



Original Article

## Regional lung volume differences between the side-lying and semi-prone positions

KYOUSHI MASE, PT, PhD<sup>1)\*</sup>, MIKI TAGAMI, PT, PhD<sup>2)</sup>, SHIGEYUKI IMURA, PT, PhD<sup>2)</sup>, KAZUHIDE TOMITA, PT, PhD<sup>3)</sup>, MASAHIKO MONMA<sup>4)</sup>, MASAFUMI NOZOE, PT, PhD<sup>1)</sup>, YUKIE TAKASHIMA, PT<sup>1)</sup>

<sup>1)</sup> Department of Physical Therapy, Faculty of Nursing and Rehabilitation, Konan Women's University: 6-2-23 Morikitamachi, Higashinada, Kobe, Hyogo 658-0001, Japan

<sup>2)</sup> Department of Physical Therapy, Uekusa Gakuen University, Japan

<sup>3)</sup> Department of Physical Therapy, Ibaraki Prefectural University of Health Sciences, Japan

<sup>4)</sup> Department of Radiological Sciences, Ibaraki Prefectural University of Health Sciences, Japan

**Abstract.** [Purpose] This study aimed to clarify the differences in regional lung volume between the semi-prone (Sim's position) and side-lying position, and the optimal position for increasing lung volume. [Methods] Measurements were performed in both positions on both sides. Sim's position was inclined 45° forward from the side-lying position. A 1.5-T system with a fast advanced spin-echo sequence in the coronal plane was used for magnetic resonance imaging. [Results] The two positions did not significantly differ in total lung capacity and its subdivisions on both sides, except the left lung in the right side-lying position and right Sim's position. In the nondependent lung, the percentage lung volume of the dorsal segment was significantly higher in the right Sim's position than in the right side-lying position. However, no significant difference was observed between the left side-lying and left Sim's position. [Conclusion] The heart was displaced ventrally by gravity in Sim's position and leaned on the ventral parapet. The spaces for the expansion of the ventral and dorsal segments of the lung were decreased and increased in Sim's position, respectively. With a nondependent left lung, the increase in the percentage lung volume of the dorsal segment was greater in Sim's position than in the side-lying position.

**Key words:** Semi-prone, Regional lung volume, Repositioning

(This article was submitted Oct. 29, 2015, and was accepted Dec. 15, 2015)

### INTRODUCTION

Physiotherapists alter the position of patients in order to improve ventilation-perfusion, increase lung volume, and help increase mucociliary clearance<sup>1, 2)</sup>. The most commonly used positions are the supine, prone, side-lying (SL), semi-prone (Sim's position [SP]), and sitting positions. Many reports have described changes in the regional distribution of ventilation in the supine, prone, SL, and erect positions<sup>3-5)</sup>. However, the regional distribution of ventilation in SP has not been clarified. As the nondependent lung is expanded and the dependent lung is contracted by the effect of gravity, repositioning to the SL position and SP is considered to improve ventilation in the nondependent lung. In particular, SP is used to improve ventilation in the dorsal segment of the nondependent lung. However, whether ventilation in the dorsal segment is better in SP or the SL position remains to be clarified. Thus, to determine the optimal position for ventilation distribution, the differences between the SL position and SP should be clarified.

In addition, repositioning in the prone position has been suggested<sup>6)</sup> and mortality<sup>7)</sup> in patients with acute respiratory distress syndrome. The mechanism underlying such improved gas exchange is increased ventilation/perfusion. However, prone positioning is not a benign procedure and carries the potential risk of

\*Corresponding author. Kyoushi Mase (E-mail: masek@konan-wu.ac.jp)

©2016 The Society of Physical Therapy Science. Published by IPEC Inc.

This is an open-access article distributed under the terms of the Creative Commons Attribution Non-Commercial No Derivatives (by-nc-nd) License <<http://creativecommons.org/licenses/by-nc-nd/4.0/>>.

complications for both patients and healthcare workers<sup>8</sup>). Notable complications include selective intubation, endotracheal tube obstruction, and pressure sores<sup>9</sup>). As such, SP was used as a substitute for the prone position to mitigate the risks and complications associated with prone position management. Therefore, understanding the ventilation distribution in SP is important.

The present study compared regional lung volumes between SP and the SL position in order to clarify the differences in regional lung volume between the two positions and to determine which position is superior in terms of increasing the lung volume of the dorsal segment.

