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Original Article

Oxygen cost of thoracic and diaphragmatic breathing during hyperventilation in healthy males

Nobuhisa Ishii, PT, MS[1, 2], Kazuhide Tomita, PT, PhD[1, 3]*, Shinsuke Suetake[3], Yukako Okuno, PT, PhD[3], Kenta Kawamura PT, MS[1], Reiko Takeshima, MD, PhD[4], Hirotaka Ohse, MD, PhD[1], Shigeyuki Imura PT, PhD[5]

[1] *Graduate School of Health Science, Ibaraki Prefectural University of Health Sciences: 4669-2 Ami, Ibaraki 300-0394, Japan*
[2] *Ibaraki Prefectural Central Hospital, Japan*
[3] *Department of Physical Therapy, Ibaraki Prefectural University of Health Sciences, Japan*
[4] *Center for Medical Sciences, Ibaraki Prefectural University of Health Sciences, Japan*
[5] *Master Course of Science in Physical Therapy, Takasaki University of Health and Welfare Graduate School of Health Care, Japan*

Abstract. [Purpose] It is unclear whether diaphragmatic breathing (DB) results in lower respiratory muscle oxygen consumption during dynamic exercise. The purpose of this study was to compare oxygen consumption in the respiratory muscles (VO_2RM) with thoracic breathing (TB) and with DB, in healthy males during hyperventilation. [Subjects and Methods] Ten healthy men participated in this study. The subjects sat on a chair with the backrest reclined at an angle of 60 degrees. Respiratory parameters were measured breath by breath, using an expired gas analyzer. Oxygen consumption was measured for three minutes during quiet breathing. Measurements during TB and DB were performed for one minute each, after connecting a rebreather loading device. The breathing pattern was analyzed by inductance plethysmography, using transducer bands placed over the chest and abdomen that recorded thoracoabdominal movements. [Results] Both ΔVO_2/body weight and VO_2RM decreased significantly with DB when compared to that with TB, during hyperventilation. [Conclusion] DB results in less respiratory muscle oxygen consumption, even during dynamic exercise.

Key words: Respiratory muscle, Oxygen consumption, Diaphragmatic breathing

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INTRODUCTION

During aerobic exercise, ventilation gradually increases proportional to the metabolic demands of exercising muscles. Changes in minute ventilation (VE) associated with exercise are induced by increased work of breathing[1]. Similar to the other skeletal muscles, respiratory muscles need sufficient blood flow to meet the oxygen demand associated with increased work of breathing[2]. In healthy humans, oxygen consumption by the respiratory muscles (VO_2RM) during maximal exercise represents 10–15% of whole-body maximal oxygen consumption (VO_2max)[3–5]. In patients with chronic obstructive pulmonary disease (COPD), in addition to the effects of impaired lung function, VO_2RM increases in relation to excessive respiratory muscle function during locomotor activity[6]. Consequently, oxygen consumption in the leg muscles decreases, with a reduction in general endurance capacity. Collins et al.[7] reported that aerobic exercise and controlled breathing with prolonged exhalation showed a significant effect compared with aerobic exercise alone in patients with COPD. In this study, controlled breathing to

*Corresponding author. Kazuhide Tomita (E-mail: tomitak@ipu.ac.jp)

extend the exhalation time, was performed to suppress dynamic hyperinflation. As a result, it was possible to reduce VO_{2RM} proportional to the decrease of VE.

As previously described, breathing control plays an important role in aerobic exercise. Jones et al.[8] reported that diaphragmatic breathing (DB) resulted in less oxygen consumption by the respiratory muscles only during static exercise. However, it is unclear whether during dynamic exercise, DB results in lower respiratory muscle oxygen consumption. We speculated that DB, which controls thoracoabdominal and diaphragmatic movement, may reduce VO_{2RM}, depending on the level of VE during exercise.

We hypothesized that during DB, with a breathing pattern associated with lower respiratory muscle activity, VO_{2RM} may be less than during thoracic breathing (TB), associated with higher respiratory muscle activity. Measurement of respiratory muscle oxygen consumption during aerobic exercise is difficult because it is not possible to measure oxygen consumption of locomotor muscles and that of respiratory muscles separately. Therefore, as an alternative method, VO_{2RM} was measured during hyperventilation while maintaining extremity muscles inactive as much as possible. The purpose of this study was to compare VO_{2RM} during TB and DB during hyperventilation induced by rebreathing in healthy males.

SUBJECTS AND METHODS

Ten healthy male subjects, with no cardiac or pulmonary disease and normal spirometry values participated in this study (Table 1). All procedures adhered to the Declaration of Helsinki and were approved by the Ibaraki Prefectural University of Health Sciences Ethics Committee (Approval number 736). The subjects provided consent after being explained the purpose of and procedures involved in the study.

