



Original Article

Instantaneous changes in respiratory function induced by passive pelvic suspension in the supine position in relation to increased diaphragm excursion

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Abstract. [Purpose] This study aimed to introduce an approach of pelvic suspension (PS) using sling cords and to obtain evidence for changes in respiratory function of healthy subjects. [Subjects and Methods] Subjects were 25 healthy men. In the supine position, with hip and knee joints flexed at 90°, the subjects' pelvises were suspended with sling belts. Diaphragm excursion, respiratory function, and respiratory comfort in these postures were measured using ultrasonography, respirometry, and visual analog scale (VAS), respectively. [Results] When the pelvis was passively suspended with sling cords, the diaphragm moved 5 mm cranially and diaphragm excursion showed an instantaneous increase compared with the control. The tidal volume (V_T) showed an increase and the respiration rate (RR) showed a decrease. The extent of diaphragm excursion was correlated with changes in V_T under the control and PS conditions. Independent measurements of pulmonary function revealed that PS reduced the expiratory reserve volume, being correlated positively and negatively to increases in vital and inspiratory capacities, respectively. Furthermore, VAS values for respiratory ease were greater with PS than with the control. [Conclusion] These results suggest that PS effectively changed diaphragm excursion and respiratory function, leading to ease of breathing (i.e., deep and slow respiration).

Key words: Pelvic suspension, Diaphragm excursion, Respiration function

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INTRODUCTION

The movement of the diaphragm is a major factor of respiration¹⁾. Cranial and caudal movements of the diaphragm are associated with expiration and inspiration phases of respiration, respectively. Diaphragmatic breathing is often used as a strategy for respiratory rehabilitation to improve the ventilation efficiency with an increase in tidal volume and a decrease in

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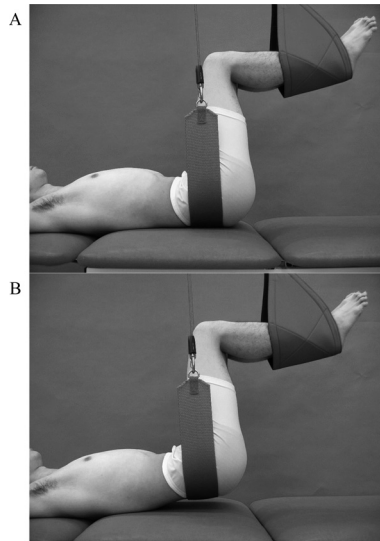


Fig. 1. Postures at resting (A, Rest) and pelvis-suspended conditions (B, PS) attained by using sling belts anchored directly above the navel

The lower legs are passively pulled up with the hip and knee joints flexed at a 90° angle using a wide cord (20 cm wide) wrapped around the lower leg distal portion. Using a narrow cord (10 cm wide) to place the belt at an objective part, under the sacral bone, of the pelvis, the pelvis is lifted up until the first lumbar spinous process, but not the thoracic spine, is only slightly lifted from the bed surface.

respiratory rate^{2, 3}). The effectiveness of diaphragmatic breathing might be partly dependent on the expiration process with the elevation of the diaphragm toward the cranial direction. For the achievement of diaphragm elevation in human subjects, the supine position is better than the standing position, as the effect of gravity on diaphragm movement decreased in the supine position. Then, we can infer that the lifting of the hip in the supine position might be beneficial for expiration, as it makes the slope of the trunk move toward the head to bring about ease in cranial movement of the diaphragm. For passively lifting up the hip without using the hands in the present experiments, we employed pelvic suspension (PS) methods by using commercially available sling belts, which have been used for sling exercises for the neck, trunk, and upper and lower extremities to improve exercise activities⁴⁻⁷). We also investigated the effects of the PS on the diaphragm excursion and respiratory function of healthy men using ultrasonography, exhaled gas analysis, and spirometry.

SUBJECTS AND METHODS

The subjects were 25 healthy men (age: 24.9 ± 2.3 years, height: 171.7 ± 5.2 cm, body mass: 65.1 ± 6.6 kg, body mass index: 22.1 ± 1.7 kg/mg² [mean \pm SD]). There were 3 smokers in the subjects. They did not have any respiratory, spinal, and chest diseases; anamneses of thoracotomy and laparotomy; or obvious spinal and thoracic deformations. Before commencement of the experiments, the subjects were informed and read the scientific purpose and significance of the research, and signed the written consent form. This study was approved by the ethics committee of Bunkyo Gakuin University in accordance with the Declaration of Helsinki revised October 2013 (approval No. 2014-MSJ19).

