

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/7679644>

The Effect of Posture on Respiratory Activity of the Abdominal Muscles

Article in *Journal of PHYSIOLOGICAL ANTHROPOLOGY and Applied Human Science* · August 2005

DOI: 10.2114/jpa.24.259 · Source: PubMed

CITATIONS

53

READS

193

2 authors:



Takeshi Kera

Takasaki University of Health and Welfare

32 PUBLICATIONS 123 CITATIONS

SEE PROFILE



Hitoshi Maruyama

International University of Health and Welfare

211 PUBLICATIONS 779 CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:



Promoting Support System for Home Care [View project](#)

The Effect of Posture on Respiratory Activity of the Abdominal Muscles

Takeshi Kera¹⁾ and Hitoshi Maruyama²⁾

1) *Department of Physical Therapy, Health Science University*

2) *Department of Physical Therapy, International University of Health and Welfare*

Abstract The purpose of this study was to determine the influence of posture on the expiratory activity of the abdominal muscles. Fifteen young adult men participated in the study. Activities of the external oblique abdominis, internal oblique abdominis, and rectus abdominis muscles were measured electromyographically in various postures. We used a pressure threshold in order to activate the abdominal muscles as these muscles are silent at rest. A spirometer was used to measure the lung volume in various postures. Subjects were placed in the supine, standing, sitting, and sitting-with-elbow-on-the-knee (SEK) positions. Electromyographic activity and mouth pressure were measured during spontaneous breathing and maximal voluntary ventilation under the respiratory load. We observed that the lung volume changed with posture; however, the breathing pattern under respiratory load did not change. During maximal voluntary ventilation, internal oblique abdominis muscle expiratory activity was lower in the SEK position than in any other position, external oblique abdominis muscle inspiratory activity was lower in the supine position than in any other position, and internal oblique abdominis muscle activity was higher in the standing position than in any other position. During spontaneous breathing, external oblique abdominis muscle activity was higher during expiration and inspiration in the SEK position than in any other position. The internal oblique abdominis muscle activity was higher during both inspiration and expiration in the standing position than in any other position. The rectus abdominis muscle activity did not change with changes in posture during both inspiration and expiration. Increase in the external oblique abdominis activity in the SEK position was due to anatomical muscle arrangement that was consistent with the direction of lower rib movement. On the other hand, increase in the internal oblique abdominis activity in the standing position was due to stretching of the abdominal wall by the viscera. We concluded that differences in activity were due to differences in the anatomy of the abdominal muscles and the influence of gravity. *J Physiol Anthropol Appl Human Sci* 24(4): 259–265, 2005 <http://www.jstage.jst.go.jp/browse/jpa> [DOI: 10.2114/jpa.24.259]

Keywords: abdominal muscles, expiration, inspiration, posture, electromyography

Introduction

Posture affects the feeling of breathlessness in patients with chronic obstructive pulmonary disease (COPD). For example, patients usually assume a sitting-with-elbow-on-the-knee (SEK) and bent trunk position when they feel breathlessness after exercise. It is believed that the pectoralis major and serratus anterior muscles can assist inspiration in this position. Positioning of the body is important in respiratory rehabilitation. Training of breathing patterns begins in the semi-Fowler position and continues in the sitting or standing position until the patient can breathe with minimal or no breathlessness while walking and during self-care activities (Kisner and Colby, 2002).

The abdominal muscles include the rectus abdominis, external oblique abdominis, internal oblique abdominis, and transversus abdominis. These muscles play a role in trunk motion, posture, labor, vomiting, dejection, and respiration (D'Angelo and Agostoni, 1995; Essendrop et al., 2002; Hodges and Gandevia, 2000). Activity of the abdominal muscles is not generally observed during respiration at rest; however, these are activated during exercise and expiratory effort. Posture is also known to affect the activity of the abdominal muscles.

De Troyer (1983) reported that upper and lower abdominal muscle activities were observed in various tilt positions; however, such activity was not observed in the supine position. In contrast, tonic activity of the abdominal muscles was observed in 6 of 10 subjects in a 45-degree head-up position and in 8 of 10 subjects in an 80-degree head-up position. De Troyer explained that this increase in tonic activity resulted from an increase in intra-abdominal pressure attributed to gravity and that this activity served to prevent a shift in the length-tension relation by shortening the diaphragm (De Troyer, 1983). Other investigators reported that tonic abdominal muscles were more active in the standing position

than in the supine position (Abe et al., 1996; Barrett et al., 1994; Strohl et al., 1981). Barrett and colleagues measured abdominal muscle activity in 0-, 60-, and 90-degree head-up positions with expiratory breathing load. The abdominal muscle activity did not change with the degree of tilting; however, the lowest load required to activate the abdominal muscles occurred in the 90-degree head-up position. Thus, the threshold for abdominal muscle activation is low.

