Original research

Role of abdominal obesity and body position in kinematics of the chest wall

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ABSTRACT

Objective: To investigate the impacts of abdominal obesity and body position on kinematics of the chest wall.
Methods: A cross-sectional design was conducted. Twenty abdominal obesity and twenty control males were performed four body positions for 5 min each: (1) sitting without back support, (2) sitting with back support, (3) Fowler's position, and (4) supine. Kinematics of chest wall including thoracoabdominal asynchrony, diameter changes, and ventilatory function were evaluated using optoelectronic plethysmography.
Results: Thoracoabdominal asynchrony in obesity group has higher than control group among body position ($p < 0.01$). Obesity group significantly decreased diameter changes across body positions compared to control group ($p < 0.01$). Sitting without and with back support showed the lowest for thoracoabdominal asynchrony but the greatest chest wall diameter changes and ventilatory function than Fowler's and supine positions ($p < 0.01$).
Conclusions: The current finding supports the significant effect of abdominal obesity and different body positions on kinematics of chest wall. Both sitting without and with support positions are recommended for synchronizing thoracoabdominal motion, maximizing chest wall diameter changes, and ventilatory function – this would therefore likely reduce the risk of respiratory disease and complications compared with lying positions.

1. Introduction

Abdominal obesity plays a critical role in the development of many health conditions (Cawley and Meyerhoefer, 2012). The global medical care cost for treating obesity-related illness has risen from 20.6% in 2005 to 28.2% in 2013 (Cawley and Meyerhoefer, 2012). Furthermore, in Thailand, abdominal obesity-related illnesses – particularly respiratory disease – has witnessed an increase in more than 35 million US dollars annually in healthcare system costs (Teerawattananon and Luz, 2017). The adverse effects of abdominal obesity include increased airflow limitations, hypoxia, base of lung atelectasis, development of respiratory diseases and complications, and an increased length of hospital stay after surgery (Mafort et al., 2016).

The negative effects of obesity on lung function are likely due to abnormal fat accumulation around the chest wall, which alters the chest wall kinematics (diameter changes and synchronous of thoracoabdominal motion), increases intra-plural and intra-abdominal pressure, reduces the upper airway caliber, and modifies airway configuration (Mafort et al., 2016; Salome et al., 2010).

One way to address the problems with lung and chest wall function in patients – including patients with obesity – is to adopt a body position that can increase breathing comfort, restore chest wall kinematics and lung function, and reduce the risk of respiratory complications (Sonpeayung et al., 2018; Dean, 1985; Nielsen et al., 2003; Katz et al., 2018). Body position-related improvements in lung function are likely due to their direct impact on chest wall kinematics (Sonpeayung et al., 2018; Barnas et al., 1993). The results of a recent systematic review indicate that different body positions affect different areas of the chest wall. Sonpeayung et al. (2018) provided very low to moderate evidence for sitting position improving function in the area of the rib cage, relative to other positions, whereas a supine position enhances movement in the abdomen region (Sonpeayung et al., 2018).

In the last decade, optoelectronic plethysmography (OEP) is a noninvasive and nonionizing tool to measure segmental movements of chest wall and can estimate regional lung volumes (Cala et al., 1996; Aliverti et al., 2000, 2001; Massaroni et al., 2017). OEP tool has been extensively employed in studies looking at kinematics of chest wall and is capable of detecting small movements of the chest wall during breathing in many populations such as healthy, COPD, asthma, spinal cord injury, infants, pediatrics, athletes, etc (Massaroni et al., 2017).

Furthermore, this tool had good reliability and validity compared with spirometers (as gold standard) (Massaroni et al., 2017).

However, research to date has focused only on chest wall motion-related changes in diameter changes in healthy adults. There has not yet been research regarding the effects of the body position on chest wall kinematics in the clinical population, including obesity individuals. Knowledge regarding the role of body positions on different parts of the chest wall in clinical populations (i.e. obesity) is important for providing such individuals with specific position recommendations that would make breathing more comfortable and reduce the risk for secondary health problems – particularly respiratory diseases.

Given all these considerations, the aim of the current study was to increase our understanding of the role of different body positions on chest wall kinematics in a sample of individuals with obesity. Specifically, we evaluated the effects of four different body positions (sitting without and with back support, Fowler's position, and supine position) on chest wall kinematics including diameter changes, thoracoabdominal asynchrony, and ventilatory function in individuals with and without abdominal obesity. Given previous research in healthy individuals, we hypothesized that the obesity individuals would display worse chest wall kinematics on all measures, relative to the non-obesity individuals.

2. Methods

2.1. Study design and ethics considerations

A cross-sectional study was approved by the Ethics Review Committee from Chulalongkorn University (ERCCU) (Approval number. 052/2017). Data were collected in the Physical Therapy Department at Chulalongkorn University in Bangkok, Thailand. The subjects were informed of the research procedures and provided written informed consent prior to performing any study procedures.