The subject was made to lie on the bed in the supine position. For the experiments, two postures, namely resting (Rest) and pelvis-suspended conditions (PS), were attained by using sling belts (Redcord, Norway) anchored directly above the navel (Fig. 1). Rest posture was attained when the lower legs were passively pulled up with the hip and knee joints were flexed at a 90° angle. This posture was attained using a wide cord (20 cm wide) wrapped around the lower leg distal portion. The cord was wide enough to obtain a stable leg position without an apparent burden of the subject. Furthermore, a narrow cord (10 cm wide) was used to place the belt on an objective part, under the sacral bone, of the pelvis for suspension. PS was achieved by pulling up the narrow cord to suspend the pelvis until the first lumbar spinous process, but not the thoracic spine, was only slightly lifted from the bed surface. When the pelvis was pulled up higher, many subjects complained with the difficulty in breathing, and the position of pelvis on the sling became unstable.

By using a real-time ultrasonography machine with high-speed and high-quality image processing (Hi Vision Preirus, Hitachi Aloka Medical, Ltd., Tokyo, Japan), the diaphragm position and excursion in the body trunk were measured. A transverse scanner with a 4-MHz convex transducer (EUP-C514, Hitachi Aloka Medical, Ltd.) was placed at the subcostal arch along the midclavicular line for the measurement; protocol adapted from Testa et al⁸). The depth as measurable using ultrasonography was set at 210-mm. The gain was adjusted appropriately to obtain clear images. The scanner was first set at

B-mode to show the gallbladder on the center and the vena cava on the right side of the screen, and the rear portion of the right diaphragm was detected through the liver. Then, switching to M-mode with the slowest sweep mode, the diaphragm excursion in a craniocaudal direction was measured as a wavelike curve.

As the bottom of the wavelike curve indicates the farthest place from the transducer, it corresponds to the diaphragm position at expiration, and the top of the curve corresponds to the diaphragm position at inspiration. Thus, the distance of the diaphragm position at expiration (the bottom of the curve) from the transducer was regarded as the reference diaphragm position in the present experiments, and the diaphragm excursion was determined by measuring the vertical distance from the bottom to the top of the wavelike curve. In the Rest and PS postures, the mean measurement values of the diaphragm position and excursion were obtained from 3 cycles of stable breathing of the individual subjects. The intraclass correlations for diaphragm excursion and position were 0.961–0.999. Simultaneously, with the ultrasonographic measurements, the tidal volume (V_T) of the individual subjects was also measured using an exhaled gas analyzer (Aero Monitor AE-300S, Minato Medical Science, Osaka, Japan).

By using an exhaled gas analyzer (Aero Monitor AE-300S, Minato Medical Science), respiration pattern was measured separately from the diaphragm excursion. The measurement items were tidal volume (V_T), respiration rate (RR), expired minute ventilation volume (VE), oxygen uptake (VO_2), carbon dioxide production (VCO_2), expiration time (Te), inspiration time (Ti), and respiratory duration (Ttot). The measurement was conducted for 3 minutes under the Rest and PS conditions and the data for the middle 1-minute (1–2 minutes after starting the sampling) were averaged and served as the representative values for the individual subjects. By using the obtained RR and V_T data, the rapid-shallow breathing index (RSBI = RR/VT), an index for weaning from the ventilator⁹⁾, was calculated as an indicator of breathing ease in the present experiments.

By using a spirometer (Autospiro AS-507, Minato Medical Science), pulmonary function was measured. The measurement items were vital capacity (VC), expiratory reserve volume (ERV), inspiratory capacity (IC), and forced expiratory volume in 1 second ($FEV_{1.0}$). In the Rest and PS conditions, each test was repeated three times and the averaged values were regarded as the representative values for the individual subjects.

Respiratory ease was also assessed by using the visual analog scale (VAS) on a horizontal line (10 cm long) with the left end score of 0 representing “very difficult to breathe” and the right end score of 10 representing “very easy to breathe.” Promptly after completion of the measurements, the degree of respiration easiness was marked up on the relevant portion of the line, and the marked distance (cm) from the left edge was regarded as the score of respiratory ease.

