. These variables are crucial physiological indicators for assessing potential health risks and are commonly employed in predicting respiratory disorders.

Several studies have demonstrated that therapeutic body positions commonly used in clinical settings, including supine, side lying (right, left), prone, and upright (Fowler's, sitting), can impact ventilation and oxygenation. Upright position was typically associated with an increase in V_T (202), which is consistent with another study reporting that sitting position augments V_A (198). The higher V_A in the sitting position was mainly performed by higher V_T which may counteract the effects of increased physiological dead space (240, 241). Lung perfusion is shown to be more uniformly distributed in the prone position than the supine one (242). This is due to the increased perfusion per alveolus in non-dependent lung regions in the prone position compared to the supine position. Oxygen consumption increased in the upright position (196, 243). This is due to the upright position resulting in increased energy expenditure (19). Additionally, the supine position was associated with significantly greater total respiratory resistance than the upright positions (head-up tilt, sitting, standing). When the body position is changed from upright to supine, functional residual capacity (FRC) is reduced, promoting airway closure in dependent lung regions because FRC is physiologically influential and keeps the small airways open (207).

Owing to previous studies, the data demonstrated that some therapeutic body positions have a supportive effect on the functioning of organ systems, and some have undesirable responses. Respiratory response consideration during different therapeutic body positions is necessary data for consideration in clinical care management. However, the conclusions drawn from previous studies have limitations as they have primarily focused on healthy individuals. Additionally, these studies have yet to cover all therapeutic body positions or have small sample sizes. It is also unclear whether a respiratory response to the alteration of therapeutic body positions is specifically observed in the context of abdominal obesity. To address some of these limitations, we examined the influence of therapeutic body positions on R_f, V_T, V_E, SaO_2, FiO_2, VO_2, and other related variables in individuals with and without abdominal obesity.

6.3 Materials and Methods

6.3.1 Experimental study and ethical considerations

This cross-sectional study was conducted at the laboratory of the Department of Physical Therapy, Faculty of Allied Health Science, Chulalongkorn University in Bangkok, Thailand. The protocol was approved by the Research Ethics Review Committee for Research Involving Human Research Participants, Group I, Chulalongkorn University (RECCU) (certificate of approval number: 186/2021). All participants provided written, informed consent before participating.

6.3.2 Participants

Ten males were enrolled in the pilot study, five of whom were normal weight and five had abdominal obesity, to calculate effect size estimates for the effects of obesity on respiration (effect size = 0.40). Fifty-two participants would be required to achieve sufficient power (80%) to identify differences between groups. The inclusion criteria were males aged 18 to 59 years old, normal weight group; BMI 18.5-22.9 Kg/m^2, WC < 90 cm, WHR ≤ 0.95 and abdominal obesity group; BMI ≥ 25 Kg/m_2, WC ≥ 90 cm, WHR > 0.95 (1, 32, 33, 176, 218). All participants had overall physical activity in the sedentary range (based on an average Baecke questionnaire score of < 6) (177), HR 60-100 beats/min, SBP < 140 mmHg, diastolic blood pressure (DBP) < 90 mmHg, respiratory frequency (R_f) 12-20 breaths/min, and oxygen saturation (SaO_2) 95-100%. Key exclusion criteria were cardiovascular, respiratory, renal, endocrine, and neurological disorders, treatment with medications that affect respiratory functions, smoking, drinking, abnormal chest shapes and/or postoperative chest wounds.

6.3.3 Research procedure

The experiments were performed in a climate-controlled laboratory at an ambient temperature of 25 °C. Participants were instructed to refrain from consuming heavy meals for 4 hours and avoid caffeine for 12 hours before the experiment. All subjects underwent participant screening, baseline assessments, and respiration measurements. The process of the research procedure is shown in Figure 31.

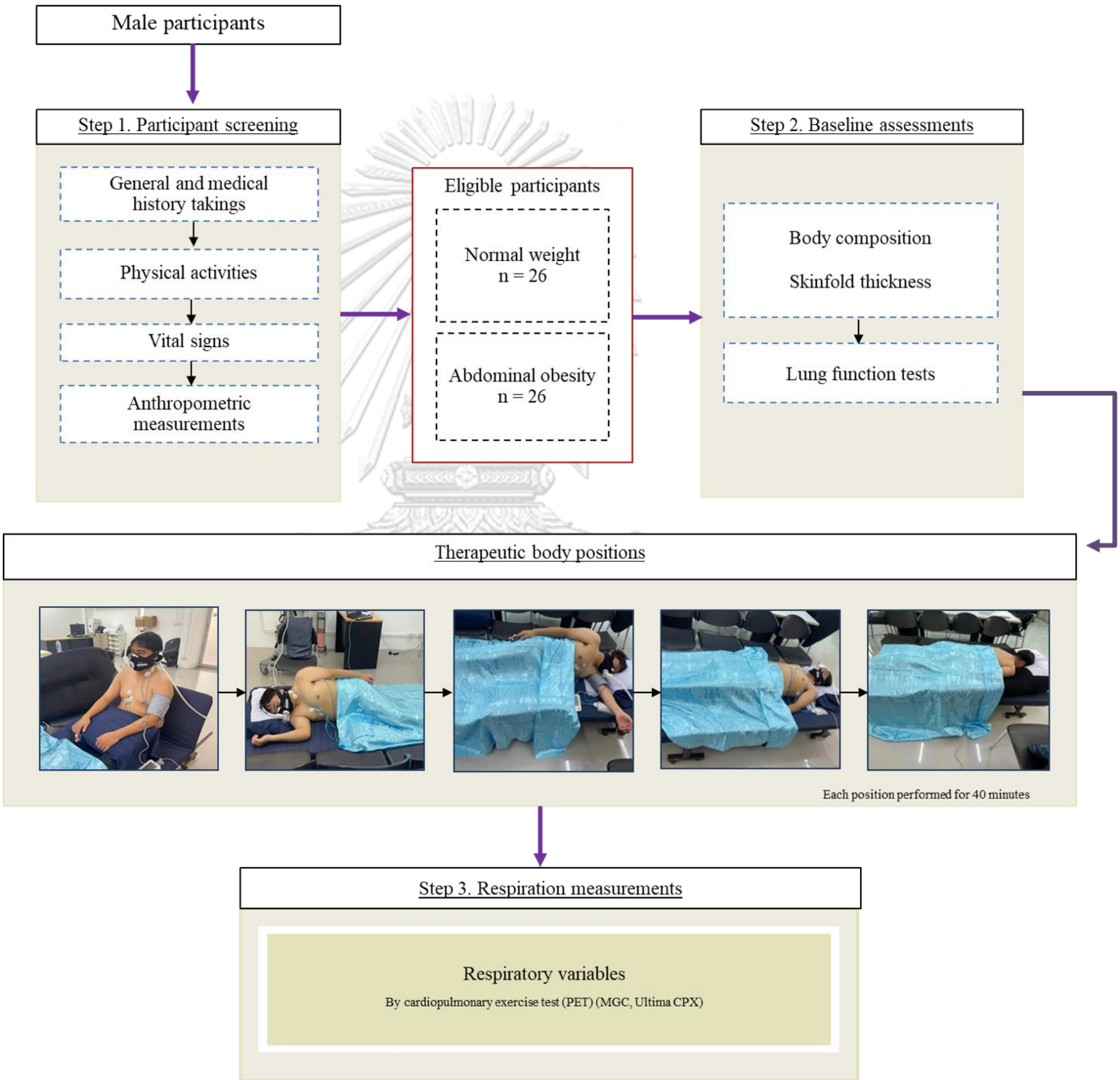

Figure 31 Research procedure

Participant screening

The screening process started with four assessments. First, an evaluation of general and medical histories was conducted using a questionnaire. Second, the overall physical activity questionnaire was assessed by Baecke questionnaire (177). Third, vital signs were obtained after a 10-minute rest or when vital signs were stable. HR, SBP, and DBP were assessed at the left arm (brachial artery) by an autonomic digital BP monitor (Yuwell, YE670D); R_f was assessed by counting the number of breaths taken over one minute; and SaO_2 was obtained from the fingertip by using a pulse oximeter (ChoiceMMedTM, MD300C1). Fourth, the anthropometric measurements used to ascertain normal weight and abdominal obesity encompassed weight, gauged with a stadiometer, and height, determined by measuring the distance from the floor to the vertex employing a height indicator tape. These measurements were then used to calculate the BMI using the formula weight (kg)/height $(m)^2$ (232). Additionally, WC and hip circumference (HC) were measured using a tape to calculate the WHR (31).