However, the relation between a posture that is commonly used by the breathless patients and respiratory activity of abdominal muscles in that posture has not been studied. Therefore, we conducted an electromyographic study to determine the effect of posture on abdominal muscle activity.

Methods

Subjects

Fifteen young adult men participated in our study (Table 1). It was confirmed that they did not have cardiovascular, pulmonary, neuromuscular, or orthopedic disease. Details of the study were explained to the subjects, and their informed consent was obtained.

Measurement of respiratory muscle strength

Respiratory muscle strength was expressed as mouth pressure during maximal expiratory and inspiratory effort (PE_{max} and PI_{max}, respectively). A cylinder 3 cm in diameter was connected to a valve, and a flange-type mouthpiece was connected at the other end. In accordance with Black and Hyatt's method, a 1.5-mm-diameter orifice was made in the valve to prevent artifacts (Black and Hyatt, 1968). A differential pressure transducer (TP-604T, Nihonkouden, Tokyo, Japan) was connected to the cylinder with a 5-mm-diameter tube. This apparatus was used to measure PE_{max} and PI_{max}. A nose clip was used during measurement. PE_{max} was measured at total lung capacity (TLC), and PI_{max} was measured at residual volume (RV). PI_{max} was expressed as an absolute value.

Spirometry

Lung capacity was measured using a spirometer (AS-300, Minato Medical Science, Osaka, Japan). A nose clip was used during spirometry. Vital capacity (VC), inspiratory residual volume (IRV), expiratory residual volume (ERV), tidal volume (TV), and forced vital capacity (FVC) were measured.

Abdominal muscle activation maneuver

The abdominal muscles are generally inactive at rest. We used an external respiratory load to activate the abdominal muscles. A Threshold[®] device (Healthscan, Cedar Grove, New Jersey, USA) was used to attain the load. The load was set at 20 cm H₂O.

Monitoring mouth pressure during loading

A differential pressure transducer (TP-604T, Nihonkouden)

Table 1 Characteristics of subject

Age (year)	25.9±3.8
Weight (kg)	67.9±4.3
Height (cm)	171.6±5.3
PE _{max} (cm H ₂ O)	150.1±36.8
PI _{max} (cm H ₂ O)	105.8±25.0
VC _(L)	4.71±0.33
FVC _(L)	4.60±0.30

Subjects were 15 men; values expressed as mean±SD, PE_{max}: maximal expiratory mouth pressure, PI_{max}: maximal inspiratory mouth pressure, VC: vital capacity, FVC: forced vital capacity

was connected to a Threshold[®] device via a side-stream port to monitor mouth pressure (P_{mus}) during loading.

Measurement of muscle activity

Electromyography was used to measure abdominal muscle activity. The external oblique abdominis, rectus abdominis, and internal oblique abdominis were chosen as target muscles. Electrodes were placed on the skin according to Ng's method (Ng et al., 1998). The skin was cleaned with an abrasive, and after the electrodes were placed, we confirmed that skin impedance was lower than 20 Ω. We used 2-cm-diameter Ag/AgCl disposable electrodes, and the electrodes were placed 2 cm apart. Each electrode was connected to an amplifier (AB-621G, Nihonkouden). Electrodes were placed on each muscle, and the placement was confirmed by flexion and rotation of the trunk (e.g., the placement of a pair of electrodes on the rectus abdominis was confirmed by flexion of the trunk, and that on the left external oblique abdominis was confirmed by right rotation of the trunk).

Electrocardiographic recording

EMG recording had to be corrected because of interference from the QRS complex. For this purpose, electrodes were placed on the upper region of the sternum and the node of the left side thorax. The ground electrode was placed on the right side of the thorax. Thus, the QRS wave was excluded from the raw EMG. The details are described in the data analysis.