Statistical data were presented as mean \pm SD of the mean ($n=25$). A comparison between the Rest and PS conditions in each parameter was performed by using a paired t test or the Wilcoxon signed-rank test. The Pearson product-moment correlation coefficient was estimated to analyze correlation between the diaphragm excursion and V_T at Rest and that at PS. Correlation was also calculated between the ratio of V_T at PS to V_T at Rest and the ratio of diaphragm excursion at PS to that at Rest. Finally, correlation was estimated among VC, IC, and ERV, using the ratio of the PS value to the Rest value. The significance level was $<5\%$.

RESULTS

The excursion of the right hemidiaphragm at Rest during stable respiratory conditions was 16.1 ± 4.0 mm. Pelvic suspension using a sling cord PS instantly and significantly increased the diaphragm excursion to 23.4 ± 6.6 mm ($p<0.001$). The expiratory positions of the right hemidiaphragm from the ultrasound probe (diaphragm position) were 159.0 ± 14.9 mm at Rest and 163.8 ± 13.7 mm at PS, indicating that the diaphragm was significantly placed more cranially at PS than at Rest ($p<0.001$), as the probe was placed on the body surface at a part lower than the diaphragm.

Table 1 shows the correlation between diaphragm excursion and V_T simultaneously obtained from 25 individuals. V_T was well correlated to diaphragm excursion at Rest ($r=0.62$, $p<0.01$) or at PS ($r=0.68$, $p<0.001$), and the slope of the linear regression line was greater at PS than at Rest. The ratio of V_T at PS to that at Rest also correlated to the ratio of the diaphragm excursion at PS to that at Rest ($r=0.53$, $p<0.01$). These results may represent that the change in V_T per unit change in diaphragm excursion was bigger at PS than at Rest.

The parameters of respiratory function measured in the exhaled gas analysis are listed in Table 2 (separate measurements from those for the diaphragm excursion). The pelvic suspension at PS increased the V_T at Rest by 1.47-folds. On the other hand, RR was smaller at PS than at Rest (PS/Rest = 0.683). Accordingly, Te, Ti, and Ttot were increased at PS (PS/Rest = 1.4–1.5). RSBI was decreased at PS (PS/Rest = 0.519). VE, VO_2 , and VCO_2 were not altered by the PS procedure. These results indicate that the significant effects of PS appeared in the increase in V_T and the decrease in RR.

The estimated respiration excursion indexes are shown in Table 3. Pelvic suspension (PS) increased the mean VC by 0.1 l ($p<0.01$), decreased the mean ERV by 0.07 l ($p<0.05$) and increased the mean IC by 0.17 l ($p<0.01$), when compared with those at Rest. $FEV_{1.0}$ at PS was significantly greater than that at Rest.

We further investigated relationships among the VC, IC, and ERV of the individual subjects in terms of the ratio of the PS value to the Rest value. As the IC ratio increased, the ERV ratio decreased ($r=-0.68$, $p<0.001$), indicating the negative correlation between changes in IC and ERV that were induced by PS. On the other hand, the ratio of ERV positively correlated to that of VC ($r=0.63$, $p<0.001$), while the ratio of IC did not correlate well to that of VC ($r=0.09$, $p=0.66$).

The VAS for respiratory ease was significantly higher at PS (7.9 ± 1.3) than at Rest (5.0 ± 2.0 ; $p<0.001$). When the pelvis

Table 1. Correlations between obtained values of tidal volume (V_T) and diaphragm excursion (A) and between changed ratios of PS to Rest of V_T and diaphragm excursion (B)

		Liner regression	R	p	n
A: obtained values	Rest	$y = 18.7 x + 244.7$	0.62	<0.01	25
	PS	$y = 23.5 x + 243.3$	0.68	<0.001	25
B: ratios of PS vs Rest		$Y = 0.4 X + 0.8$	0.53	<0.01	25

y: Tidal volume (ml); x: diaphragm excursion (mm). Y: ratio of V_T (PS/Rest); X: ratio of diaphragm excursion (PS/Rest). R: correlation coefficient. p: significance level of R. n: number of subjects

Table 2. The functional parameters of respiration under resting (Rest) and pelvis-suspended (PS) conditions estimated by using the exhaled gas analysis