2.2. Subjects

Sample size was calculated by G*Power software (G*Power version 3.1.9.2, University Kiel, Germany) based on a pilot study (5 obese, 5 control). A total of 40 subjects were needed to provide the sufficient power (80%) to detect any difference between groups with the effect size at the medium level (d = 0.47–0.49). The inclusion criteria of the study sample included Thai males aged 20–40 years old without any underlying disease. The physical activity of the subjects was that of a sedentary life style, scoring less than 6 on the Baecke habitual physical activity questionnaire (Baecke et al., 1982). This tool is a short questionnaire, easy to understand and fill out, and its validity and repeatability for measurement the physical activity (Baecke et al., 1982). Subjects were grouped into control and abdominal obesity groups according to their body mass index (BMI), weight-hip ratio (WHR), and skinfold thickness. For the control group, their BMI, WHR and skinfold thickness ranged in the normal level based on WHO expert consultation, 2008 (World Health Organization, 2008). The scores for the obesity group were 25–34.99 kg/m^2 (BMI), more than 0.9 for WHR, and more than 90 mm for skinfold thickness (Surendar et al., 2016). Subjects who complained of any respiratory symptoms and illness, presented skin allergy from placement of the reflective markers, or wanted to stop during the test were excluded.

2.3. Research procedures

The process of the research procedures is shown in Fig. 1.

2.3.1. Baseline assessments

All subjects underwent baseline assessments, including anthropometric measurements, body compositions, and truncal skinfold thickness.
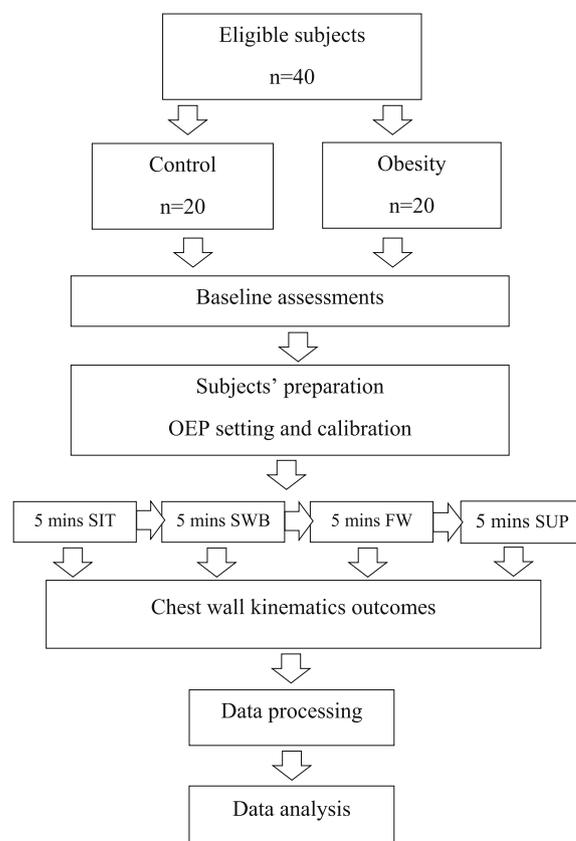

Fig. 1. The research procedure; SIT, sitting without back support; SWB, sitting with back support; FW, Fowler's position; SUP, supine position.

Anthropometric measurements. Height, weight, and waist and hip circumferences were assessed based on the guidelines of WHO expert consultation (World Health Organization, 2008). Subjects' weight and height were measured using the stadiometer after removing shoes and heavy clothing. A tape measure was used to evaluate waist circumference (WC), i.e. the midpoint between the lower costal margin and the iliac crest, and hip circumference (HC), i.e. at the greater prominence of the buttock (World Health Organization, 2008). Weight and height were also used to compute body mass index (BMI, kg/m^2). WC and HC variables were used to calculate waist to hip ratio (WHR).

Body composition. Bioelectrical impedance (OMRON Healthcare Ltd., Karada scan Model HBF-375, Kyoto, Japan) was used to analyze subjects' body compositions, including percentage of body fat, subcutaneous fat, and visceral fat rating.

Skinfold thickness. Truncal skinfold thickness was measured in five sites (pectoral, mid-axillary, subscapular, supra-iliac, and abdomen sites) using digital outside the skinfold caliper (Moore and Wright Ltd., Sheffield, UK). Skinfold thickness measurement was evaluated according to the method of Surendar et al. (2016) (Surendar et al., 2016). Three repeated skinfold thickness measurements at each site were averaged, and these averages was summed up and recorded.

2.3.2. Subjects' preparation

The subjects were asked to attach the reflective markers on their chest wall surface for estimating three-dimensional (3D) chest wall kinematics. Reflective marker placement protocol was performed as previously described (Cala et al., 1996; Aliverti et al., 2000, 2001; Massaroni et al., 2017). In brief, for the position of sitting without back support, 89 markers were covered in anatomical structures from the clavicles line to the level of the anterior superior iliac crest line (Cala et al., 1996; Aliverti et al., 2000; Massaroni et al., 2017). For the positions of sitting without back support and lying, 52 markers were

employed (excluding posterior marker placements of the chest wall) (Aliverti et al., 2001). The eight infrared cameras were set to surround the subject to ensure that every marker is captured by at least two cameras with the sampling rate at 60 Hz. The calibration procedure was as previously described and completed before performing the test (Cala et al., 1996; Aliverti et al., 2000, 2001; Massaroni et al., 2017).

2.3.3. Body position

The subjects were asked to perform the body positions including sitting without back support (SIT), sitting with back support (SWB), Fowler's position (FW), and supine position (SUP) after the subjects' preparation process was undertaken. The duration for each position was 5-min. The subjects' vital signs (blood pressure, heart rate, respiratory rate, and oxygen saturation) were evaluated to ensure that there was a stable stage. The order of the body positions was SIT, SWB, Fowler's, and supine positions in order to minimize small airway collapse from body weight during the lying position. The details of the body positions were as follows.