Data collection

The measurement system is shown in Fig. 1. The P_{mus}, electromyography, and electrocardiography signals were synchronized; all signals were sampled at 2000 Hz with a PowerLab (AD Instruments, N.S.W, Australia). Digital signal data were stored in a personal computer (LB400/J, NEC, Tokyo, Japan) and were analyzed using wave analysis software (Chart Ver 4.2, AD Instruments).

Procedure

We defined the position that a patient usually assumes during dyspnea as sitting-with-elbow-on-the-knee (SEK). The order of positions (supine, standing, sitting, SEK) assumed during measurements was determined randomly. The spirometric measurements were taken three times for each

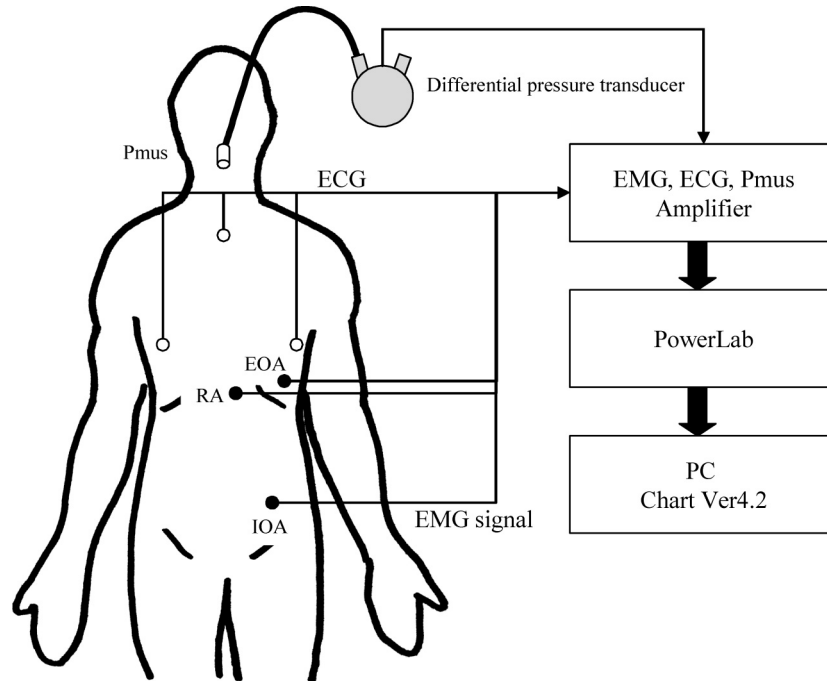


Fig. 1 Materials.

position. Prior to the experiment, the subjects were trained several times for the measurement of P_{Emax} and P_{Imax}. P_{Emax} and P_{Imax} were measured three times in the sitting position.

All subjects breathed with a 20 cm H₂O threshold load. Each subject stopped breathing for 5 s at the functional residual capacity (FRC) to determine the baseline P_{mus} and the baseline electromyographic values. The subject then breathed spontaneously with a normal rhythm under load (SB). Finally, the subject breathed with his best effort for 15 s for the measurement of maximal voluntary ventilation (MV). A verbal command was given to the subject to begin MV.

Data analysis

P_{mus} measured during respiration smoothed by a 1 s moving average. Maximal positive and negative values were determined for P_{Emax} and P_{Imax} (Enright et al., 1994). The P_{mus} measured at FRC during the stopped-breathing condition was defined as the baseline P_{mus}=0, and the respiratory phases were determined based on the P_{mus} record. The expiratory phase was defined as P_{mus} measured at positive pressure, and the inspiratory phase as P_{mus} measured at negative pressure. The expiratory time (T_e), inspiratory time (T_i), inspiratory time to total time ratio (T_i/T_{tot}), and respiratory frequency (f) were calculated from the P_{mus} values. The electromyogram of the abdominal muscles was calculated to root-mean-square values. The expiratory and inspiratory phase of the electromyogram wave that coincided with the QRS complex of the electrocardiogram was excluded because the QRS complex affected the numerical electromyographic value. The average expiration

and inspiration electromyogram amplitudes were calculated from 3 successive phases.

The lung volume, respiratory time, and average electromyogram amplitude in each position were compared by analysis of variance (ANOVA). Fisher's PLSD was used for comparisons between positions. $p < 0.05$ was considered as statistically significant.