Baseline assessments

After the screening period, participants were assessed for baseline characteristics, including body composition, using bioelectric impedance analysis (BIA) (Karada scan: OMRON, Model HBF-375) based on the rate at which an electrical current travels through the body, measured skinfold thickness, using a digital outside skinfold caliper (Digital Caliper Gauge, EDC-A1150). Skinfold thickness was measured three times to determine an average at five sites in standing position, including 1) Chest, a diagonal fold halfway between the top of the axillary and the nipple. 2) Mid-axillary, where a vertical line from the mid-axilla intersects with a horizontal line level with the bottom edge of the xiphoid process. 3) Subscapular, which is 2 cm below the inferior angle of the scapular. 4) Suprailiac is the point above the iliac crest in the mid-axillary line. 5) Abdomen, which is 5 cm to the right of the umbilicus. After that, all eligible participants were measured for lung function. The test was done sitting using spirometry (MGC, Ultima CPX™). The participants sat on a chair and put on a mouthpiece and nose clip. They were asked to breathe five times at V_T, take maximal inspiration, and then forcefully expel air for as long and quickly as possible.

Respiratory measurements

The respiratory responses were recorded by the Metabolic Stress Testing System (MGC, Ultima CPX ™) for one minute after forty minutes in each position, and the average of the data was counted. During each position, participants were assessed on the system using a breath-by-breath analysis, which CPET calibrated before the test. For one minute, SaO_2 was obtained using a pulse oximeter (ChoiceMedTM, MD300C1). All respiratory variables are demonstrated in the following:

- Respiratory frequency (R_f) represents the number of breaths within one minute.
- Tidal volume (V_T) represents the average volume of air inhaled into or exhaled with each breath during normal breathing.
- Minute ventilation (V_E) represents the volume of air inhaled into or exhaled from the lungs within one minute.
- The fraction of inspired oxygen (FiO_2) represents the oxygen concentration in the inspired air.
- Oxygen saturation (SaO_2) represents the percentage of oxygenated hemoglobin.
- The partial pressure of oxygen estimation (PaO_2est) represents the estimated oxygen pressure in arterial blood, calculated by multiplying the fractional concentration (or proportion) of oxygen by the total pressure of the gas mixture.
- The partial pressure of carbon dioxide estimation ($PaCO_2$est) represents the estimated carbon dioxide pressure in arterial blood, calculated by multiplying the fractional concentration (or proportion) of carbon dioxide by the total pressure of the gas mixture.
- End-tidal oxygen tension ($PETO_2$) represents the oxygen concentration at the end of an exhaled breath, reflecting the oxygen concentration in the alveolar space.
- End-tidal carbon dioxide tension ($PETCO_2$) represents the carbon dioxide concentration at the end of an exhaled breath, reflecting the carbon dioxide concentration in the alveolar space.
- Oxygen consumption (VO_2) represents the rate at which the body can absorb oxygen for aerobic metabolism.
- Carbon dioxide production (VCO_2) represents the volume of carbon dioxide produced by a product of the working muscles and cellular metabolism.

- The ventilatory equivalent for oxygen (V_E/VO_2) represents the ratio of the volume of air exhaled per minute to the volume of oxygen consumed per minute, reflecting ventilatory efficiency.
- The ventilatory equivalent for carbon dioxide (V_E/VCO_2), represents the ratio of air exhaled per minute to the volume of carbon dioxide produced per minute, reflecting ventilatory efficiency.
- The respiratory quotient (RQ) represents the relationship between the amount of carbon dioxide produced and the amount of oxygen consumed (VCO_2/VO_2), which reflects cellular gas exchange.
- Metabolic Equivalent (MET) represents the metabolic cost of work, relating work to rest, with a resting level of 1 MET equivalent to 3.5 ml/kg/min of VO_2.

Experimental protocol

All participants underwent five conditions, each lasting 40 minutes. The five experimental conditions were:

- Fowler's: sitting on the bed with backrest at 90° trunk inclination, hips

flex at 90° with slightly abducted and straight knees

- Right lateral: lying on the right side, straight right leg, left leg placed on a pillow
- Left lateral: lying on the left side, straight left leg, right leg placed on a pillow
- Supine: lying on the back, head and neck kept in neutral, with support of a pillow, hips and knees slightly flexed, with support of a pillow
- Prone: lying on the abdomen, head and neck kept in the neutral position, with support of a U-shaped pillow

The five experimental conditions were performed on the same days, and the sequence of conditions progressed from the position exerting the least pressure on the chest to the one exerting the most pressure. This sequence began with the Fowler's position, followed by the supine, right lateral, left lateral, and prone positions. Following each 40-minute session of a specific condition (allowing time for the influence of the preceding condition to dissipate), respiratory variables were measured for one minute.

6.3.4 Analyses and statistics

All statistics were done using statistical software 22.0 (Chicago, IL, USA). The means and standard deviations of all relevant variables were computed. The normal distribution of all variables was tested with the Komokorov-Sminov test. An independent sample t-test was used to compare the baseline characteristics of the normal weight and abdominal obesity groups. A two-way mixed ANOVA with the Bonferroni post hoc test was used to compare the differences between normal weight and abdominal obesity groups, considering different body positions. Differences were considered to be significant at $p < 0.05$.

6.4 Results

6.4.1 Participant characteristics

Table 11 shows the baseline characteristics of the participants, categorized into normal weight and abdominal obesity groups. A total of 52 males between 18 and 59 years of age were included in the study. The mean age for normal weight and abdominal obesity was 41.96 ± 8.55 years and 41.31 ± 7.44 years, respectively. The abdominal obesity group exhibited notably higher values in body weight, BMI, WC, HC, and WHR than the normal weight group ($p < 0.001$). Moreover, the abdominal obesity group demonstrated substantially elevated body fat, visceral fat, subcutaneous fat, and skinfold thickness across all measured sites compared to the normal weight group ($p < 0.001$). These results underscore the pronounced distinctions in various anthropometric and adiposity measures between the two groups, emphasizing the impact of abdominal obesity on the studied variables.