	Rest	PS
V_T (ml)	569.7 ± 138.4	838.8 ± 270.0**
VE (l/min)	7.5 ± 1.4	7.4 ± 1.9
RR (breaths/min)	13.9 ± 3.9	9.5 ± 3.1**
VO ₂ (ml/min)	244.0 ± 37.2	232.3 ± 28.3
VCO ₂ (ml/min)	196.6 ± 37.6	200.3 ± 39.5
Te (s)	2.9 ± 1.0	4.2 ± 1.3††
Ti (s)	1.9 ± 0.6	2.8 ± 1.1††
Ttotal (s)	4.7 ± 1.5	7.0 ± 2.3**
RSBI	27.0 ± 12.0	14.0 ± 9.6††

Values are mean ± SD (n=25).

** , ††Significant differences from Rest (paired t-test, p<0.001 and Wilcoxon signed-rank test, p<0.001, respectively).

The measurement was conducted for 3 minutes at Rest and PS, respectively, and the data for the middle 1 minute (1–2 minutes after starting the sampling) were averaged and used as the representative values for the individual subjects. These measurements were performed separately from the acquisition of ultrasonographic pictures.

V_T : tidal volume; VE: expired minute ventilation volume; RR: respiration rate; VO₂: oxygen uptake; VCO₂: carbon dioxide production; Te: expiration time; Ti: inspiration time; Ttotal: respiratory duration; RSBI: rapid-shallow breathing index calculated as RR/V_T

Table 3. Vital capacity (VC), expiratory reserve volume (ERV), inspiratory capacity (IC), and forced expiratory volume in 1 second (FEV_{1.0}) measured by using a spirometer under resting (Rest) and pelvis-suspended (PS) conditions

	Rest	PS
VC (l)	4.62 ± 0.53	4.72 ± 0.53††
ERV (l)	1.34 ± 0.27	1.27 ± 0.25*
IC (l)	3.28 ± 0.41	3.45 ± 0.42††
FEV _{1.0} (l)	3.67 ± 0.40	3.71 ± 0.41*

Values are mean ± SD (n=25).

*, ††Significant differences from Rest (paired t-test, p<0.05 and Wilcoxon signed-rank test, p<0.001, respectively).

In Rest and PS, each test was repeated three times and the averaged values were regarded as the representative values for the individual subjects. These measurements were performed separately from the acquisition of the ultrasonographic images.

was suspended, all the subjects had higher VAS scores than their scores at Rest. However, VAS score did not correlate to the other respiratory function parameters tested.

DISCUSSION

When the pelvis was passively lifted up from the bed surface using sling cords in the supine position at only the lumbar spine level, and not the thoracic spine level, the subjects were able to instantly breathe more easily. This might be corroborated by the PS-induced increases in diaphragm excursion and V_T , as well as the decrease in RR.

The increase in diaphragm excursion may be attained by optimizing the muscle length⁽¹⁰⁾ of the diaphragm upon PS. When the pelvis is suspended, it is tilted backwards, and is at a higher vertical position than its position at the Rest. These changes might lead to the movement of the visceral organs in the cranial direction, pushing the diaphragm more cephalodorsally. In fact, the right hemisphere of the diaphragm was located about 5 mm more cranially in the expiratory conditions at PS than at Rest. Thus, PS might expand the diaphragm to be more optimal in the length-tension relation to produce greater force, presumably resulting in the greater diaphragm excursion at PS than at Rest, which might eventually result in respiration ease. A drawback of this suspension method may reside in the requirement of careful adjustment in the suspension distance, which varies among people. When the pelvis suspension is too high to lift the sacral bone more than 5 cm, the visceral organs push the diaphragm beyond the muscle length to generate the maximum force, limiting diaphragm excursion. This might have occurred in the two subjects who did not show any positive change in pulmonary function.

Previously a relationship between diaphragm excursion and ventilatory volume, have been reported¹¹⁻¹⁴. It is noteworthy that the correlation seemed to be stronger at PS than at Rest, as suggested by the increased correlation coefficient and slope of the regression line at PS. This increment in slope (5 ml/mm excursion) might be due to the increase in the expansion of the thoracic cage with the help of moderate pressure directed cranially by PS. These results suggest that the increased V_T might be a beneficial effect of PS and may help in breathing more easily.