Results

Lung volume in each position

The lung volumes in each position are given in Table 2. VC, IRV, and ERV changed with changes in posture ($p < 0.01$, 0.001, 0.001, respectively). VC in the standing, sitting, and SEK positions were larger than VC in the supine positions ($p < 0.05$, 0.01, 0.01, respectively). IRV was larger in the supine position than in the other positions ($p < 0.001$ for each), and IRVs in the sitting and standing positions were larger than that in the SEK position ($p < 0.01$ for each position). ERV was smaller in the supine position than in the other position ($p < 0.001$ for each position) and larger in the SEK position than in the sitting or standing positions ($p < 0.01$, 0.001, respectively).

Breathing pattern during SB and MV

The breathing pattern observed in each position is given in Table 3. The T_e, T_i, T_i/T_{tot}, and f during MV did not change significantly with changes in posture, except T_i/tot, which was longer in the sitting position than in the supine position. Similarly, the breathing pattern did not change with position during SB.

Table 2 The lung volume in various postures

	VC (L) ^{§§}	IRV (L) ^{§§§}	TV (L)	ERV (L) ^{§§§}
SEK	4.72±0.37	1.85±0.37	0.68±0.19	2.20±0.30
Supine	4.46±0.48	2.60±0.48	0.59±0.15	1.33±0.26
Sitting	4.71±0.35	2.12±0.43	0.67±0.18	1.91±0.26
Standing	4.63±0.37	2.15±0.32	0.69±0.26	1.78±0.35

Mean±SD
ANOVA § $p<0.05$ §§ $p<0.01$ §§§ $p<0.001$
Fisher's PLSD * $p<0.05$ † $p<0.01$ ‡ $p<0.001$

The PEmax, PImax, VC and FVC measured in sitting. VC: vital capacity, IRV: inspiratory residual volume, TV: tidal volume, ERV: expiratory residual volume

Table 3 The breathing pattern in various postures

Maximal voluntary ventilation (MV)				
	TE (sec)	Ti (sec)	Ti/Ttot	f (c/min)
SEK	0.39±0.57	0.34±0.44	0.49±0.03	126.14±41.37
Supine	0.25±0.08	0.23±0.09	0.48±0.02	134.94±34.79
Sitting	0.25±0.08	0.25±0.09	0.50±0.03	127.98±31.62
Standing	0.24±0.07	0.23±0.07	0.49±0.03	135.07±34.32

Spontaneous breathing (SB)				
	TE (sec)	Ti (sec)	Ti/Ttot	f (c/min)
SEK	0.61±0.88	1.56±0.57	0.38±0.11	15.23±3.88
Supine	2.97±1.66	1.59±0.63	0.37±0.12	14.83±5.22
Sitting	2.52±0.79	1.61±0.74	0.38±0.11	15.86±5.02
Standing	2.80±1.18	1.59±0.61	0.37±0.10	15.11±5.08

Mean±SD
ANOVA § $p<0.05$ §§ $p<0.01$ §§§ $p<0.001$
Fisher's PLSD * $p<0.05$ † $p<0.01$ ‡ $p<0.001$

Te: expiratory time, Ti: inspiratory time, Ti/Ttot: inspiratory time to total time ratio, f: respiratory frequency

Abdominal muscle activities in each position

Abdominal muscles activities during MV are given in Table 4. On expiration, the external oblique abdominis was not affected by posture, rectus abdominis muscle activity was higher in the supine position than in the standing position ($p<0.05$), and internal oblique abdominis muscle activity was lower in the SEK position than in the sitting or standing positions ($p<0.05$ for each position). On inspiration, external oblique abdominis and internal oblique abdominis muscle activities changed significantly with changes in position ($p<0.05$, 0.05, respectively). External oblique abdominis muscle activity was significantly higher in the SEK and standing positions than in the supine position ($p<0.01$, 0.05, respectively), and internal oblique abdominis muscle activity was higher in the sitting and standing positions than in the SEK position ($p<0.05$, 0.01, respectively).

Abdominal muscle activities in each position during SB are given in Table 5. On expiration, external oblique abdominis and internal oblique abdominis muscle activities changed significantly with changes in posture ($p<0.05$, 0.001,

respectively). External oblique abdominis muscle activity was higher in the SEK position than in the other positions ($p<0.05$ for each position). Internal oblique abdominis muscle activity was higher in the standing position than in the SEK or supine positions ($p<0.001$, 0.05, respectively), and also higher in the supine and sitting positions than in the SEK position ($p<0.05$, 0.01, respectively). On inspiration, external oblique abdominis and internal oblique abdominis muscle activities changed significantly with changes in posture ($p<0.05$, 0.001, respectively). External oblique abdominis muscle activity was higher in the SEK position than in the supine, sitting, or standing positions ($p<0.01$, 0.05, 0.05, respectively), and internal oblique abdominis muscle activity was higher in the standing position than in the SEK, supine, or sitting positions ($p<0.001$, 0.001, 0.01, respectively).

