ORIGINAL ARTICLE

EFFECTS OF ASYMMETRIC CHEST VOLUME DEPENDING ON INSPIRATION LOAD

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ABSTRACT

Background: The purpose of this study was to investigate the effects of asymmetric chest volume depending on inspiration load using 3-dimensional motion analysis in a sitting position.

Methods: The participants were 13 sedentary healthy men with a mean age of 21.6 years, mean weight of 58.2 kg, mean height of 169.1 cm and a mean body mass index of 20.3 kg/m2. Using 3-dimensional motion analysis, changes were assessed in the upper thorax defined as the anterior position from the midpoint of the total chest volume from the sternal notch to the 3rd rib, and the lower thorax defined as the posterior portion from the midpoint of the total chest volume from the xiphoid process to the 10th rib.

Result: During both quiet breathing and deep breathing, and under any of the intake loads investigated, the upper right thorax exhibited a significantly larger change in chest volume than the upper left thorax($p=0.013$, $p=0.009$,$p=0.005$,$p=0.005$). Conversely, the lower left thorax exhibited a significantly larger change in chest volume than the lower right thorax ($p=0.009$, $p=0.005$, $p=0.013$, $p=0.009$).

Conclusion: The results of the current study, suggested that about chest configuration in the sitting positions, inspiration loads are larger in the upper right thorax and the lower left thorax than they are in the upper left thorax and lower right thorax.

Keywords: Three-dimensional motion analysis, thoracic volume, hemithorax, inspiration load, upright sitting, breathing

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INTRODUCTION

Respiratory muscles are one of the vital pump lines along with the heart and have an important role in the human body. The abilities of respiratory muscles can be divided into strength and endurance. Respiratory muscles can be assessed via mouth pressure. The maximum negative pressure during the inspiration phase is the maximum inspiratory mouth pressure(PImax) [1]. The maximum positive pressure during the expiration phase is the maximum expiratory mouth pressure (PEmax) [1]. In recent years, inspiratory muscle training (IMT) has been used as an endurance improvement training method by endurance athletes[2].

Respiratory excursion involves the contraction of respiratory muscles and acts as a vital pump. The respiratory excursion is diastolic motion caused by inspiration in the thorax and abdomen, and a relaxation movement caused by exhalation. The main muscle that contributes to the relaxation movement is the diaphragm [3].

This activity of the diaphragm is associated with the direct expansion of expanding the lower thorax to the exterior upside, and indirect expansion action that expands the upper thorax, in addition to intercostal muscle activity along with the expansion of the lower thorax.

Reduction in the mobility of each joint constituting the thorax confines thoracic motion. Increased oxygen consumption associated with respiratory movement, fatigue, and the sensation of dyspnea[4]. Therefore, improving thoracic mobility enhances excursion and reduces the effort required to breath.

Disturbed alignment of the thorax results in costal alignment deflection and influences the activity of the related trunk muscle. Due to the activities of the left and right asymmetrical trunk muscles, torsion appears in the upper thorax and the lower thorax with an inverted shape [5].

Kakizaki [6] reported that when resting, the upper thorax was in a right rotatory position and the lower thorax was in a left rotatory position.

In that evaluation attention was focused on the hemithoraces. In addition to abnormal alignment on the sagittal plane, Kakizaki reported asymmetric displacement of the thorax in the pelvis on the frontal plane, and in thoracic motion during breathing. This suggests that respiratory muscles are involved in respiratory excursion and thoracic mobility, and are affected by the muscles in the trunk.

In the present study, we investigated left- right discrepancies in chest expansion while sitting upright during two breathing patterns resulting in asymmetry of chest volume on the frontal plane. The specific purpose of the study was to investigate the effect of changes in volume during resulting load and increasing muscle activity while sitting upright, including any changes in left -right thoracic volume of the upper and lower hemithoraces using 3-dimensional motion analysis.