Table 11 Participant characteristics

characteristics	Mean ± SD		*p* - value
	Normal weight (N = 26)	Abdominal obesity (N = 26)	
Age (y)	41.96 ± 8.55	41.31 ± 7.44	0.385
Body weight (kg)	63.03 ± 6.64	80.02 ± 9.20	<0.001*
Height	169.33 ± 7.26	168.73 ± 6.54	0.379
BMI (kg/m^2)	21.95 ± 1.29	28.07 ± 2.44	<0.001*
WC	83.98 ± 4.78	97.91 ± 5.42	<0.001*
HC	95.65 ± 4.85	100.69 ± 4.58	<0.001*
WHR	0.88 ± 0.05	0.97 ± 0.03	<0.001*
Physical activity	5.50 ± 0.42	5.38 ± 0.49	0.394
HR (bpm)	72.35 ± 10.45	75.38 ± 8.97	0.133
SBP (mmHg)	121.81 ± 10.32	125.58 ± 10.18	0.096
DBP (mmHg)	82.08 ± 9.02	82.85 ± 7.35	0.369
MAP (mmHg)	95.32 ± 8.66	97.09 ± 7.70	0.220
R_f (bpm)	14.46 ± 3.40	15.46 ± 2.83	0.127
SaO_2 (%)	98.00 ± 0.69	97.92 ± 0.89	0.905
Body compositions			
Body fat (%)	22.05 ± 4.22	27.35 ± 3.55	< 0.001*
Visceral fat (%)	7.69 ± 3.07	13.48 ± 2.67	< 0.001*
Subcutaneous fat (%)	15.97 ± 4.19	19.98 ± 3.81	< 0.001*
Skinfold thickness			
Chest (mm)	10.49 ± 4.21	17.38 ± 6.55	< 0.001*
Mid axillary (mm)	8.65 ± 3.64	16.97 ± 7.87	< 0.001*
Subscapular (mm)	13.67 ± 5.00	25.38 ± 7.72	< 0.001*
Suprailiac (mm)	16.28 ± 6.58	23.85 ± 7.81	< 0.001*
Abdomen (mm)	16.71 ± 5.82	27.56 ± 7.43	< 0.001*
Sum skinfold thickness (mm)	65.80 ± 20.96	111.14 ± 30.37	< 0.001*
Lung functions			
V_T (ml)	503.85 ± 162.78	490.46 ± 96.50	0.869
SVC (L)	3.58 ± 0.84	3.83 ± 1.17	0.194
ERV (L)	1.03 ± 0.32	1.14 ± 0.68	0.212
IRV (ml)	2.08 ± 0.64	2.24 ± 0.77	0.208
IC (L)	2.58 ± 0.62	2.73 ± 0.74	0.222
VC (ml)	3.61 ± 0.83	3.87 ± 1.19	0.177
FVC (L)	4.05 ± 0.63	3.78 ± 0.65	0.197
FEV_1 (L)	3.40 ± 0.55	3.14 ± 0.58	0.051

FEV_1/FVC	84.00 ± 4.66	83.04 ± 5.81	0.257
FEF 25-75% (l/s)	3.58 ± 1.10	3.43 ± 0.93	0.294
FEF max (l/s)	6.49 ± 2.14	6.05 ± 2.04	0.228

BMI, body mass index; WC, waist circumference; HC, hip circumference; WHR, waist to hip ratio; HR, heart rate; SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure; R_f, respiratory frequency; SaO_2, peripheral oxygen saturation; V_T, tidal volume; SVC, slow vital capacity; ERV, expiratory reserve volume; IRV, inspiratory reserve volume; IC, inspiratory capacity; VC, vital capacity; FVC, force vital capacity; FEV_1, force expiratory volume in 1 second; FEV1/FVC, force expiratory volume in 1 second per force vital capacity; FEF 25-75%, forced expiratory flow between 25% and 75% of vital capacity; FEF max, maximum forced expiratory flow. Data are represented as mean ± SD. All characteristics were tested by independent samples t-test. * represents $p < 0.001$ (significance of the difference between normal weight and abdominal obesity group.

6.4.2 The influence of therapeutic body position on respiratory responses

Ventilation

As illustrated in Figure 32, the ventilatory responses indicate no significant differences in R_f in both normal weight and abdominal obesity groups. Nevertheless, V_T, and V_E were significantly highest during the prone position in both groups ($p < 0.01$). Conversely, FiO_2 was significantly lowest in the prone position, while it reached its highest levels in the supine position, with these results being consistent across both groups ($p < 0.01$). However, no significant differences were observed between groups within the same therapeutic body position regarding R_f, V_T, V_E, and FiO_2.

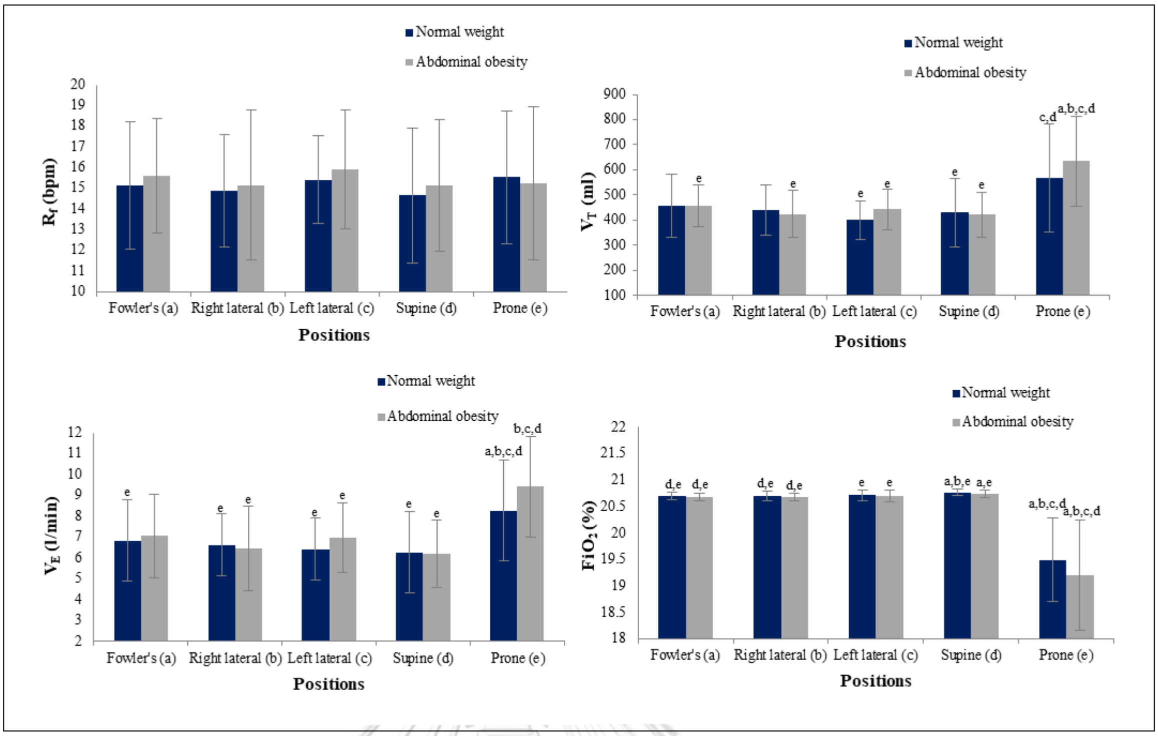

Figure 32 The influence of therapeutic body positions on ventilation

The data were tested by two-way mixed ANOVA with Bonferroni post hoc analyses. Data are represented as mean ± SD. R_f, respiratory frequency; V_T, tidal volume; V_E, minute ventilation; FiO_2, fraction of inspired oxygen; a, significance difference compared with Fowler's in the same group ($p < 0.05$); b, significance difference compared with right lateral in the same group ($p < 0.05$); c, significance difference compared with left lateral in the same group ($p < 0.05$); d, significance difference compared with supine in the same group ($p < 0.05$); e, significance difference compared with prone in the same group ($p < 0.05$).

Oxygenation

In Figure 33, it is evident that VO_2, VCO_2, $PaCO_2$est, and $PETCO_2$ were significantly highest in the prone position for both the normal weight and abdominal obesity groups ($p < 0.001$), while PaO_2est and $PETO_2$ were significantly lowest in the prone position for both groups. The results indicate that SaO_2, V_E/VO_2, V_E/VCO_2, and RQ showed no significant differences among the therapeutic body positions in both groups.