SIT: sitting upright without a backrest at 90-degree trunk inclination. The position of the subject's hips and knees were flexed 90˚ with abducted their hips at less than 10˚.

SWB: sitting upright with a backrest at 90-degree trunk inclination. The subject's hip and knee positions were set the same as the SIT position.

FW: semi-sitting upright on a bed at a 45-degree trunk inclination. The subject's hip and knee positions were slightly flexed (15˚).

SUP: a lying position on the bed. The subject's head and neck positions were in neutral position supported by a pillow. The hips and knees of the subjects were set the same as Fowler's position.

2.3.4. Outcome measures

The chest wall kinematics outcomes comprised chest wall diameter changes, thoracoabdominal asynchrony that represented diaphragmatic dysfunction and ventilatory function. Based on the chest wall model, compartments of the chest wall are classified into 3 parts, the pulmonary rib cage (RCp), abdominal ribcage (RCa), and the abdomen (AB) (Cala et al., 1996; Aliverti et al., 2000, 2001; Massaroni et al., 2017). The summation of 3 parts represented the total of chest wall. The changes of ribcage compartment (RCp and RCa) is directly related to intercostal, accessory, and diaphragmatic muscle recruitment and to pressure changes in the lung and pleural cavity. The changes of abdomen compartment involved activity of diaphragmatic muscle and pressure changes in the intra-abdominal region. Furthermore, motion of the chest wall was composed of three directional motion including anteroposterior, transverse, and craniocaudal directions (Romei et al., 2010; Takashima et al., 2017; De Groote et al., 1997). In order to measure the outcomes of the chest wall kinematics, optoelectronic plethysmography (OEP-BTS® Bioengineering, Milan, Italy) was used to analyze the 3D chest wall kinematics, which has been previously described in detail and validated tools (Cala et al., 1996; Aliverti et al., 2000, 2001; Massaroni et al., 2017). The data acquisitions of the OEP system were recorded breath by breath during 5-min of quiet breathing in each body position. Subjects were asked to breathe spontaneously, and not to speak or move their body during the protocol testing. The OEP system was tracked in 3D with the sampling rate at 60 Hz and the chest wall kinematics computed by integrating the surface using the Gaussing theorem as described previously by Cala et al., (1996) (Cala et al., 1996). MATLAB® software program version 2018a (The Math-Works Inc., Nattick, Massachusetts, USA) was used to analyze chest wall kinematics outcomes (Romei et al., 2010; Takashima et al., 2017; De Groote et al., 1997). The details of all chest wall kinematics outcomes are as follows.

Thoracoabdominal asynchrony (TAA): Asynchrony was quantified by determining the phase angle (θ) between ribcage (RC) and abdomen (AB) volume. The phase angle (θ) used the Lissajous approach in which the RC was plotted against AB. The θ was computed as $\theta = \sin^{-1}(m/s)$,

when "m" is the distance between the two midpoints (50%) of the RC excursion, and "s" is the maximum volume of abdomen or AB excursion, as the protocol used previously described (Aliverti et al., 2009; Konno and Mead, 1967). Moreover, a positive θ means that the AB movement precedes RC movement; conversely, negative θ describes the reverse situation (Aliverti et al., 2009; Konno and Mead, 1967).

Chest wall diameter changes: The direction of the chest wall diameter changes was assessed in three directions (anteroposterior, transverse, and craniocaudal directions). The anteroposterior and transverse directions comprised three levels including upper level, i.e. referred to the changes in upper lung zone and pulmonary rib cage part of the chest wall, middle level, i.e. referred to the changes in middle lung zone and abdominal rib cage part of the chest wall, and lower level, i.e. referred the changes in lower lung zone and abdomen part of the chest wall. The method of measurements was based on those of Romei et al. (2010), Takashima et al. (2017), and De Groote et al. (1997) (Romei et al., 2010; Takashima et al., 2017; De Groote et al., 1997).

Ventilatory function: The ventilatory parameters including tidal volume (VT), respiratory rate (RR), and minute ventilation (VE), were calculated based on the data of chest wall kinematics tracked and analyzed using the MATLAB® software program. This method has been widely used and showed the good reliability and validity compared with spirometers (Massaroni et al., 2017). The ratio of the rapid shallow breathing rate was obtained as the ratio between RR and VT (Yang and Tobin, 1991).

2.4. Data analysis

Data were analyzed with statistics software (Version 22.0, SPSS Inc., Chicago, USA). The means and standard deviations of all relevant variables were computed. The Shapiro-Wilk test was used to verify normal distribution of the data. Independent *t*-test was used to compare the baseline characteristic parameters between the two groups. Two-way repeated ANOVA with Bonferroni post hoc test was employed to evaluate the differences between control and obesity group considering different body positions. The level of significance was set at $p < 0.05$.

3. Results

3.1. Characteristics of subjects

Forty male potential subjects participated in this study. The baseline parameters are given in Table 1. BMI, WHR, percentage of visceral fat and subcutaneous fat, and skinfold thickness parameters in the obesity group had significantly higher than the control group ($p < 0.01$).

Table 1
The characteristics of subjects.