METHODS

Participants

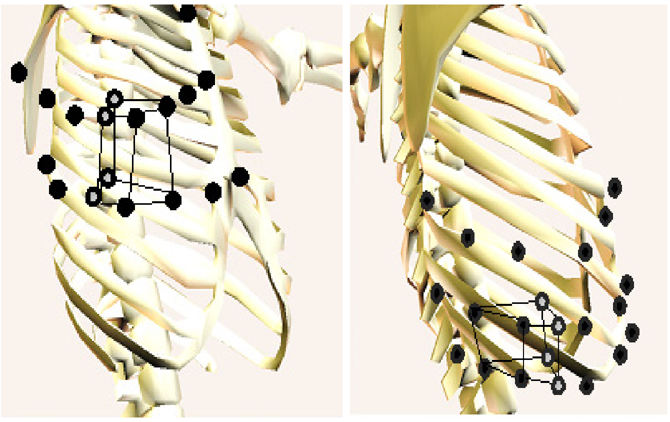
The participants were ten sedentary men with no history of smoking or respiratory or spinal conditions. They had a mean (SD)age of 21.6 (1.7) years (range:20-26), mean (SD)weight mass of 58.2 kg (8.9) (range:48-72), mean (SD) height of 169.1 (4.4) cm (range:162-175), and a mean (SD) body mass index of 20.3 kg/m^2 (2.5) (range:17.30-23.51). All purposes and procedures of the study were explained to the participants, and all provided written consent. This study was conducted in the Kinematics Laboratory at Bunkyo Gakuin University.

PROCEDURE

The participants were tested in an upright sitting position with a pelvic tilt of 0°, their feet flat on the floor, and 90° flexion of the hip and knee joints. The pelvic angle was defined as the angle created by an intersecting line formed by infrared reflective markers attached to the skin over the anterior and posterior superior iliac spines together with a spatial horizontal line, which was determined using a spirit level. A total of 84 infrared reflective markers each with a diameter of 9.5 mm were placed at specific points on the skin over the anterior and posterior aspects of the trunk. Their movement was used to record changes in thoracic volume. The precise positioning for both the anterior and posterior markers was determined via six midline markers placed in a vertical line on six levels, these being the sternal notch, 3rd rib, xiphoid process, 8th rib, 10th rib, and umbilicus, all of which are commonly used as guides for Palpation of chest movement. The 78 trunk markers were placed medially, centrally, and laterally to the midline markers on the anterior and posterior aspects of the trunk. Specifically, three markers were placed on either side of a midline marker, totaling seven markers in all. This procedure was repeated on the posterior aspect of the trunk at the levels above. The distance between each marker was based on the participant's physique and was set at 15% of the distance between the left and right acromion processes.

Using a 3-dimensional motion analyzer (Vicon MX, Vicon, Inc), the differences in volume within the upper and lower hemithoraces were measured in the testing above position during quiet breathing and deep volitional breathing, each with five or more consecutive breaths. An average value of three consistent breaths was used for the calculation. By previous studies [7-14], changes in thoracic volume were calculated based on the amount of change in the movement of the infrared reflective markers attached to the body surface. Seven infrared cameras were used, and the data were stored on a personal computer with a sampling frequency of 100 Hz.

Thoracic volume was calculated by the methods described by Ferrigno et al. [7] and Nakabo et al. [9]. Specifically, six imaginary hexahedra were visualized for the upper thorax three for the right and three for the left, using four markers for each on the anterior and posterior aspects at the levels of the sternal notch and third rib (Figure 1a). Similarly, this was repeated for the lower thorax at the levels of the xiphoid process and tenth rib (Figure 1b).



a b

Figure 1: Illustration of imaginary hexahedra.

a) One of six hexahedra on the upper thorax is seen demonstrated within the anterior markers and midpoints.

b) One of six hexahedra on the lower thorax is seen demonstrated within the posterior markers and midpoints.