## SUBJECTS AND METHODS

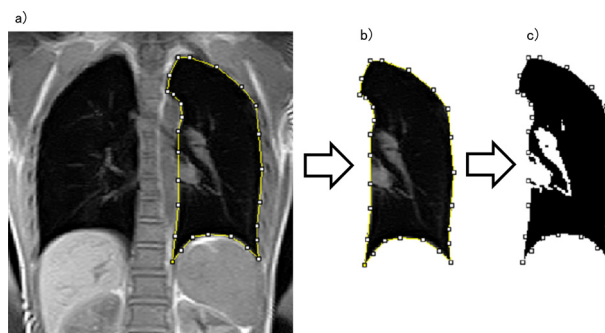
The study subjects comprised 8 healthy volunteers (6 men and 2 women; mean age,  $29.0 \pm 9.2$  years; mean height,  $167.0 \pm 9.8$  cm; mean body weight,  $60.6 \pm 10.3$  kg). None of the subjects had any history of pulmonary or cardiovascular disease. Prior to participation in the study, all the subjects provided written informed consent. The study was approved by the ethics committee of Ibaraki Prefectural University of Health Sciences.

Measurements were performed in the right and left SL position and SP. SP was inclined  $45^\circ$  forward from the SL position. Magnetic resonance imaging (MRI) scans were obtained by using a 1.5-T system (Excelart Vantage 1.5 T, Toshiba Medical Systems, Otawara, Japan). MRI was performed by using the fast advanced spin-echo method in the coronal plane, covering the entire thoracic cavity. The scan parameters were as follows: repetition time, 191 ms; echo time, 4.8 ms; number of signal averages, 1; and slice thickness, 10 mm. The 17 slices were scanned for 30 s on MRI. The subjects assumed each position and were instructed to breath-hold for 30 s at each of the following measurement conditions: maximum inspiratory lung volume (MILV), maximum expiratory lung volume (MELV), end-tidal expiratory lung volume (EELV), and end-inspiratory lung volume (EILV).

By using the ImageJ software (Rasband, W.S., ImageJ, US National Institutes of Health, Bethesda, Maryland, USA, <http://imagej.nih.gov/ij/>, 1997–2014), the MRI scans were analyzed as follows: To determine the lung area of each coronal slice, the lung border was checked visually and the outline of the lung was traced. Within this traced area, tissues other than the lung parenchyma (e.g., blood vessels of the pulmonary hilum, mediastinum, and chest wall) were also included. On the image, portions displaying higher pixel values than those in the peripheral lung field were considered to represent other tissues. The other-tissue area with higher pixel values was thus calculated. Lung area was determined by subtracting the other-tissue area from the traced area (Fig. 1). Lung volume was calculated as the sum of the lung areas from the 17 slices. Based on these results, total lung capacity (TLC) and its subdivisions (inspiratory capacity, functional residual capacity (FRC), residual volume (RV), expiratory residual volume, tidal volume, and inspiratory residual volume) were calculated for the right and left lungs in each position.

In all the slices, including the lung regions captured at MILV, EELV, MELV, the sum of the lung areas located in the dorsal one-third was assumed to represent the dorsal segment lung volume. Similarly, the ventral and middle one-third were considered the ventral and middle segments, respectively. The lung volume in each segment was expressed as a percentage of the sum of the three segments (%lung volume).

For statistical analysis, position differences were first tested by using repeated-measures analysis of variance, followed by the Student-Newman-Keuls test to determine differences between each level of significance. For statistical processing, a risk function value of  $<5\%$  was fixed as the level of significance.



**Fig. 1.** MRI image analysis using ImageJ

a) To determine the lung area of each coronal slice, the lung border was checked visually and the outline of the lung was traced. b) Within this traced area, tissues other than lung parenchyma (e.g., blood vessels of the pulmonary hilum, mediastinum, chest wall, etc.) were also included. Traced area of left lung was  $165 \text{ cm}^2$ . c) The other-tissue area showing higher pixel values (white area) was calculated. The other tissue area of left lung was  $17 \text{ cm}^2$ . The left lung area =  $165 \text{ cm}^2 - 17 \text{ cm}^2 = 148 \text{ cm}^2$ . In this image, the white area comprises more than 600 pixels. Lung area was then determined by subtracting the other-tissue area from the traced area. Lung volume was calculated as the sum of lung areas from the 17 slices.

## RESULTS

The TLC of both lungs and its subdivisions in each of the four positions are summarized in Table 1. No significant differences in TLC and its subdivisions were observed between the positions. In the four positions of the nondependent lung, TLC, FRC, and RV were significantly lower in the right SP than in the left SL position or left SP (Table 2). FRC was significantly lower in the right SL position than in the left SL position, while TLC and RV were significantly lower in right SP than in the right SL position. No significant differences in TLC and its subdivisions were found between the left SL position and the left SP.