Parameters	Mean (SD)		P-value
	Control (n = 20)	Obesity (n = 20)	
Age (yrs)	27.20 (3.90)	27.40 (4.35)	0.88
Weight (kg)	64.23 (5.19)	85.36 (9.19)	< 0.01*
Height (cm)	171.95 (5.32)	171.65 (4.08)	0.84
Body mass index (kg/m²)	21.62 (0.95)	28.92 (2.80)	< 0.01*
Physical activity (score)	5.16 (0.39)	5.08 (0.67)	0.65
Waist Hip Ratio	0.83 (0.03)	0.96 (0.05)	< 0.01*
Visceral fat rating	5.18 (1.25)	13.29 (3.28)	< 0.01*
Percentage of subcutaneous fat	11.27 (2.28)	19.57 (3.39)	< 0.01*
Truncal skinfold thickness (mm)	57.66 (20.63)	123.01 (23.47)	< 0.01*

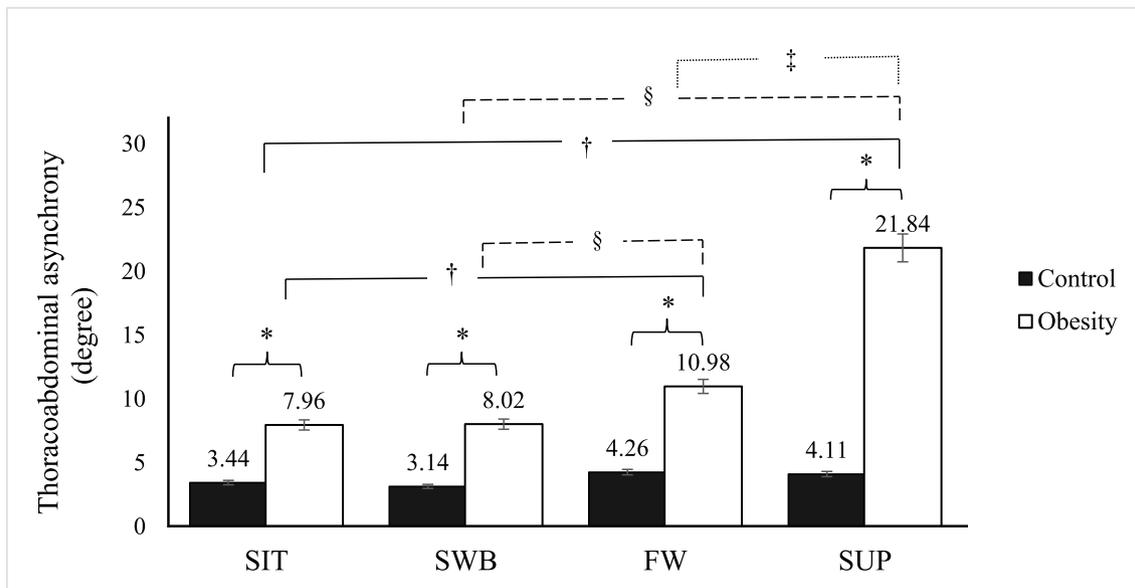*significant differences ($p < 0.01$).

Fig. 2. Effects of body positions on thoracoabdominal asynchrony; *significant between obesity and control groups in the same body position (p < 0.01); [†] significant compared with SIT in the same groups (p < 0.01); [§] significant compared with SWB in the same groups (p < 0.01); [‡] significant compared with FW in the same groups (p < 0.01).

3.2. Effects of the body position on chest wall kinematics: thoracoabdominal asynchrony

Fig. 2 demonstrates the effects of body positions on thoracoabdominal asynchrony. The obesity group significantly increased in the degree of thoracoabdominal asynchrony across body positions compared with the control group (p < 0.01). Comparison of the four body positions in the control group revealed there to be no difference in the degree of thoracoabdominal asynchrony between body positions. For the obesity group, the supine position showed the highest degree of thoracoabdominal asynchrony, followed by Fowler's and both sitting positions (SIT and SWB) (p < 0.01).

3.3. Effects of the body position on chest wall kinematics: chest wall diameter changes

3.3.1. Anteroposterior diameter changes
Table 2 shows the effects of body positions on chest wall diameter

changes. For the obesity group, the anteroposterior diameter changes at upper, middle, and lower levels across different body positions significantly decreased relative to the control group (p < 0.01). Comparison of the four body positions revealed that both SIT and SWB positions had the highest anteroposterior diameter changes at the upper and middle levels, followed by Fowler's and supine positions in both groups (p < 0.01). Furthermore, the supine position showed the greatest anteroposterior diameter changes at a lower level.

3.3.2. Transverse diameter changes
The results in Table 2 found that only the lower level of transverse diameter changes in the obesity group were significantly lowered relative to the control group (p < 0.01). Regardless of body position in each group, Fowler's and the supine positions showed significantly lower transverse diameter changes at the middle and lower levels than the SIT and SWB positions (p < 0.01).

Table 2
Effects of the body position on chest wall diameter changes.