Notable differences were observed in the data between the normal weight and abdominal obesity groups within the same therapeutic body position. The result showed VO_2 and VCO_2 were significantly higher in the abdominal obesity group compared to the normal weight group during the prone position ($p = 0.016$, $p = 0.049$, respectively). Furthermore, V_E/VO_2 exhibited significant reductions in the abdominal obesity group as compared to the normal weight group in Fowler's and supine positions ($p = 0.046$ and $p = 0.016$, respectively). Likewise, V_E/VCO_2 also showed significant decreases in the abdominal obesity group in the Fowler's, supine, and left lateral positions compared to the normal weight group ($p = 0.035$, $p = 0.046$, $p = 0.013$, respectively). SaO_2 was significantly lower in the abdominal obesity group than the normal weight group during Fowler’s, right lateral, and supine positions ($p = 0.035$, 0.021, 0.041, respectively). However, no noteworthy variations were observed in PaO_2est, $PETO_2$, $PaCO_2$est, $PETCO_2$, and RQ between groups within the same position.

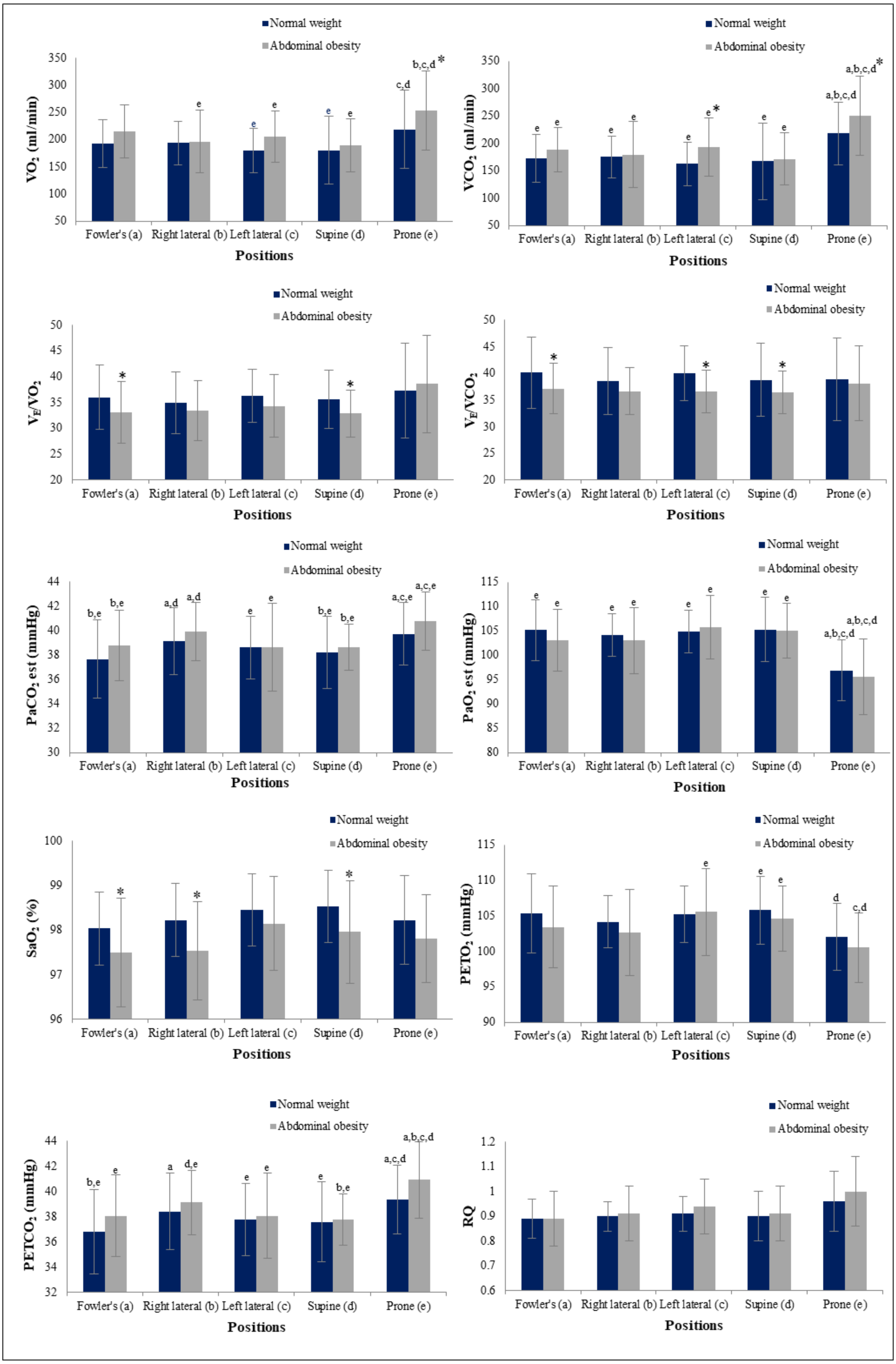
Normal weight
Abdominal obesity
VO2 (ml/min)
Fowler's (a)
Right lateral (b)
Left lateral (c)
Supine (d)
Prone (e)
Positions
VCO2 (ml/min)
VE/VO2
VE/VCO2
PaCO2 est (mmHg)
PaO2 est (mmHg)
Position
SaO2 (%)
PETO2 (mmHg)
PETCO2 (mmHg)
RQ

Figure 33 The influence of therapeutic body positions on oxygenation

The data were tested by two-way mixed ANOVA with Bonferroni post hoc analyses. Data are represented as mean ± SD. SaO_2 , oxygen saturation; PaO_2est, partial pressure of oxygen estimation; $PaCO_2$est, partial pressure of carbon dioxide estimation; $PETO_2$, end-tidal oxygen tension; $PETCO_2$, end-tidal carbon dioxide tension VO_2, oxygen consumption; VCO_2, carbon dioxide production; V_E/VO_2, ventilator equivalent for oxygen; V_E/VCO_2, ventilatory equivalent for carbon dioxide; RQ, respiratory quotient; *, significant difference between normal weight and abdominal obesity in the same therapeutic body position ($p < 0.05$); a, significance difference compared with Fowler's in the same group ($p < 0.05$); b, significance difference compared with right lateral in the same group ($p < 0.05$); c, significance difference compared with left lateral in the same group ($p < 0.05$); d, significance difference compared with supine in the same group ($p < 0.05$); e, significance difference compared with prone in the same group ($p < 0.05$).

Metabolic equivalent (MET)

As expected, the therapeutic body positions induced alterations in MET, as demonstrated in Figure 34. The findings clearly indicated that MET were significantly highest in the prone position and tended to be lowest in the supine position for both normal weight and abdominal obesity groups (p < 0.01). When comparing between groups, it was observed that the abdominal obesity group exhibited significantly lower MET than the normal weight group during the right lateral, left lateral, and supine positions (p <0.010, p = 0.039, p = 0.013, respectively).

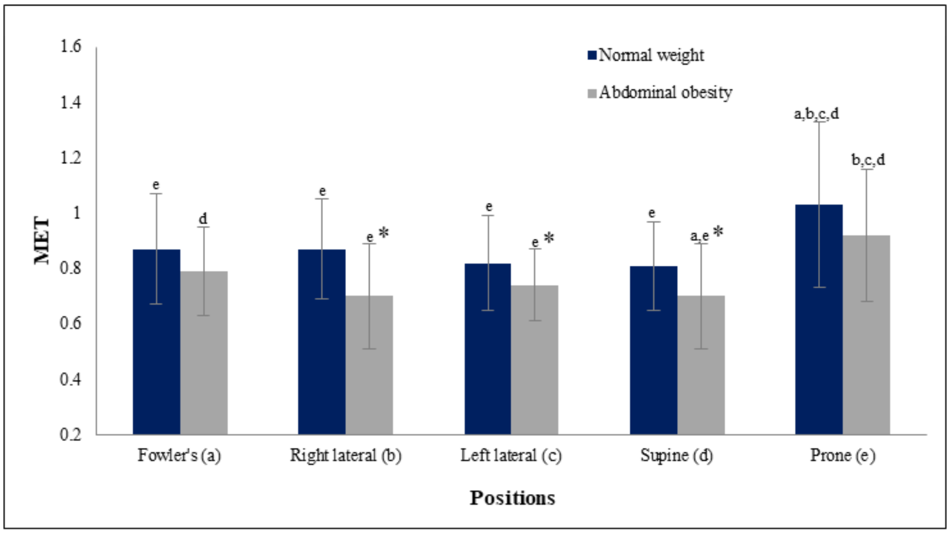

Figure 34 The influence of therapeutic body positions on aerobic energy and MET

The data were tested by two-way mixed ANOVA with Bonferroni post hoc analyses. Data are represented as mean ± SD. MET, Metabolic equivalent. *, significant difference between normal weight and abdominal obesity in the same therapeutic body position; a, significance difference compared with Fowler's in the same group; b, significance difference compared with right lateral in the same group; c, significance difference compared with left lateral in the same group; d, significance difference compared with supine in the same group; e, significance difference compared with prone in the same group.