When respiration function was measured independently, it was observed that PS consistently increased the V_T and prominently decreased the RR values accompanied with increases in T_e , T_i , and T_{tot} values; hence, indicating that PS makes respiration deep and slow. PS-induced increases in the values of V_T and RR was 1.47 times and 0.68 times, respectively. This indicates that PS elicits reciprocal alterations between V_T and RR. This reciprocal nature may bring about nearly the same values of VE, and hence, VO_2 and VCO_2 , between PS and Rest, suggesting that PS in the present experiments did not induce a malfunction in respiration in the healthy subjects. From these changes in respiration pattern, the estimated RSBI was reduced by PS to about half of that at Rest. These results further suggest that PS brings about easy respiration of deep and slow breathing under quiet breathing conditions.

The relationship between RR and V_T in quiet breathing is also affected by the relationship between elastic resistance of the lung/chest wall and resistance to airflow, which provide the optimal RR and V_T to achieve the minimal amount of respiration work at quiet breathing (i.e., unconscious respiration). As PS did not change in VE, VO_2 , and VCO_2 , PS might elicit the change in unconscious respiration pattern, without changing conscious respiratory pattern, which is often observed in pulmonary rehabilitation interventions for pulmonary disease patients with the increased work of breathing and ingravescence of dyspnea^{15, 16}. Unconscious changes in the respiration pattern by PS seem likely to increase ventilation efficiency without dyspnea.

When forced respiration was performed, PS slightly increased VC by about 0.1 l and IC by 0.17 l, but reduced ERV by 0.07 l. As described earlier, the diaphragm disposition at the normal expiration state induced by PS was 5 mm. Then, the space volume equivalent to a height of 5 mm, assuming a 90-cm circumference of the diaphragm, is estimated to be about 0.3 l in the circular cylinder or 0.1 l in the circular cone. These estimated volumes in diaphragm disposition may somehow contribute to the changes in the forced respiration parameters measured. Most plausibly, the reduced ERV by PS may be attributed to the cranial disposition of the diaphragm. On the other hand, the increased volumes of VC and IC induced by PS may be achieved by the increased diaphragm excursion due to the increased muscle force depending on the length-tension relationship, as described earlier. Therefore, $FEV_{1,0}$ may be increased by PS. Corroboratively, the PS-induced changes in ERV negatively correlated to those in IC but positively correlated to those in VC, although no apparent correlation was found between the changes in VC and IC at PS. Thus, the reduction in ERV seems to be the principal events to improve forced breathing. With respect to functional residual capacity, its reduction may be desirable to obtain respiratory ease, but the present experiments could not address this issue well. In addition, other factors of functional changes in accessory respiratory muscles and thoracic shape could contribute to the respiratory function changes induced by PS. More or less, all our results on normal and forced respiration states consistently suggest that PS provides respiratory ease.

The instantaneous or prompt effects of PS may provide the possibility for the application of PS in the treatment of the patients with respiratory deficiency such as chronic obstructive pulmonary disease (COPD) in physical therapy because PS is a passive intervention for patients to obtain instant relief from the dyspnea, through which patients could learn the strategy for easy respiration. As previously reported, COPD patients possess pulmonary hyperinflation associated with the flattened diaphragm and the restricted range of diaphragm excursion, presumably leading to the reduction in intake capacity at inspiration^{17, 18}. PS seems to be effective for ameliorating the reported dysfunctions in respiration, as PS instantaneously increased IC and V_T , and reduced ERV and RR, leading to breathing ease. Specifically, the PS-induced reduction in ERV might be a favorable factor to improve the expanded volume in hyperinflation observed in COPD patients.

Lastly, the present study has some limitations. First, we did not evaluate how long the benefits of PS lasted after the PS conditions were released. Second, healthy elderly and patients with COPD were not recruited as research participants. Despite these limitations, this investigation suggests that PS elicited instantaneous changes in diaphragmatic and respiratory functions of the healthy men, at least to trigger improvements in respiratory conditions.

Our results provide evidence for the effectiveness of PS for diaphragm excursion and respiratory function that leads to breathing ease by increasing V_T and reducing RR (i.e., deep and slow respiration). PS-induced action is characteristically instantaneous, as the effects emerged promptly after PS treatment. PS might be a new approach to directly improve diaphragmatic function and might be applicable as an intervention in respiratory rehabilitation for COPD patients with dyspnea.

Conflicts of interests

The authors declare that there is no conflict of interests regarding the publication of this article.

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