Groups	Control				Obesity				Interaction effects ($F_{3,63}$) P-value
Body position	SIT	SWB	FW	SUP	SIT	SWB	FW	SUP	
Anteroposterior diameter changes (cm)									
Upper level	0.69 ± 0.72	0.65 ± 0.72	0.34 ± 0.10‡,§	0.35 ± 0.25‡,§	0.56 ± 0.10*	0.49 ± 0.07*	0.28 ± 0.07*,‡,§	0.23 ± 0.08*,‡,§	0.037
Middle level	0.61 ± 0.15	0.69 ± 0.11	0.46 ± 0.11‡,§	0.45 ± 0.30‡,§	0.52 ± 0.10*	0.59 ± 0.07*	0.30 ± 0.08*,‡,§	0.29 ± 0.09*,‡,§	0.028
Lower level	0.53 ± 0.17	0.51 ± 0.09	0.56 ± 0.12	0.60 ± 0.13‡,§	0.43 ± 0.07*	0.45 ± 0.07*	0.48 ± 0.08*	0.49 ± 0.13*	0.042
Transvers diameter changes (cm)									
Upper level	0.18 ± 0.04	0.17 ± 0.02	0.17 ± 0.07	0.16 ± 0.06	0.16 ± 0.04	0.17 ± 0.04	0.16 ± 0.04	0.15 ± 0.05	0.746
Middle level	0.62 ± 0.22	0.63 ± 0.11	0.31 ± 0.33‡,§	0.21 ± 0.11‡,§	0.61 ± 0.09	0.60 ± 0.12	0.28 ± 0.06‡,§	0.21 ± 0.05‡,§	0.017
Lower level	0.51 ± 0.18	0.49 ± 0.11	0.37 ± 0.23‡,§	0.41 ± 0.11‡,§	0.39 ± 0.08*	0.35 ± 0.14*	0.28 ± 0.09*	0.31 ± 0.07*	0.034
Craniocaudal diameter changes (cm)									
	1.2 ± 0.16	1.11 ± 0.16	0.96 ± 0.26	0.99 ± 0.34	0.79 ± 0.14*	0.81 ± 0.09*	0.59 ± 0.10*,‡,§	0.53 ± 0.01*,‡,§	0.033

SIT: sitting without back support; SWB: sitting with back support; FW: Fowler's position; SUP: supine position.
*Significant difference between obesity and control groups in the same body position (p < 0.05).
[‡]Significant difference compared with SIT in the same groups (p < 0.05), Bonferroni post hoc test.
[§]Significant difference compared with SWB in the same groups (p < 0.05), Bonferroni post hoc test.

Table 3
Effects of the body position on ventilatory function.

Groups	Control				Obesity				Interaction effects ($F_{3,63}$) P-value
Body position	SIT	SWB	FW	SUP	SIT	SWB	FW	SUP	
VT (L)	0.55 ± 0.05	0.54 ± 0.06	0.43 ± 0.03†,§	0.39 ± 0.02†,§	0.44 ± 0.04*	0.42 ± 0.03*	0.38 ± 0.03*	0.31 ± 0.02*	< 0.01
RR (bpm)	15.39 ± 2.80	14.92 ± 2.91	15.48 ± 2.65	15.43 ± 2.93	17.52 ± 1.78*	17.38 ± 1.65*	18.07 ± 1.37*	18.46 ± 1.72*	< 0.01
VE (L.min−1)	8.46 ± 0.97	8.06 ± 0.92	6.87 ± 1.23†,§	6.06 ± 0.91†,§,‡	7.71 ± 0.95*	7.29 ± 0.86*	6.87 ± 1.37†,§	5.72 ± 0.81*,†,§,‡	0.03
RR/VT (bpm/L)	27.92 ± 0.03	27.63 ± 0.05	36 ± 0.03†,§	39.56 ± 0.03†,§	39.82 ± 0.04*	41.38 ± 0.03*	47.55 ± 0.03*	59.55 ± 0.02*,†,§,‡	0.02

SIT: sitting without back support; SWB: sitting with back support; FW: Fowler's position; SUP: supine position; VT: tidal volume; RR: respiratory rate; VE: minute ventilation; RR/VT: ratio of rapid shallow rate.
*Significant difference between obesity and control groups in the same body position (p < 0.01).
†Significant difference compared with SIT in the same group (p < 0.01);§: significant difference compared with SWB in the same group (p < 0.01).
‡Significant difference compared with FW in the same group (p < 0.01).

3.3.3. Craniocaudal diameter changes

The obesity group had significantly lowered craniocaudal diameter changes in all body positions compared with the control group (p < 0.01) (Table 2). Comparison of the four body positions revealed there was no difference in craniocaudal diameter changes in the control group. Only in the obesity group did the supine position show the smallest craniocaudal diameter changes, followed by Fowler's and both SIT and SWB positions (p < 0.01).

3.4. Effects of the body position on chest wall kinematics: ventilatory function

The results are presented in Table 3. The obesity group had significantly reduced VT and VE but had significantly increased RR and ratio of RR/VT in all body positions relative to the control group (p < 0.01). Considering of the body positions revealed that the supine position showed the lowest VT and VE while the greatest RR and the ratio of RR/VT was in the obesity group (p < 0.01).

4. Discussion

The present study is the first study to examine the impact of abdominal obesity and body position on chest wall kinematics, including diameter changes, thoracoabdominal asynchrony, and ventilatory function. The current findings highlighted that the body positions influenced chest wall kinematics in individuals with and without abdominal obesity. Furthermore, abdominal obesity significant decreased the chest wall kinematics and ventilatory function. Reduction of chest wall kinematics and ventilatory function led to a deterioration of lung volume and capacities and gas exchanges, an increased work of breathing, and risk of respiratory problems and medical complications (Kaneko et al., 2016; Zoumot et al., 2015). Kaneko et al. (2016) found that limitation chest wall movement strongly associated with reduction of lung function, respiratory muscle strength, and excercise capacity (Kaneko et al., 2016). Thus, decreasing in chest wall diameter changes and ventiltation in abdominal obesity would likely to a risk of impairment of lung function, gas exchange abnormalities, and development to respiratory diseases and complications.