Discussion

We are aware that a patient with COPD can breathe with ease in the SEK position. The accessory inspiratory muscles

Table 4 The abdominal muscle activity in various postures during maximal voluntary ventilation (MV)

Expiration			
	EOA _(mV)	RA _(mV)	IOA _(mV)
SEK	1.13±0.65	1.00±1.09	1.44±1.30
Supine	0.95±0.51	1.15±1.24	2.16±1.82
Sitting	1.02±0.54	0.90±1.16	2.05±1.92
Standing	1.07±0.73	0.78±0.67	2.02±1.93

Inspiration			
	EOA _(mV) [§]	RA _(mV)	IOA _(mV) [§]
SEK	1.10±0.68	0.67±0.54	1.25±1.06
Supine	0.72±0.38	0.86±0.82	1.82±1.53
Sitting	0.86±0.57	0.70±0.83	1.93±1.64
Standing	0.99±0.83	0.80±0.75	2.13±2.04

ANOVA § $p < 0.05$ §§ $p < 0.01$ §§§ $p < 0.001$
 Fisher's PLSD * $p < 0.05$ † $p < 0.01$ ‡ $p < 0.001$
 EOA: external oblique abdominis, RA: rectus abdominis, IOA: internal oblique abdominis

Table 5 The abdominal muscle activity in various postures during spontaneous breathing (SB)

Expiration			
	EOA _(mV) [§]	RA _(mV)	IOA _(mV) ^{§§§}
SEK	0.23±0.21	0.26±0.12	0.19±0.12
Supine	0.14±0.08	0.24±0.10	0.47±0.38
Sitting	0.15±0.10	0.26±0.14	0.52±0.47
Standing	0.14±0.08	0.26±0.11	0.69±0.68

Inspiration			
	EOA _(mV) [§]	RA _(mV)	IOA _(mV) ^{§§§}
SEK	0.22±0.25	0.24±0.09	0.16±0.11
Supine	0.12±0.07	0.20±0.09	0.16±0.12
Sitting	0.13±0.11	0.23±0.11	0.24±0.16
Standing	0.12±0.07	0.22±0.11	0.41±0.37

ANOVA § $p < 0.05$ §§ $p < 0.01$ §§§ $p < 0.001$
 Fisher's PLSD * $p < 0.05$ † $p < 0.01$ ‡ $p < 0.001$
 EOA: external oblique abdominis, RA: rectus abdominis, IOA: internal oblique abdominis

around the pectoral girdle are easily activated in the SEK position owing to placement of the upper limbs on the thighs. We expected similar findings in case of the abdominal muscles.

We used EMG for analysis of muscle activity; however, the amplitudes varied in each subject because the electrical muscle activity amplitude is affected by muscle size and thickness, fatty tissue on the muscle, skin impedance, and electrode placement. Therefore, we did not change electrode placement once the measurements had started.

Lung volume changes with changes in posture, particularly when affected by gravity (D'Angelo and Agostoni, 1995). VC and TLC values showed a relative decrease in the supine position as compared to those in the standing position. This

change is mainly attributed to a shift in blood flow from the lower limbs to the thoracic cavity. The FRC also changes with change in posture; however, the cause is different. Assuming that the abdomen is like a cavity filled with fluid, the upper abdominal pressure in the supine position is higher than that in the standing position (Agostoni et al., 1970). In the supine position, the abdominal contents push the diaphragm into the thoracic cavity, thus raising the diaphragm and decreasing the FRC relative to standing conditions. In our study, we measured the FRC, and the ERV was expressed relative to the FRC.

We expected that in the SEK position, the VC would decrease with increasing intra-abdominal pressure due to the flexed trunk. However, the results obtained were contrary to

our expectations; the VC in the SEK position was similar to that in the standing position, and it was larger than that in the supine position. Others have reported the same findings (Craig et al., 1960). It is reasoned that in the SEK position, the abdominal wall is pulled by gravity, and this prevents an increase in intra-abdominal pressure. Furthermore, the accessory inspiratory muscles that connect the ribs and scapula (e.g., the pectoralis major and minor muscles) are easily activated when the arms are pressing on the thighs, and these muscles extend the rib cage.