Respiratory parameters were measured using a breath by breath method with an expired gas analyzer (AE 100i, Minato Medical Science, Tokyo). Using a one-way valve attachment to each of the 'Y' pieces, a rebreathing mechanism was created in the circuit with a capacity of about 6 l. The device was attached to the mask of the expired gas analyzer and the rebreathing load was measured. Concentrations of oxygen and carbon dioxide in the inspired gas were measured within the circuit using another expired gas analyzer (Benchmark Exercise Test System, PK Morgan Ltd., UK). The breathing pattern was analyzed by inductance plethysmography, using transducer bands attached to the chest and abdomen (Respitrace, Ardsley, NY, USA). The bands were placed approximately at the level of the xiphoid process and the umbilicus, and fixed to avoid loosening. In addition, an ECG electrode and a transcutaneous oxygen saturation sensor were attached. All measured data were synchronously recorded as analog signals at a sampling frequency of 100 Hz using time series analysis application software (Chart 5.5.6, ADInstruments, Australia) on a personal computer (Fig. 1).

The subjects sat on a chair with the backrest reclined at angle of 60 degrees. In addition, the head was placed on a stable pillow, the upper extremities were held still on a table beside the subject and the lower extremities were held in minimal knee flexion. The subjects were instructed not to activate muscles other than the respiratory muscles to enable measurement of VO_{2RM}.

First, the oxygen consumption was measured for three minutes during quiet breathing, ensuring no increase in oxygen consumption due to excessive muscle activity. Prior to measuring the test task, the subjects practiced both TB and DB for about five minutes guided by the Konno-Mead diagram displayed on the monitor screen[9]. The measurement started after familiarization with the technique. Secondly, measurements of TB and DB were performed for one minute each after connecting the rebreather device and stabilizing the ventilatory state. During this measurement, switching from TB to DB was carried out by verbal instruction. Data acquired included respiratory rate (fR), tidal volume (VT), VE, VO_2, VO_2 per body weight (VO_2/BW), heart rate (HR), transcutaneous oxygen saturation (SpO_2), and excursions of the thorax and abdomen during TB and DB. Thoracic (MTH) and abdominal (MABD) excursions accompanying tidal breathing were defined as MTH / (MTH + MABD), ($Ratio_{TH\text{-}ABD}$). The values of $Ratio_{TH\text{-}ABD}$ and ventilatory parameters were calculated as an average value over a minute.

The VO_{2RM} of TB and DB was defined as the oxygen consumption required to generate 1 l of ventilation, that is, (ΔVO_2 / BW) / ΔVE. In detail, the experimental protocol was as follows: (*a*) the subjects performed quiet breathing for three min, (*b*) performed TB for a minute, and (*c*) DB for a minute. Effects of TB and DB on VO_{2RM} were compared using the following formula: (VO_2 / BW at *b* or *c* −VO_2 / BW at *a*) / (VE at *b* or *c* −VE at *a*) [ml/min/kg/l]. The VO_{2RM} values during TB and DB were statistically analyzed by a paired t-test using a SPSS, Statistics 22 software package. Statistical significance was set at $p<0.05$. All values were presented as means ± SD.

RESULTS

During quiet breathing, the $Ratio_{TH\text{-}ABD}$ was 29.5 ± 8.0%. SpO_2 and HR were 96.4 ± 0.8% and 64.9 ± 8.9 beats/min, respectively; VT was 715.6 ± 224.1 ml; fR, 12.1 ± 4.6 breaths / min and VE, 7.8 ± 2.0 l / min. In this ventilatory state, the VO_2 / BW was 4.4 ± 0.4 ml/kg.

After attachment of the rebreather device, FIO_2 and $FICO_2$ of inspired gas in the device were 20.3 ± 0.3% and 0.4 ± 0.2%, respectively; SpO_2 was 95.9 ± 1.1%, HR was 67.8 ± 8.2 beats/min, and remained nearly constant. Table 2 shows the averages of the $Ratio_{TH\text{-}ABD}$ and the ventilatory parameters during TB and DB during hyperventilation. The average of the

Table 1. Anthropometric and spirometric values

Characteristic	Men (n=10)
Age (years)	21.2 ± 0.9
Height (cm)	169.8 ± 5.2
Mass (kg)	60.8 ± 7.9
VC (l)	4.9 ± 0.7
VC (% predicted)	115.1 ± 13.2
FEV1/FVC (%)	88.9 ± 7.6

VC: vital capacity; FEV1: forced expired volume in 1 s. Values in this table are means ± SD.

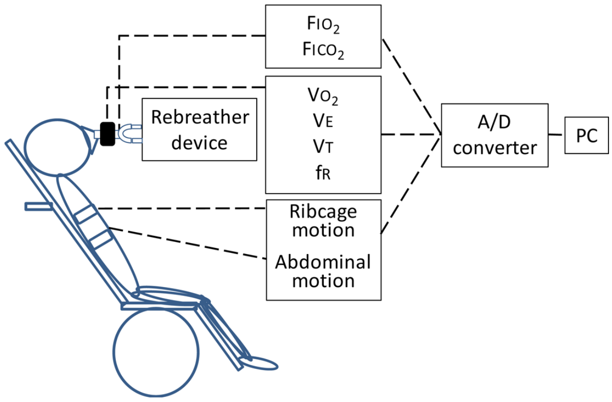

Fig. 1. Experimental equipment.
Measurements were carried out with an expired gas analyzer and respiratory inductive plethysmography (RIP). The rebreather device was connected to the gas analyzer. The analog signals obtained by the expired gas analyzer and RIP were converted to digital format with a computerized analysis system.