4.1. Effects of the body position on chest wall kinematics

4.1.1. Thoracoabdominal asynchrony

The current findings revealed that there was no effect of the body positions on thoracoabdominal asynchrony in the control group. However, the degree of thoracoabdominal asynchrony significantly increased for the obesity group when shifting from the sitting to supine positions. Thoracoabdominal asynchrony determines the uncoordinated motion of the ribcage and the abdomen compartments of the chest wall, which is often clinically detected as a symptom of respiratory disorders, breathing dysfunctions, ventilatory mechanics disturbance, diaphragm muscle weakness/paralysis, and respiratory distress syndrome (Behrakis et al., 1983). In healthy subjects, the contraction of the diaphragm and intercostal muscles and also the motion between the ribcage and the abdomen are synchronous during quiet breathing. So, changing from the sitting to the supine position did not affect the degree of thoracoabdominal asynchrony in the control subjects. However, the body positions influenced the degree of thoracoabdominal asynchrony in abdominal obesity. It might be that the extreme fat accumulation around the chest wall resulted in the limitation of chest wall compliance, reduction of chest wall compartment volume, alteration of the breathing pattern, and increasing the work of breathing (Zoumot et al., 2015). These factors may increase the uncoordinated motion between the ribcage and abdomen resulting in raising the degree of thoracoabdominal asynchrony in abdominal obesity. Furthermore, the supine position demonstrated the greatest degree of thoracoabdominal asynchrony. This can be explained by the

indrawing of the lower part of chest wall motion (abdomen region) in abdominal obesity but the compensation increasing of the upper and middle part of the chest wall motion might induce the asynchronous thoracoabdominal movement. Previous studies reported that the obesity are prone to have respiratory muscle weakness by increasing intracellular lipid concentration and reducing the activity of the oxidative enzymes and numbers of mitochondria in skeletal muscles relative to the control group (Simoneau et al., 1999). In addition, individual with abdominal obesity may have muscles weakness particularly in the diaphragmatic muscle, which results in decreasing the chest wall motion in part of the abdomen more than the rib cage part (Barcelar et al., 2013; Benedik et al., 2009). These factors are one possible mechanism that induces the asynchronous motion between the ribcage and abdomen, especially the supine position. Thus, the occurrence of thoracoabdominal asynchronous in individuals with abdominal obesity would contribute to the development of a high risk of hypoxia, ventilation-perfusion mismatching, impaired gas exchanges, and respiratory-related illness (Zoumot et al., 2015). Hence, individuals with abdominal obesity should take special care in undertaking the supine position.

4.1.2. Chest wall diameter changes

This study found that both the SIT and SWB positions had higher diameter changes in all three directions except the anteroposterior diameter changes at the lower level and transverse diameter changes at the upper level. In the sitting position, the increase in diameter changes in anteroposterior and transverse directions may be related to gravitational effects, local chest wall compliance changes, and the mechanical advantage of respiratory muscles (Dean, 2012; Behrakis et al., 1983). The less gravitational effects in the sitting position, which results in higher ribcage compliance, the greater the mechanical advantage of the intercostal and diaphragm muscles (Dean, 2012; Behrakis et al., 1983). These possible mechanisms led to increasing diameter changes in the anteroposterior and transverse directions in the sitting position compared to Fowler's and the supine positions. Interestingly, not only did the anteroposterior and transverse directions impact chest wall diameter changes but also the craniocaudal direction. SIT and SWB positions showed the highest craniocaudal diameter changes that can be explained by the viscoelastic properties of the chest wall (Behrakis et al., 1983). In the sitting position, the elastance between the diaphragm and abdominal wall was less than the lying positions. Consequently, the sitting position had less resistance of diaphragm excursion resulting in greater craniocaudal diameter changes than the lying positions. Furthermore, based on the magnetic resonance imaging and chest radiography showed that upright position had greater diaphragmatic excursion than supine position (Yamada et al., 2017). These possible mechanisms may result in a higher craniocaudal diameter changes in sitting position than the others body positions. Regarding abdominal obesity, the excessive fat around the thorax and chest wall may greatly limit diameter changes and resist chest wall expansion during performance of the body positions, especially the supine position. These might lead to the supine position showing the lowest diameter changes in the craniocaudal direction.

4.1.3. Ventilatory function

Regarding the ventilatory function, the obesity group showed a reduction in the tidal volume but compensated by increasing the respiratory rate and the ratio of rapid shallow breathing rate compared with the control group. The fat mass loading around the chest wall and visceral organs mainly impact the chest wall and lung expansion resulting in decreasing the tidal volume but compensating through the rapid respiratory rate for maintaining the ventilation. Although the minute ventilation ranged in the normal level for the obesity the breathing pattern changed one of rapid shallow breathing in obesity individuals. This abnormal breathing pattern for the obesity partially increased the ventilatory dead space which led to a risk of ventilation-perfusion mismatching at the base of the lungs, micro-atelectasis,

hypoxia, and increased work of breathing (Dixon and Peters, 2018; Steier et al., 2014). Comparison of the body positions revealed that the supine position demonstrated the worst on the ventilatory function parameters in abdominal obesity. This may be due to both the gravitational effects combined with the fat mass loading on the chest wall, which may greatly limit local compliance of the chest wall, increase thoracic and intra-abdominal pressure, and also restrict diaphragmatic excursion resulting in changing the breathing pattern to one of rapid shallow breathing in order to preserve normal ventilation (Benedik et al., 2009; Steier et al., 2014).