Dots indicate markers from which the hexahedra were constructed.

Circles indicate imaginary midpoints.

Each of these hexahedra was then divided into three imaginary triangular pyramids to calculate positional vectors using the data obtained from the position of each marker in accordance with Ferrigno et al.'s [7] method. Lastly, the volume of the hexahedra and the triangular pyramids was calculated, and these volumes were used to calculate changes in thoracic volume.

Four thoracic volumes were measured: a) upper right and left hemithoraces' volumes emanating from a midpoint on an imaginary line connecting the sternal notch and the third rib; b) the lower right and left hemithoraces' volumes emanating from a midpoint on an imaginary line from the xiphoid process to the 10th rib(Thorax Motion System Analysis Model:TMSA-Model). The Vicon Body Builder and MATLAB (Math Works, Inc., Natick, U.S.A.) were used to calculate thoracic volumes.

As an index of respiratory muscle strength, a SPIROMETER HI-801(CHEST, Inc) respiratory function test device was used to measure for PImax. The participants were tested in an upright sitting position with a pelvic tilt of 0°, their feet flat on the floor, and 90° flexion of the hip and knee joints, and they were fitted with a nose clip and a mouthpiece.

The measurements were conducted by the method described by Black and Hyatt [14] for measuring PImax during maximum inspiration at the residual volume position. Each measurement was performed three times, and the maximum value was recorded as the PImax.

The intake load was 30% and 50% of PImax. The resistance load method was used Threshold IMT (Respironics).

For statistical analysis, the Wilcoxon rank-sum test was used for the comparison of changes in volume in the bilateral hemithoraces. The level of significance was set at $p < 0.05$, and the Statistics Package for Social Sciences version 23.0 (SPSS Japan Inc., Tokyo, Japan) for Windows was used for all data analysis. The study was approved by the Bunkyo University Medical Ethics Review Board (Approval No. 2016-0034).

RESULTS

In an upright sitting position, the mean PImax was 74.4 ± 23.9 cmH_2O, the mean 30%PImax was 22.3±7.2 cmH_2O, and the mean 50%PImax was 37.2±12.0 cmH_2O. During quiet and volitional deep breathing in an upright sitting position, for both 30%PImax and 50%PImax, the left upper hemithorax yielded a significantly larger volume than the right upper hemithorax (Table 1). However, this was reversed for the lower hemithoraces for both breathing patterns.

For both breathing patterns and 30%PImax and 50%PImax in an upright sitting position during expiration and inspiration, the left upper hemithorax yielded a significantly larger volume than the right upper hemithorax. However, this was reversed for the lower hemithoraces (Table 2).

Table 1: Relationship between the changes in the volume of the right and left hemithoraces depending on Inspiration load

Table 1.

N=10

		Thoracic volume (ml)							
		Quiet breathing	**p value**	**Volitional deep breathing**	**p value**	**30%PImax**	**p value**	**50%PImax**	**p value**
Upper thorax	Right	18.6±12.2	0.013*	85.4±84.7	0.009*	58.8±29.7	0.005*	62.0±24.7	0.005*
	Left	26.9±16.8		126.7±105.9		83.1±38.2		89.9±35.5	
Lower thorax	Right	54.5±15.1	0.009*	167.4±75.2	0.005*	124.1±41.8	0.013*	116.3±72.3	0.009*
	Left	44.2±13.8		114.6±46.9		97.7±41.3		92.7±39.2	

Mean (SD)

*p<0.05 (right hemithorax vs. left hemithorax)

Table 2: Changes in the volume of the right and left hemithoraces depending on Inspiration load during inspiration and expiration

Table 2

N=10

Change in the thoracic volume (ml)