Table 2. Comparison of cardiopulmonary values between TB and DB during hyperventilation

	TB	DB
$Ratio_{TH\text{-}ABD}$ [%]	65.9 ± 12.5	14.5 ± 5.2*
VT [ml]	1,485.4 ± 273.4	1,344.9 ± 250.9*
fR [breaths/min]	9.5 ± 2.6	9.6 ± 2.5
VE [l/min]	13.7 ± 4.9	12.8 ± 4.0
VO_2 / BW [ml/min/kg]	5.1 ± 1.1	4.1 ± 1.0*

TB: thoracic breathing; DB: diaphragmatic breathing; $Ratio_{TH\text{-}ABD}$: percent thoracic movement excursions to total thoraco-abdominal movement excursions; VT: tidal volume; fR: breathing frequency; VE: minute ventilation; VO_2/BW: oxygen uptake per body weight. *Significantly different ($p<0.05$).

Table 3. Oxygen cost between TB and DB under hyperventilation

	Calculating formula	TB	DB
ΔVO_2/BW [ml/min/kg]	VO_2/BW at b or c −VO_2/BW at a	0.69 ± 0.84	−0.31 ± 0.95*
ΔVE [l/min]	VE at b or c −VE at a [l/min]	5.8 ± 3.2	4.9 ± 2.7
VO_2RM [ml/min/kg/l]	(ΔVO_2/BW)/ΔVE	0.11 ± 0.14	−0.11 ± 0.26*

TB: thoracic breathing; DB: diaphragmatic breathing; VO_2/BW: oxygen uptake per body weight; VE: minute ventilation; VO_2RM: respiratory muscle oxygen uptake; *a*: quiet breathing; *b*: thoracic breathing; *c*: diaphragmatic breathing. *Significantly different ($p<0.05$).

$Ratio_{TH\text{-}ABD}$ was significantly lower by approximately 15% during DB than in approximately 66% during the TB ($p<0.05$). There was no significant difference in fR and VE between both types of breaths, though VT significantly increased with the DB compared to TB ($p<0.05$). The average of VO_2 / BW during DB was lower by 1.0 ml/kg compared to that during TB ($p<0.05$). Table 3 shows calculated oxygen consumption with both TB and DB during hyperventilation. Both ΔVO_2 / BW and VO_2RM significantly decreased during DB compared to TB ($p<0.05$). There was no significant difference in ΔVE between both types of breathing. DB improved VO_2RM twice as much as TB.

DISCUSSION

DB has been reported to result in less oxygen consumption by the respiratory muscles in the resting state[8]; it is, however, unknown whether oxygen consumption remains low even during dynamic exercise, with DB. We hypothesized that DB, with a breathing pattern associated with lower respiratory muscle activity, would result in lower oxygen consumption compared to TB, associated with higher respiratory muscle activity. This study compared VO_{2RM} between the two types of breathing using an expiratory gas analyzer during hyperventilation induced by rebreathing. As a result, in spite of similar fR and the VE during both types of breathing, the average of VO_2 / BW during DB decreased than that of TB. Furthermore, the average of VO_{2RM} calculated by the formula of $(\Delta VO_2 / BW) / \Delta VE$ remained significantly lower with DB rather than TB.

Teramoto et al.[10] reported that the thoracic contribution during tidal breathing increases with a higher exercise load in young, healthy subjects. The mechanism by which oxygen consumption by the respiratory muscles markedly increases during dynamic exercise may be due to increased recruitment and increased work of the respiratory muscles as the thoracic contribution increases[11, 12]. Comparing the oxygen consumption with breathing patterns, Taguchi et al.[13] reported that VO_2 during diaphragmatic breathing is lower with experimental tasks that restricted the movement of either the thorax or abdomen using a band that controlled for thoracic and/or diaphragmatic breathing. Breathing exercises involving the diaphragm are reported to generate low electromyographic activity in accessory respiratory muscles[14]. Therefore, VO_{2RM} decreases during diaphragmatic breathing with dynamic exercise probably because diaphragmatic breathing is with less recruitment of the respiratory muscles compared to that with thoracic breathing.

These results show that the DB is a respiratory pattern with less respiratory muscle oxygen consumption compared to the TB even during dynamic exercise. Therefore, it may be expected that reduction of oxygen consumption by the respiratory muscles with DB during dynamic exercise improves exercise tolerance because total oxygen consumption does not increase with excessive activity of the respiratory muscles. On the other hand, diaphragmatic breathing is also shown to be slightly variable during breathing practice, without visual feedback[15]. Consequently, when performing diaphragmatic breathing during dynamic exercise, it is also necessary to offer visual feedback so that diaphragmatic respiration can be maintained continuously, with better precision.

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