6.5 Discussion

The primary objective of this study was to conduct comprehensive measurements of respiratory responses during therapeutic body positions using the Metabolic Stress Testing System (Ultima CPX™). The main findings from this investigation revealed noteworthy variables. Notably, the prone position displayed the highest values for variables such as V_T, V_E, VO_2, VCO_2, $PaCO_2$, $PETCO_2$, and MET in normal weight and abdominal obesity groups. Conversely, the prone position exhibited the lowest FiO_2, PaO_2est, and $PETO_2$ levels in both groups. In the comparative analysis between groups, the abdominal obesity group exhibited lower SaO_2, V_E/VO_2, and V_E/VCO_2 levels in the Fowler's, side-lying (both right and left lateral), and supine positions compared to the normal weight group. In contrast, the abdominal obesity group demonstrated higher values for VO_2 and VCO_2 compared to the normal-weight group when placed in the prone position. When considering MET values, the abdominal obesity group exhibited lower values than the normal weight group in the right lateral, left lateral, and supine positions. These findings provide further substantiation for previous research, which indicated that gravitational effects on the lungs and adjacent structures can significantly influence the mechanical and functional aspects of the respiratory system (244).

Ventilation

While therapeutic body positioning did not yield statistically significant impacts on R_f, it is notable that the prone position consistently demonstrated higher values for V_T and V_E compared to other positions in both normal weight and abdominal obesity groups. This observation suggests a plausible mechanism where prone positioning may contribute to increased lung volume and improved alveolar recruitment (245). Placing an individual in a prone position led to increased expansion of the posterior portion of the lungs (more alveoli), contributing to overall improved lung function (246). These alterations contributed to an increased volume of air being inhaled or exhaled from the lungs, consequently resulting in elevated values for both V_T and V_E. Furthermore, when considering the data, even though there were no statistically significant differences, the data indicated that Fowler's position had the second-highest V_T and V_E values in both groups, following the prone position. The elevated ventilation observed in the prone position aligns with the low levels of FiO_2 recorded in this study for both groups. Our findings are in harmony with earlier research, illustrating that variation in V_T impacts the measured oxygen concentration. This suggests that as V_T increases, oxygen concentration becomes diluted (247), resulting in decreased FiO_2 levels. The mentioned mechanism operates in the opposite direction when an individual is supine.

Ventilation exhibited no significant differences between the groups, likely because both groups had the same level of lung functions. In the case of the abdominal obesity group, the average BMI in the Asia-Pacific classification was categorized as obesity class l (BMI: 25-29.9) (1, 248, 249), and all obese participants had no underlying medical conditions, especially respiratory diseases. It is reasonable to assume that their ventilation values do not significantly deviate from those of the normal weight group.

Oxygenation

The rise in VO_2, VCO_2, $PaCO_2est$, and $PETCO_2$ observed during the prone position in both normal weight and abdominal obesity groups can be elucidated through a physiological mechanism. The prone position imposes pressure on the thoracic region, restricting chest wall expansion during breathing (250). This restriction necessitates increased effort by the respiratory muscles and a heightened demand for oxygen within the respiratory muscle cells. Furthermore, assuming the prone position also triggers heightened overall muscular activity. These factors collectively contribute to elevated levels of VO_2 (251), which is broken down and converted into energy. Simultaneously, this process produces a higher VCO_2 in the muscles, leading to elevated $PaCO_2$ and $PETCO_2$ levels (170). The study's findings revealed that the prone position reduced PaO_2est and low $PETO_2$ levels, primarily because of the low FiO_2 values. Consequently, the measured PaO_2 and $PETO_2$ values were also diminished. Based on the findings, notwithstanding the lack of statistically significant differences, it is apparent that the right lateral position demonstrated effectiveness in improving oxygenation following the prone position, as indicated by the second-highest levels of $PaCO_2$ and $PETCO_2$, along with the second-lowest levels of PaO_2 and $PETO_2$. These can be attributed to the gravitational force's influence in the right lateral position, where the force acting on blood volume is aligned in a beneficial manner for blood circulation. Moreover, placing on the right lateral position also alleviates pressure of the heart on the lung parenchyma, resulting in increased pulmonary circulation.

Our results revealed that individuals with abdominal obesity demonstrated decreased V_E/VO_2 and V_E/VCO_2 levels compared to those with normal weight in Fowler's and lying down positions (supine and left lateral). In these positions, excess fat can shift and pressure the lung parenchyma, resulting in the closure of lung units during regular breathing (252). Consequently, this diminishes lung capacities and potentially leads to decreased ventilation in individuals with abdominal obesity. This finding aligns with the low SaO_2 values detected in these positions. The diminished ventilation reduces arterial blood's oxygen content, leading to a lower amount of oxygen binding to hemoglobin. In addition, the individuals with abdominal obesity had higher levels of both VO_2 and VCO_2 compared to the normal weight group. It can indicate that weight gain in abdominal obesity was a high load on skeletal muscle, leading to increased muscular effort or activity. VO_2 and VCO_2 in obese people are, therefore, higher than those of normal weight.

Metabolic equivalent (MET)

The congruity of our results with the MET values is evident, as the prone position exhibited the highest MET value while the supine position demonstrated the lowest. This contrast indicates reduced muscle activation in the supine position. Furthermore, the prone position could entail heightened respiratory effort, potentially leading to increased energy expenditure due to the amplified force necessary for breathing. Additionally, the weight gain in the obesity group results in increased muscular exertion required for the prone position.

In the right lateral, left lateral, and supine positions, the abdominal obesity group showed lower MET values than the normal weight group. Obesity is now recognized as a chronic low-grade, systemic inflammatory state predisposing to other chronic conditions contributing to metabolic disturbances (253).

6.6 Conclusion

In our investigation of respiratory responses during therapeutic body positions, we observed significant variations in certain physiological values within and between groups. The results reveal that the prone position was the most effective for enhancing ventilation and improving oxygenation compared to other positions. However, this study found that the prone position demands the highest energy expenditure.

Acknowledgements

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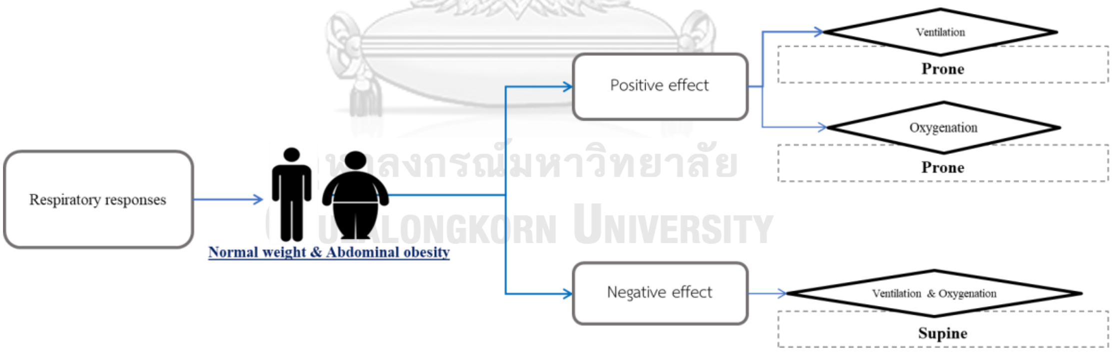
Summary

Certainly, when individuals of normal weight and those with abdominal obesity adjust their therapeutic body positions, it prompts respiratory responses. These observed changes are likely a consequence of gravitational forces acting on organ structures, such as the chest wall, lungs, and are linked to the physiological functions necessary for oxygen transport.