The determining factor for FRC is the elastic recoil pressure of the rib cage and the reduced pressure in the lungs. The FRC is affected by changes in pressure over and under the diaphragm. In our study, ERV, which is closely related to FRC, increased in the SEK position. Craig et al. explained these effects in terms of a shift of the volume-pressure curve of the whole respiratory system, including the abdominal contents. Usually, the respiratory system is thought to include only the lungs and thorax, and muscles generate positive pressure above the FRC and negative pressure below the FRC (Craig et al., 1960). The volume-pressure curve shifts to the left in the SEK position; therefore, the intra-thoracic pressure is more negative in the SEK than in the sitting position. Consequently, the diaphragm moves down, and FRC is increased.

The ventilation time is usually calculated from flowmeter data; however, we calculated each time value from Pmus. These values were not consistent with flow data because muscle activities start when pressure develops, even in the absence of airflow.

Although many studies have been conducted on respiratory responses to a threshold-type respiratory load, those studies were about inspiratory load (Goldstein et al., 1989; Larson et al., 1988; McElvaney et al., 1989) because P_{imax} is of most interest in a patient with respiratory muscle weakness, and the inspiratory muscles are trained more than expiratory muscles. Thus, we were able to compare our load with a continuous positive airway expiratory threshold load, which is classified as a static load. The TV was reduced and T_e was prolonged at this load in comparison to values in the absence of a load (Daubenspeck, 1995). These changes may reflect an attempt to preserve the TV. However, in our study, the respiratory pattern did not change with changes in posture, i.e., posture change did not affect the respiratory control system.

External oblique abdominis activity during expiratory and inspiratory breathing was increased in the SEK position. The abdominal muscles can contract strongly when the trunk is flexed and the upper limbs are pressed against the thighs. Contraction of trunk muscle is not always necessary for trunk fixation in the SEK position because of gravity, and the abdominal muscles can be used for respiration. We predicted that the VC would decrease with trunk flexion because this posture induces an increase in intra-abdominal pressure. However, the VC did not decrease in the SEK position. The lack of change in the VC was due to the shift in the volume-pressure curve of the respiratory system and the raising of the

rib cage by the pectoralis major and minor muscles. Furthermore, the external oblique abdominis muscle was stretched with the rib motion, resulting in a muscle stretch reflex; therefore, external oblique abdominis activity increased on inspiration.

The increased external oblique abdominis activity on expiration was due to a different cause. On expiration, differential activation of the external oblique abdominis, internal oblique abdominis, and rectus abdominis is due to the different anatomical arrangements of these muscles. The external oblique abdominis is arranged from the lateral direction—forward, centrally, and downward. This arrangement is consistent with the direction of lower rib movement; however, the internal oblique abdominis and rectus abdominis muscle arrangements are not. Thus, the external oblique abdominis affects the movement of the rib cage. We believe that external oblique abdominis activity in the SEK position contributes to decreased dyspnea in patients with COPD.

Internal oblique abdominis activity during expiration was decreased in the SEK position; however, it was increased during inspiration in the standing position. Pressure on the lower abdominal wall by the thigh caused a decrease in internal oblique abdominis activity in the SEK position. In this position, the hip is flexed, and the lower abdominal wall is close to the proximal part of the thigh. The reason for the increase in internal oblique abdominis activity on standing is clear. De Troyer et al. showed that in the standing position the abdominal wall is stretched by the viscera (De Tryoer, 1983). We measured internal oblique abdominis activity on the lower abdominal wall to avoid abdominal muscle crosstalk in our study, and we assumed that the increased internal oblique abdominis activity on standing was due to gravity. The rectus abdominis activity was not affected by posture. It is the least effective muscle among all the abdominal muscles for expiration.

The patients with severe COPD assume an SEK when they experience breathlessness after exercising, which is a part of the rehabilitation program. This behavior is not only related to the activities of the inspiratory accessory muscle (e.g., pectoral major and serratus anterior muscles) but also to expiratory muscles such as the external oblique muscle. The activation of the external oblique muscle assists inspiration in patients with COPD who experience breathlessness because a deep expiration naturally induces a deep inspiration. Inspiratory muscles, such as the diaphragm, are stretched or strained during expiration and the length-tension relationships of these muscles are improved. According to the pressure-volume diagram, the expansion elastic recoil of the respiratory system increases during expiration (Rahn et al., 1946). Following this, the inspiratory muscles do not need to contract while the thorax and lungs expand from the end of expiration to FRC, but they need to contract above FRC. Furthermore, patients with COPD have a limited airflow on expiration, and the abdominal muscle activities are activated in patients with

severe COPD (Vincent et al., 1992). Thus, the external oblique muscle activation in SEK is beneficial to respiratory muscle dysfunction.