			Quiet breathing	p value	Volitional deep breathing	p value	30%PImax	p value	50%Pimax	p value
Upper thorax	Inspiration	Right	805.3±186.5	0.005*	949.6±436.5	0.007*	837.1±82.9	0.005*	898.2±156.4	0.005*
		Left	1103.1±237.3		1241.1±423.2		1092.7±106.7		1124.3±160.5	
	Expiration	Right	786.6±177.8	0.005*	864.2±84.7	0.007*	778.3±72.5	0.005*	779.7±72.3	0.005*
		Left	1076.2±227.0		1114.4±330.2		1009.7±102.5		1034.4±141.6	
Lower thorax	Inspiration	Right	1451.2±342.6	0.005*	1491.2±35.8	0.005*	1534.2±437.1	0.007*	1492.9±406.6	0.005*
		Left	1253.6±293.7		1292.2±332.4		1311.2±382.2		1301.7±364.7	
	Expiration	Right	1396.7±337.1	0.005*	1323.8±317.7	0.005*	1407.1±406.1	0.007*	1376.5±381.8	0.005*
		Left	1209.5±290.9		1146.4±46.9		1213.5±353.5		1209.1±337.7	

Mean (SD)

*p<0.05 (right hemithorax vs. left hemithorax)

DISCUSSION

As an index of respiratory muscle strength, 30% PImax and 50% PImax from PImax are used to measure respiratory load [2]. To calculate volume change, we compared left and right hemithoraces volume changes based on inspiratory load in an upright sitting position with a pelvic tilt angle of 0°. Kakizaki in 2016 [6] states that, in an upright sitting, the left upper thoracic configuration is larger than the right. This is, however, reversed for the lower thoracic configurations even during deep volitional breathing. It has been suggested from results of a study by Shōbo and Kakizaki in 2016 [16] that this occurs because the anterior half is encompassed within the space of the upper thorax and the posterior half within the space of the lower thorax. In the current study, the left upper and right lower thoraces exhibited larger volume changes during inspiratory loading in the upright sitting position. These findings were in concordance with previous research results [15].

Kakizaki 2016[6] reported that the upper thorax exhibited a right rotation shape and the lower thorax exhibited a left rotation shape during a resting period. It was suggested that this was because the erector spinae muscle group was hypertonic on the left side from the axis to the center of the upper body mass and hypertonic on the right side of the axis to the center of the upper body mass. The results of the current study indicate similar thoracic motion, as shown in Table 2, In cases where the tidal volume increased from resting, the same breath movements occurred. This suggests that thoracic movement at rest is affected even when a larger thoracic movement is required. The left-right difference in the thorax causes a reduction in thoracic movement due to deterioration of the adaptability of the costovertebral joint, and declining thoracic movement is thought to affect the increase in respiratory rate and respiratory effort. Evaluation of the left and right thoraoes on the frontal plane at rest is considered to be one method for estimating increases in thoracic movements, such as those that occur during exercise.

The diaphragm exhibits inspiration motion and one of the inner unit in a breathing exercise. It is also involved in attitude control and maintaining the trunk in the extended position. An asymmetrical rib cage shape with the rotation of the rib functions to hold the trunk in an extended position. These factors may lead to functional deterioration of the diaphragm. However, neither ultrasonic examinations nor electromyogram examinations were used in the current study. Thus it was not possible to determine the condition of the diaphragm. Therefore, future investigations should include the examination of respiratory muscle activity and related factors via differences in thoracic configuration. Another of the limitations of the current study was that it only included healthy young men, and in the future, it will also be necessary to investigate these phenomena in the elderly, and patients with respiratory diseases.

CONCLUSION

The results of the current study suggest that the upper thorax may be rotated to the right and the lower thorax to the left even at the very commencement of quiet breathing, and such a configuration becomes exaggerated even when the amount of ventilation increases. It is thought that the evaluation of thoracic movement at rest is one means of estimating thoracic movement when tidal volume increases and thorax motion increases. Evaluating asymmetry of the thoracic configuration on the frontal plane and making efforts to improve it leads to maintenance and improvement of thoracic mobility and also may improve ventilation function.

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