CHAPTER 7 Conclusions

7.1 Summary of the results

This research unequivocally indicates that when individuals adopt different body positions as part of therapeutic interventions or medical treatments, it can lead to a wide range of effects on how their circulatory and respiratory systems react. This underscores the importance of taking into account body position when making healthcare decisions and planning treatments for such individuals. This importance is underscored by the evidence, which illustrates both positive and negative responses in terms of hemodynamics and respiration. In light of the findings from this study on healthy individuals, it becomes evident that the supine position has the most favorable impact on hemodynamic parameters. In the context of respiration, the upright positions, specifically at 70 degrees head-up tilt (HUT) and standing positions, appear to exert the most beneficial influence on respiratory variables. When examining the impact of therapeutic body positions on individuals with abdominal obesity compared to those with a normal weight, it becomes evident that these positions have a significant influence on hemodynamic changes in both groups. The research has established that the most effective posture for improving blood distribution in both groups is the supine position, followed by Fowler's position. When the goal is to optimize BP, the right lateral position emerges as the preferred choice. In contrast, the prone position should be avoided in individuals with cardiovascular issues, especially those with abdominal obesity, as it seems to have a detrimental effect on hemodynamics. Conversely, in our investigation of respiratory responses, the results of our study indicate that the prone position stands out as the most effective in enhancing ventilation and improving oxygenation, with Fowler's position following closely behind in terms of its positive impact on ventilation. On the other hand, the right lateral position ranks second when considering its effect on oxygenation. However, it's worth noting that the prone position also comes with a drawback, as it demands the highest energy expenditure, while the supine position requires the least energy for individuals in these positions. It became evident that therapeutic body positions have a notable influence on hemodynamics and respiratory function in both groups, primarily due to the gravitational forces affecting anatomical structures.

7.2 Limitations of the study and suggestions for further study

7.2.1 Study 1 (Chapter 3)

The study has four main limitations. First, only full English texts were included in this study. Due to language barriers, there may not be as much relevant research published in other languages, which could have an impact on the study's findings. Second, all of the included studies were experimental designs. There were no randomized controlled trials (RCTs). RCTs minimize bias and maximize data reliability, which would be beneficial for identifying the causal effects of body positions on hemodynamics and respiration. Third, there are a limited number of studies. Moreover, some of the variables were only assessed in one study. These limitations undermine the quality of evidence. Thus, such findings should be interpreted with care and could require more assessment to elevate the quality of the evidence and clarify the findings.

7.2.2 Study 2 and 3 (Chapter 4 and 5)

There are some limitations in these studies. First, all blood pressure measurements are conducted on the left arm. Consequently, in the left lateral position, the ascertained blood pressure values may not be solely influenced by the position; the effects of compression should also be considered. Therefore, the interpretation of blood pressure in this position should be done with caution. Second, all participants in our study were adult males, but therapeutic body positions were used for patients of all ages and genders. Differentiation in these characteristics may result in different responses. It is imperative to extend the analysis of therapeutic body positions to encompass diverse recipients, including females, children, and elderly individuals confined to bed or with fragility and those grappling with respiratory ailments. Third, our study focused solely on a 90-degree Fowler's position. Patients are placed in Fowler's position at different angles in clinical settings. Evaluating the impact of different trunk angles in Fowler's position is crucial for identifying the most suitable patient positioning within a clinical setting.

7.3 Clinical implications

Considering the hemodynamic responses, the most favorable therapeutic body position for cardiovascular function appears to be the supine position, followed by the Fowler's position. These findings suggest that patients who are bedridden or have blood ciculation disorders such as coronary artery disease, peripheral artery disease, cerebrovascular disease. For patients with high blood pressure, the position associated with reduced blood pressure was the right lateral position. Individuals, irrespective of their weight status (normal weight or abdominal obesity), may derive benefits from adopting these positions. On the other hand, the prone position should be avoided in cardiovascular patients, particularly those with abdominal obesity. Furthermore, the findings strongly support the utilization of the prone position to enhance ventilation and oxygenation in patients with respiratory conditions. However, it's important to acknowledge certain limitations associated with adopting the prone position, including increased energy demands, discomfort reported by a majority of participants, and constraints related to medical equipment. Therefore, it is advisable to consider alternative secondary positions for patients facing difficulties or limitations.

This study underscores the idea that patients facing immobilization or compromised gas exchange, irrespective of their weight status, can benefit from adopting specific body positions to optimize both hemodynamic and respiratory functions. This knowledge can assist healthcare professionals in making well-informed decisions regarding appropriate body positions for clinical management, ultimately contributing to increased treatment efficiency, reduced hospitalization duration, and improved chances of survival in patients.

APPENDICES

APPENDIX A Certificate of ethical approval

The Research Ethics Review Committee for Reseach Involving Human Research Participants, Group I, Chulalongkorn University

Chamchuri 1 Building, 2nd Floor, 254 Phayathai Road, Pathumwan, Bangkok 10330 Thailand

Telephone: 02-218-3202, 02-218-3049 Email: eccu@chula.ac.th

COA No. 186/65

Certificate of Approval

Study Title No. 650112 : THE INFLUENCE OF THERAPEUTIC BODY POSITIONS ON HEMODYNAMICS AND RESPIRATION IN ADULTS WITH AND WITHOUT ABDOMINAL OBESITY

Principal Investigator : Ms. Ruchada Sriamad

Place of Proposed Study/institution : Faculty of Allied Health Sciences, Chulalongkorn University

The Research Ethics Review Committee for Research Involving Human Research Participants, Group I, Chulalongkorn University, Thailand, has approved constituted in accordance with Belmont Report 1979, Declaration of Helsinki 2013, Council for International Organizations of Medical Sciences (CIOM) 2016, Standards of Research Ethics Committee (SREC) 2017, and National Policy and guidelines for Human Research 2015.

Signature Prida Tasanapradit	Signature Raveenan Mingpakanee
(Associate Prof. Prida Tasanapradit)	(Assistant Prof. Dr. Raveenan Mingpakanee)
Chairman	Secretary
Date of Approval : 19 September 2022	**Approval Expire date :** 18 September 2023

The approval documents including:

1. Participant Information Sheet and Consent Form
2. Research proposal
3. Researcher
4. Research instruments/tools
5. Recruitment flyer

__Conditions__

The approved investigator must comply with the following conditions:

1. It's unethical to collect data of research participants before the project has been approved by the committee.

2. The research/project activities must end on the approval expired date. To renew the approval, it can be applied one month prior to the expired date with submission of progress report.

3. Strictly conduct the research/project activities as written in the proposal.

4. Using only the documents that bearing the RECCU's seal of approval: research tools, information sheet, consent form, invitation letter for research participation (if applicable).

5. Report to the RECCU for any serious adverse events within 5 working days.

6. Report to the RECCU for any amendment of the research project prior to conduct the research activities.

7. Report to the RECCU for termination of the research project within 2 weeks with reasons.

8. Final report (AF 01-15) and abstract is required for a one year (or less) research/project and report within 30 days after the completion of the research/project.

9. Research project with several phases; approval will be approved phase by phase, progress report and relevant documents for the next phase must be submitted for review.

10. The committee reserves the right to site visit to follow up how the research project being conducted.

11. For external research proposal the dean or head of department oversees how the research being conducted

The Research Ethics Review Committee for Research Involving Human Research Participants Group 1

Study Title No. 650112
Date of Approval 19 Sep 2022
Approval Expire date 18 Sep 2023

Digital Certificate

APPENDIX B Advertising poster

APPENDIX C Screening form

(แบบคัดกรองอาสาสมัคร)

Research ID..........................