The abdominal muscle activity differed in various postures. Those differences in activity were due to differences in the anatomical arrangements of abdominal muscle. We concluded that external oblique muscle activity in SEK was availed of for decreasing dyspnea in patients with COPD when they became exhausted.

References

- Abe T, Kusahara N, Yoshimura N, Tomita T, Easton PA (1996) Differential respiratory activity of four abdominal muscles in humans. *J Appl Physiol* 80: 1379–1389
- Agostoni E (1970) Mechanics and neural control. In Campbell EJM ed. *The Respiratory Muscles*. Lloyd-Luke, London, 48–79
- Agostoni E, Campbell EJM (1970) The abdominal muscles. In Campbell EJM ed. *The Respiratory Muscles*. Lloyd-Luke, London, 175–180
- Barrett J, Cerny F, Hirsch JA, Bishop B (1994) Control of breathing patterns and abdominal muscles during graded loads and tilt. *J Appl Physiol* 76: 2473–2480
- Black LF, Hyatt RE (1968) Maximal respiratory pressures: normal values and relationship to age and sex. *Am Rev Respir Dis* 99: 696–702
- Craig AB Jr (1960) Effects of position on expiratory reserve volume of the lungs. *J Appl Physiol* 15: 59–61
- D'Angelo ED, Agostoni E (1995) Statics of the chest wall. In Roussos C, Macklem PT eds. *The Thorax*. 2nd ed., Dekker, New York, 457–493
- Daubenspeck JA (1995) Mechanical Aspects of Loaded Breathing. In Roussos C, Macklem PT eds. *The Thorax*. 2nd ed., Dekker, New York, 953–985
- De Troyer A (1983) Mechanical role of the abdominal muscles in relation to posture. *Respir Physiol* 53: 341–353
- Enright PL, Kromal AR, Manolio TA, Schenker MB, Hyatt RE (1994) Respiratory muscle strength in the elderly. *Am J Respir Crit Care Med* 149: 430–438
- Essendrop M, Schibye B, Hye-Knudsen C (2002) Intra-abdominal pressure increases during exhausting back extension in humans. *Eur J Appl Physiol* 87: 167–173
- Goldstein R, De Rosie J, Long S, Dolmage T, Avendano MA (1989) Applicability of a threshold loading device for inspiratory muscle testing and training in patients with COPD. *Chest* 96: 564–571
- Hodges PW, Gandevia SC (2000) Changes in intra-abdominal pressure during postural and respiratory activation of the human diaphragm. *J Appl Physiol* 89: 967–976
- Kisner C, Colby LA (2002) Management of pulmonary conditions. In *Therapeutic Exercise; Foundations and Techniques*. 4th ed., F.A. Davis Company, Philadelphia, 783–774
- Larson JL, Kim MJ, Sharp JT, Larson DA (1988) Inspiratory muscle training with a pressure threshold breathing device in patients with chronic obstructive pulmonary disease. *Am Rev Respir Dis* 138: 689–696
- McElvaney G, Fairbairn MS, Wilcox PG, Pardy RL (1989) Comparison of two-minute incremental threshold loading and maximal loading as measures of respiratory muscle endurance. *Chest* 96: 557–563
- Ng JK, Kippers V, Richardson CA (1998) Muscle fibre orientation of abdominal muscles and suggested surface EMG electrode positions. *Electromyogr Clin Neurophysiol* 38: 51–58
- Strohl KP, Mead J, Banzett RB, Loring SH, Kosch PC (1981) Regional differences in abdominal muscles activity during various maneuvers in humans. *J Appl Physiol* 51: 1471–1476

Received: June 7, 2004

Accepted: April 7, 2005

Correspondence to: Takeshi Kera, Department of Physical Therapy, Health Science University, 7187 Kodachi, Fujikawaguchikomachi, Minamitsurugun, Yamanashi, Japan

Phone: +81-0555-83-5286

Fax: +81-0555-83-5286