4.2. Clinical implications

The current findings revealed that asymptomatic abdominal obesity individuals showed adversely effects on chest wall diameter changes, asynchronous thoracoabdominal motion, and the alteration of the ventilation. These alterations can contribute to respiratory symptoms and illness. Our findings suggest clinicians emphasize the need for action at the early development prior to chronic diseases. Using the sitting with and without back support positions would restore lung volumes and capacities, gas exchange, ventilation, diaphragmatic muscle performance, and reduce the risk of respiratory problem-related illnesses. Furthermore, the supine position showed the greatest asynchronous of thoracoabdominal motion resulted in disturbance of ventilation and gas exchanges. Thus, obesity patients who had prolong bedridden should be prevention the adverse effects of the supine position. The therapeutic intervention such as localized of breathing exercise are needed for prevention the adverse effects of lung function and chest wall kinematics in supine position. Moreover, health promotion, primary prevention, and controlling of abdominal obesity-related illness should be further addressed.

4.3. Limitations

The current findings should be interpreted considering certain limitations. First, the study was restricted to male abdominal obesity. Females with abdominal obesity may provide different results compared with males. Research is needed to examine the effects of sex differences to determine which findings from the current study are replicated in other groups. Second, the study investigated the four body positions (sitting with and without back support, Fowler's position, and supine positions) in asymptomatic populations. The current results may not be applicable to some patients who need to be in specific body positions such as side lying and prone positions. Future studies are needed to investigate the effects of these body positions on lung function measures as well. Third, this study examined the effects of obesity and body positions only on chest wall kinematics. It is possible, even likely, that physiological response parameters in the respiratory system such as gas exchanges, carbon monoxide diffusion capacity (DLCO), and airway resistance are impacted by both abdominal obesity and body positions. Research is needed to examine these other outcomes as well. Fourth, there is also needed to use a randomization of body position between the test. The sequence of body positions may influence the results. Further studies should be concerned. Fifth, although the effect size is ranged in the medium size, the findings in this study should be interpreted with care because it came from a small sample size. Further study should be investigated with a large sample size to clarify the results.

5. Conclusion

The current findings supported the assertion that body positions influenced chest wall kinematics in the individual with and without abdominal obesity. All chest wall kinematics parameters were reduced in the obesity group compared with the control group in all body positions. Both the SIT and SWB positions are recommended for

promoting the chest wall kinematics. The supine position should be used with caution when considering implementation into a clinical setting for patients with abdominal obesity.

Conflicts of interest

The authors report no conflict of interest.

Author contributions

R. S. was responsible for the conception and design of the study, acquisition, analysis, and interpretation of the data, manuscript preparation and manuscript writing; A. T. was responsible for review of manuscript; P. J. was responsible for review of manuscript; P. T. was responsible for the conception and design of the study, interpretation of the data, manuscript preparation and review of manuscript. All authors read and approved the final version of the manuscript, and agreed with the order of presentation of the authors.

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References

Aliverti, A., Dellacà, R., Pelosi, P., Chiumello, D., Gatihnoni, L., Pedoti, A., 2001. Compartmental analysis of breathing in the supine and prone positions by optoelectronic plethysmography. Ann. Biomed. Eng. 29 (1), 60–70.

Aliverti, A., Dellacà, R., Pelosi, P., Chiumello, D., Pedotti, A., Gattinoni, L., 2000. Optoelectronic plethysmography in intensive care patients. Am. J. Respir. Crit. Care. Med. 161 (5), 1546–1552.

Aliverti, A., Quaranta, M., Chakrabarti, B., Albuquerque, A.L., Calverley, P.M., 2009. Paradoxical movement of the lower ribcage at rest and during exercise in COPD patients. Eur. Respir. J. 33 (1), 49–60.

Baecke, J.A., Burema, J., Frijters, J.E., 1982. A short questionnaire for the measurement of habitual physical activity in epidemiological studies. Am. J. Clin. Nutr. 36 (5), 936–942.

Barcelar, J.M., Aliverti, A., Melo, T.L., Dornelas, C.S., Lima, C.S., Reinaux, C.M., de-Andrade, A.D., 2013. Chest wall regional volumes in obese women. Respir. Physiol. Neurobiol. 189 (1), 167–173.

Barnas, G.M., Green, M.D., Mackenzie, C.F., Fletcher, S.J., Campbell, D.N., Runcie, C., Broderick, G.E., 1993. Effect of posture on lung and regional chest wall mechanics. Anesthesiology. 78 (2), 251–259.

Behrakis, P.K., Baydur, A., Jaeger, M.J., Milic-Emili, J., 1983. Lung mechanics in sitting and horizontal body positions. Chest. 83 (4), 643–646.

Benedik, P.S., Baun, M.M., Keus, L., Jimenez, C., Morice, R., Bidani, A., Meininger, J., 2009. Effects of body position on resting lung volume in overweight and mildly to moderately obesity subjects. Respir. Care. 54 (3), 334–339.

Cala, S.J., Kenyon, C.M., Ferrigno, G., Carnevali, P., Aliverti, A., Pedotti, A., Macklem, P.T., Rochester, D.F., 1996. Chest wall and lung volume estimation by optical reflectance motion analysis. J. Appl. Physiol. 81 (6), 2680–2689.

Cawley, J., Meyerhoefer, C., 2012. The medical care costs of obesity: an instrumental variables approach. J. Health. Econ. 31 (1), 219–230.