เบอร์โทรศัพท์...

....

คำชี้แจง: โปรดกรอกข้อมูล และตอบคำถามต่อไปนี้ตามความเป็นจริง ข้อมูลทั้งหมดในแบบสอบถามนี้จะถูกเก็บไว้เป็น

ความลับ และถูกใช้ในงานวิจัยนี้เท่านั้น

<u>ส่วนที่ 1 ข้อมูลทั่วไป (General information)</u>

อายุ.................................ปี วัน/เดือน/ปีเกิด...

สำหรับนักวิจัย ☐ (Aged 30-59 years)

<u>ส่วนที่ 2 ประวัติสุขภาพ (Clinical history)</u>

โรคประจำตัว..การรักษาที่ได้รับ..

ตรวจสุขภาพครั้งล่าสุดเมื่อ...

ยาที่ใช้ในปัจจุบัน............................... (เช่น ยาลดความดันโลหิต ยาลดไขมันในเลือด ยาขยายหลอดลม)

อาหารเสริมที่รับประทานเป็นประจำ..

ท่านมีประวัติของโรค หรือความผิดปกติดังต่อไปนี้

( ) มีความผิดปกติเกี่ยวกับสมอง และระบบประสาท เช่น อ่อนแรงครึ่งซีก อัมพฤกษ์ อื่นๆ ระบุ......................

( ) มีความผิดปกติทางระบบหายใจ เช่น ไอ มีเสมหะ หอบเหนื่อย หายใจมีเสียงดังหวีด อื่นๆ ระบุ.................

( ) มีความผิดปกติทางระบบข้อ กระดูก และกล้ามเนื้อ ระบุ...

( ) โรคลมชัก

( ) มีความผิดปกติทางระบบหัวใจ และหลอดเลือด เช่น แน่นหน้าอก หายใจลำบาก ปวดน่องเวลาเดิน

อื่นๆ ระบุ..

( ) โรค หรือความผิดปกติเกี่ยวกับการทำงานของไต เช่น บวมน้ำตามข้อ ขา และเท้า ปัสสาวะบ่อย อื่นๆ ระบุ

( ) มีความผิดปกติทางการมองเห็น ระบุ..

( ) มีความผิดปกติทางการได้ยิน ระบุ...

( ) มีความผิดปกติทางการพูด การสื่อสาร ระบุ...

( ) มีสภาวะของความเจ็บป่วยอื่นๆ เช่น ไม่สบาย เป็นไข้ ปวดศีรษะ วิงเวียน หน้ามืด อ่อนแรง เป็นต้น............

สำหรับนักวิจัย ☐ No underlying diseases

สำหรับนักวิจัย ☐ Not being any drug (stimulate/depress the cardiovascular and respiratory system)

ประวัติการสูบบุหรี่

( ) สูบบุหรี่........................มวน/วัน สูบมาเป็นระยะเวลา.................................ปี

กรณีเลิกบุหรี่ (โปรดระบุระยะเวลาที่เลิก)..

( ) ไม่สูบบุหรี่

สำหรับนักวิจัย ☐ No smoking

ประวัติการดื่มแอลกอฮอล์

( ) ดื่มแอลกอฮอล์ ....ครั้ง/สัปดาห์ ปริมาณ..........................เป็ก/ครั้ง

กรณีเลิกดื่มแอลกอฮอล์ (โปรดระบุระยะเวลาที่เลิก).......................................

( ) ไม่ดื่มแอลกอฮอล์

สำหรับนักวิจัย ☐ No drinking

ประวัติการออกกำลังกาย

ในช่วง 3 เดือนที่ผ่านมาท่านออกกำลังกาย หรือเล่นกีฬาหรือไม่ (การทำงาน การทำสวน ไม่จัดว่าเป็นการออกกำลังกาย)

( ) ออกกำลังกายระบุ.............................ครั้ง/สัปดาห์ ระยะเวลา..นาที/ครั้ง

ประเภทของการออกกำลังกาย หรือกีฬาที่เล่น โปรดระบุ...

( ) ไม่ออกกำลังกาย

<u>ส่วนที่ 3 ระดับกิจกรรมที่ทำเป็นประจำ (Baecke Habitual Physical Activity)</u>

1. อาชีพหลักของท่าน คือ...

2. ขณะทำงาน ท่านนั่งบ่อยแค่ไหน ?

...ไม่เคย ...บ่อย

...นานๆ ครั้ง ...ตลอดเวลา

...บางครั้ง

3. ขณะทำงาน ท่านยืนบ่อยแค่ไหน ?

...ไม่เคย ...บ่อย

...นานๆ ครั้ง ...ตลอดเวลา

...บางครั้ง

4. ขณะทำงาน ท่านเดินบ่อยแค่ไหน ?

...ไม่เคย ...บ่อย

...นานๆ ครั้ง ...ตลอดเวลา

...บางครั้ง

5. ขณะทำงาน ท่านยกของหนักบ่อยแค่ไหน ?

...ไม่เคย ...บ่อย

...นานๆ ครั้ง ...ตลอดเวลา

...บางครั้ง

6. หลังเลิกงาน ท่านรู้สึกเหนื่อยบ่อยแค่ไหน ?

...ไม่เคย ...บ่อย

...นานๆ ครั้ง ...ตลอดเวลา

...บางครั้ง

7. ขณะทำงาน ท่านมีเหงื่อออกบ่อยแค่ไหน ?

...ไม่เคย ...บ่อย

...นานๆ ครั้ง ...ตลอดเวลา

...บางครั้ง

8. เมื่อเปรียบเทียบกับคนที่อายุเท่ากับท่าน ท่านคิดว่างานที่ท่านทำหนักหรือเบากว่าแค่ไหน ?

...หนักกว่ามาก ...เบากว่า

...หนักกว่า ...เบากว่ามาก

...หนักเท่ากัน

9. ท่านเล่นกีฬาหรือไม่ ?

...เล่น ...ไม่เล่น

...ถ้าเล่น

- กีฬาที่ท่านเล่นบ่อยที่สุด คือ...

- ท่านเล่นกีฬากี่ชั่วโมงต่อสัปดาห์ ?

...น้อยกว่า 1 ชม. ...3 - 4 ชม.

...1 - 2 ชม. ...มากกว่า 4 ชม.

...2 - 3 ชม.

- ท่านเล่นกีฬากี่เดือนต่อปี ?

...น้อยกว่า 1 เดือน ...7 - 9 เดือน

...1 - 3 เดือน ... มากกว่า 9 เดือน

...4 - 6 เดือน

ถ้าท่านมีกีฬาอื่นที่เล่นรองลงมา

- กีฬาที่ท่านเล่นบ่อยรองลงมา คือ...

- ท่านเล่นกีฬากี่ชั่วโมงต่อสัปดาห์ ?

...น้อยกว่า 1 ชม. ...3 - 4 ชม.

...1 - 2 ชม. ...มากกว่า 4 ชม.

...2 - 3 ชม.

- ท่านเล่นกีฬากี่เดือนต่อปี ?

...น้อยกว่า 1 เดือน ...7 - 9 เดือน

...1 - 3 เดือน ...มากกว่า 9 เดือน

...4 - 6 เดือน

10. เมื่อเปรียบเทียบกับคนที่อายุเท่ากับท่าน ท่านคิดว่างานที่ท่านทำในเวลาว่างมากหรือน้อยกว่าแค่ไหน ?

...มากกว่ามาก ...น้อยกว่า

...มากกว่า ...น้อยกว่ามาก

...เท่ากัน

11. ในเวลาว่าง ท่านมีเหงื่อออกบ่อยแค่ไหน ?