Dean, E., 1985. Effect of body position on pulmonary function. Phys. Ther. 65 (5), 613–618.

De Groote, A., Wantier, M., Cheron, G., Estenne, M., Paiva, M., 1997. Chest wall motion during tidal breathing. J. Appl. Physiol. 83 (5), 1531–1537.

Dean, E., 2012. Part III: cardiovascular and pulmonary physical therapy: interventions (body positioning). In: Frownfelter, D., Dean, E. (Eds.), Cardiovascular and Pulmonary Physical Therapy: Evidence and Practice, second ed. Elsevier, St. Louis, MO, pp. 293–295.

Dixon, A.E., Peters, U., 2018. The effect of obesity on lung function. Expert Rev. Respir. Med. 12 (9), 755–767.

Kaneko, H., Shiranita, S., Horie, J., Hayashi, S., 2016. Reduced chest and abdominal wall mobility and their relationship to lung function, respiratory muscle strength, and exercise tolerance in subjects with COPD. Respir. Care. 61 (11), 1472–1480.

Katz, S., Arish, N., Rokach, A., Zaltzman, Y., Marcus, E.L., 2018. The effect of body position on pulmonary function: a systematic review. BMC. Pulm. Med. 18 (1), 159.

Konno, K., Mead, J., 1967. Measurement of the separate volume changes of rib cage and abdomen during breathing. J. Appl. Physiol. 22 (3), 407–422.

Mafort, T.T., Rufino, R., Costa, C.H., Lopes, A.J., 2016. Obesity: systemic and pulmonary complications, biochemical abnormalities, and impairment of lung function. Multidiscip. Respir. Med. 11 (1), 28.

Massaroni, C., Carraro, E., Vianello, A., Miccinilli, S., Morrone, M., Levai, I.K., Schena, E., Saccomandi, P., Sterzi, S., Dickinson, J.W., Winter, S., Silvestri, S., 2017. Optoelectronic plethysmography in clinical practice and research: a review. Respiration. 93 (5), 339–354.

Nielsen, K.G., Holte, K., Kehlet, H., 2003. Effects of posture on postoperative pulmonary function. Acta. Anaesthesiol. Scand. 47 (10), 1270–1275.

Romei, M., Mauro, A.L., D'Angelo, M.G., Turconi, A.C., Bresolin, N., Pedotti, A., Aliverti, A., 2010. Effects of gender and posture on thoraco-abdominal kinematics during quiet breathing in healthy adults. Respir. Physiol. Neurobiol. 172 (3), 184–191.

Salome, C.M., King, G.G., Berend, N., 2010. Physiology of obesity and effects on lung function. J. Appl. Physiol. 108 (1), 206–211.

Simoneau, J.A., Veerkamp, J.H., Turcotte, L.P., Kelley, D.E., 1999. Markers of capacity to utilize fatty acids in human skeletal muscle: relation to insulin resistance and obesity and effects of weight loss. FASEB. J. 13 (14), 2051–2060.

Sonpeayung, R., Tantisuwat, A., Klinsophon, T., Thaveeratitham, P., 2018. Which body position is the best for chest wall motion in healthy adults? A meta-analysis. Respir. Care. 63 (11), 1439–1451.

Steier, J., Lunt, A., Hart, N., Polkey, M.I., Moxham, J., 2014. Observational study of the effect of obesity on lung volumes. Thorax. 69 (8), 752–759.

Surendar, J., Indulekha, K., Deepa, M., Mohan, V., Pradeepa, R., 2016. Association of adiposity, measured by skinfold thickness, with parental history of diabetes in a South Indian population: data from CURES-114. Postgrad. Med. J. 92 (1089), 379–385.

Takashima, S., Nozoe, M., Mase, K., Kouyama, Y., Matsushita, K., Ando, H., 2017. Effects of posture on chest-wall configuration and motion during tidal breathing in normal men. J. Phys. Ther. Sci. 29 (1), 29–34.

Teerawattananon, Y., Luz, A., 2017. Obesity in Thailand and its Economic Cost Estimation Asian Development Bank Institute. ADBI Working Papers Series, vol.703. pp. 1–25. Available at: https://www.adb.org/sites/default/files/publication/236536/adbi-wp703.pdf, Accessed date: 31 December 2018.

World Health Organization, 2008. Waist Circumference and Waist to Hip Ratio: A Report of a WHO Expert Consultation, Geneva, 8-11 December 2008. Available at: https://apps.who.int/iris/bitstream/handle/10665/44583/9789241501491_eng.pdf, Accessed date: 31 October 2018.

Yamada, Y., Ueyama, M., Abe, T., Araki, T., Abe, T., Nishino, M., Jinzaki, M., Hatabu, H., Kudoh, S., 2017. Time-resolved quantitative analysis of the diaphragms during tidal breathing in a standing position using dynamic chest radiography with a flat panel detector system ("Dynamic X-ray phrenicography"): initial experience in 172 volunteers. Acad. Radiol. 24 (4), 393–400.

Yang, K.L., Tobin, M.J., 1991. A prospective study of indexes predicting the outcome of trials of weaning from mechanical ventilation. N. Engl. J. Med. 324 (21), 1445–1450.

Zoumot, Z., LoMauro, A., Aliverti, A., Nelson, C., Ward, S., Jordan, S., Michael, I.P., Pallav, L.S., Nicholas, S.H., 2015. Lung volume reduction in emphysema improves chest wall asynchrony. Chest. 148 (1), 185–195.