...บ่อยมาก ...นานๆ ครั้ง

...บ่อย ...ไม่เคย

...บางครั้ง

12. ในเวลาว่าง ท่านเล่นกีฬาบ่อยแค่ไหน ?

...ไม่เคย ...บ่อย

...นานๆ ครั้ง ...บ่อยมาก

...บางครั้ง

13. ในเวลาว่าง ท่านดูโทรทัศน์บ่อยแค่ไหน ?

...ไม่เคย ...บ่อย

...นานๆ ครั้ง ...บ่อยมาก

...บางครั้ง

14. ในเวลาว่าง ท่านเดินบ่อยแค่ไหน ?

...ไม่เคย ...บ่อย

...นานๆ ครั้ง ...บ่อยมาก

...บางครั้ง

15. ในเวลาว่าง ท่านปั่นจักรยานบ่อยแค่ไหน ?

...ไม่เคย ...บ่อย

...นานๆ ครั้ง ...บ่อยมาก

...บางครั้ง

16. ท่านใช้เวลากี่นาทีต่อวัน ในการเดินและ/หรือปั่นจักรยาน เพื่อไปและกลับจากที่ทำงานโรงเรียน และซื้อของ ?

...น้อยกว่า 5 นาที

...5 - 15 นาที

...15 - 30 นาที

...30 - 45 นาที

...มากกว่า 45 นาที

<u>สำหรับนักวิจัย</u>

คำนวณคะแนนกิจกรรมที่ทำเป็นประจำ

การทำงาน = [(1).....+(6-(2).....)+(254).....+(4).....+(5).....+(6).....+(7).....+(8).....]/8 =..............................

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

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

คะแนนรวม =..

*** Activity level: Sedentary subject = < 6, Active subject = 6 – 8, Athletic subject = > 8

☐ *Overall physical activity = sedentary*

☐ *No abnormal chest shape and postoperative chest wound*

☐ *No disability such as vision, movement, communication, hearing, etc.*

☐ *Listen, speak, read, and write in Thai language*

ส่วนที่ 4 สัญญาณชีพ และสัดส่วนร่างกาย (Vital sign and anthropometrics)

Check lists	Participant data	Screening results
1. Vital signs		
Heart rate; HR (bpm)		☐ 60-100 bpm
Systolic arterial blood pressure; SABP (mmHg)		☐ < 140 mmHg
Diastolic arterial blood pressure; DABP (mmHg)		☐ < 90 mmHg
Respiratory frequency (R_f) (bpm)		☐ 12-20 bpm
Oxygen saturation (SaO_2)		☐ 95-100%
2. Anthropometrics		
Weight (kg)		
Height (36)		
Body mass index; BMI (kg/m^2)		☐ 18.5-22.9 Kg/m^2 ☐ ≥ 25 Kg/m^2
Waist circumference; WC (97)		☐ < 90 cm ☐ ≥ 90 cm
Hip circumference; HC (97)		
Waist-to-hip Ratio; WHR		☐ ≤ 0.95 ☐ > 0.95

APPENDIX D Data collection form

(แบบบันทึกข้อมูลอาสาสมัคร)

Research ID..........................

Outcomes	Participant data
Baseline assessment	
1. Body compositions	
Percentage of body fat; %BF (%)	
Percentage of visceral fat (%)	
Percentage of subcutaneous fat (%)	

2. Skinfold thickness (SFT))

Areas	1st time	2nd time	3rd time	Mean
Chest (mm)				
Mid-axillary (mm)				
Subscapular (mm)				
Suprailiac (mm)				
Abdomen (mm)				
Sum skinfold thickness (mm)				

3. Lung function

Parameters	1st time	2nd time	3rd time
Expiratory reserve volume; ERV (ml)			
Inspiratory reserve volume; IRV (ml)			
Inspiratory capacity; IC (ml)			
Vital capacity; VC (ml)			
Vital capacity; V_T (ml)			
Slow vital capacity; SVC (L)			

Forced vital capacity; FVC (ml)			
Forced expiratory volume in the 1 second; FEV_1 (%)			
Forced expiratory volume in 1 second / Forced vital capacity; FEV_1/FVC (%)			
Forced expiratory flow at 25-75 %; FEF 25-75 % (l/s)			
Maximum forced expiratory flow; FEF max (l/s)			

4. Respiratory outcomes

Parameters	Therapeutic body positions				
	Fowler	Right lateral	Left lateral	Supine	Prone
Respiratory frequency; Rf (bpm)					
Tidal volume (202) (ml)					
Minute ventilation; V_E (l/min)					
Fraction of inspired oxygen; FiO_2 (%)					
Respiratory oxygen uptake; VO_2 (ml/min)					
Carbon dioxide production; VCO_2 (ml/min)					
Minute ventilation/Respiratory oxygen uptake; V_E/VO_2					
Minute ventilation/Carbon dioxide production; V_E/VCO_2					
Partial pressure of arterial oxygen; PaO_2 (mmHg)					
Partial pressure of arterial carbon dioxide; $PaCO_2$ (mmHg)					
Arterial oxygen saturation (SaO_2) (%)					
End-tidal Oxygen; $PETO_2$ (mmHg)					
End-tidal carbon dioxide; $PETCO_2$ (mmHg)					
Respiratory quotient; RQ					
Metabolic equivalent; MET					

5. Hemodynamic outcomes

Parameters	Therapeutic body positions				
	Fowler	Right lateral	Left lateral	Supine	Prone
Heart rate; HR (bpm)					
Systolic arterial blood pressure; SABP (mmHg)					
Diastolic arterial blood pressure; DABP (mmHg)					
Mean arterial blood pressure; MABP (mmHg)					
Stroke volume; SV (ml)					
Stroke volume index; SVI (ml/m^2)					
Cardiac output; CO (l/m)					
Cardiac index; CI (l/min/m^2)					
Contractility index; CTI					
Systemic vascular resistance; SVR (dyn.s/cm^5)					
Systematic vascular resistance index; SVRi (dyn.s/cm5.m^2)					
End diastolic volume; EDV (ml)					

APPENDIX E Comfort questionnaire

(แบบสอบถามความรู้สึกสบาย)

Research ID..........................

แบบสอบถามชุดนี้ มีวัตถุประสงค์ในการสำรวจความรู้สึกสบายของท่านต่อท่าทางที่ถูกดำเนินการในการวิจัยครั้งนี้ เพื่อประกอบการตัดสินใจในการเลือกใช้ในผู้ป่วย โดยให้ท่าน<u>เรียงลำดับท่าทางที่ท่านรู้สึกสบายจากมากที่สุดไปน้อยที่สุดลงในตารางด้านล่าง</u>

ท่านั่งบนเตียง ท่านอนตะแคงขวา ท่านอนตะแคงซ้าย ท่านอนหงาย ท่านอนคว่ำ

	ลำดับความรู้สึกสบาย	ท่าทาง
สบายมากที่สุด	1	
	2	
	3	
	4	
สบายน้อยที่สุด	5	

ความคิดเห็นเพิ่มเติม

....

ขอขอบพระคุณในความร่วมมือในการตอบแบบสอบถา

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AWARD RECEIVED	1. รางวัลผลงานวิจัยดี: Sriamad R, Prasertsri P, Sriwannawit P, Roengrit T, Sriwannawit P. Pulse Wave Velocity Associated with Metabolic Syndrome Component in the Elderly: A Pilot Study. The 28st National Taksin Conference 2018, Taksin University, Thailand. 2. รางวัลชนะเลิศการนำเสนอผลงานวิจัย: Sriamad R, Prasertsri P, Sriwannawit P, Roengrit T. Association between Cardio-ankle Vascular Index and Blood Pressure in Elderly with Dyslipidemia. Proceedings of the 1st National Public Health Research Conference 2018, Nakhon Si Thammarat, Thailand. 3. รางวัลนักศึกษาแบบอย่างมหาวิทยาลัยสงขลานครินทร์