Table 3 shows the TLC of the dependent lung and its subdivisions. TLC, FRC, and RV were significantly higher in the right SL position and right SP than in the left SL position and left SP. No significant differences in TLC and its subdivisions were evident between the right SL position and the right SP. In addition, no significant difference was apparent between the left SL position and left SP.

In MILV and EELV, the %lung volume of the dorsal segment was significantly higher in the right SP than in the right SL position (Table 4). However, no significant difference was observed between the left SL position and left SP. In MILV and EELV, the %lung volume of the dorsal segment was significantly higher in the right SP than in the left SL position or left SP, and the ventral segment showed a significantly lower value in the latter positions.

No significant difference in %lung volume for the dependent lung was observed between the SL position and SP on both sides (Table 5). In MILV, EELV, and MELV, the %lung volume of the dorsal segment was significantly higher in the left SL position and left SP than in the right SL position or right SP, and the ventral segment showed a significantly lower value in the former positions.

**Table 1.** TLC and its subdivisions for bilateral lungs in four positions (N=8) (unit: L)

	Lt side lying	Lt semi-prone	Rt side lying	Rt semi-prone
TLC	4.85±0.98	4.97±0.86	5.03±0.99	4.86±0.79
IC	1.93±0.59	2.10±0.53	2.09±0.52	1.98±0.42
FRC	2.92±0.65	2.88±0.56	2.93±0.66	2.87±0.52
IRV	1.51±0.46	1.67±0.43	1.69±0.44	1.59±0.45
TV	0.42±0.16	0.43±0.18	0.40±0.18	0.39±0.35
ERV	0.62±0.29	0.53±0.40	0.55±0.28	0.62±0.41
RV	2.30±0.51	2.35±0.48	2.38±0.53	2.25±0.43

Values are mean ±SE.

Lt: left, Rt: right, SL: side lying, SP: semi-prone, TLC: total lung capacity, IC: inspiratory capacity, FRC: functional residual capacity, IRV: inspiratory residual volume, TV: tidal volume, ERV: expiratory residual volume, RV: residual volume

**Table 2.** TLC and its subdivisions in the nondependent lung in the four positions (N=8) (unit: L)

	Lt side lying (Rt lung)	Lt semi-prone (Rt lung)	Rt side lying (Lt lung)	Rt semi-prone (Lt lung)
TLC	2.85±0.61	2.86±0.52	2.71±0.59	2.55±0.42**††#
IC	0.92±0.28	1.02±0.27	0.95±0.21	0.89±0.20
FRC	1.93±0.48	1.84±0.35	1.77±0.43*	1.65±0.31**†
IRV	0.70±0.23	0.79±0.22	0.75±0.20	0.70±0.21
TV	0.22±0.07	0.24±0.10	0.20±0.09	0.20±0.19
ERV	0.45±0.22	0.35±0.27	0.38±0.23	0.42±0.28
RV	1.49±0.37	1.49±0.34	1.40±0.37	1.23±0.24**††#

Values are mean ±SE. \*p<0.05 vs. Lt SL (Rt lung). \*\*p<0.01 vs. Lt SL (Rt lung). † vs. Lt SP (Rt lung). ††p<0.01 vs. Lt SP (Rt lung). #p<0.05 vs. Rt SL (Lt lung)

Lt: left, Rt: right, SL: side lying, SP: semi-prone, TLC: total lung capacity, IC: inspiratory capacity, FRC: functional residual capacity, IRV: inspiratory residual volume, TV: tidal volume, ERV: expiratory residual volume, RV: residual volume

**Table 3.** TLC and its subdivisions in the dependent lung in the four positions (N=8) (unit: L)

	Lt side lying (Lt lung)	Lt semi-prone (Lt lung)	Rt side lying (Rt lung)	Rt semi-prone (Rt lung)
TLC	2.00±0.44	2.11±0.43	2.31±0.46***††	2.31±0.42*†
IC	1.01±0.31	1.07±0.28	1.15±0.30	1.09±0.24
FRC	0.98±0.21	1.04±0.24	1.17±0.27***††	1.22±0.26*††
IRV	0.81±0.28	0.88±0.26	0.95±0.29	0.89±0.29
TV	0.21±0.10	0.19±0.10	0.20±0.11	0.20±0.19
ERV	0.17±0.09	0.18±0.15	0.17±0.10	0.20±0.16
RV	0.82±0.17	0.86±0.17	0.99±0.20***††	1.02±0.22*††

Values are mean ±SE. \*p<0.05 vs. Lt SL (Lt lung), \*\*p<0.01 vs. Lt SL (Lt lung), † vs. Lt SP (Lt lung), ††p<0.01 vs. Lt SP (Lt lung)

Lt: left, Rt: right, SL: side lying, SP: semi-prone, TLC: total lung capacity, IC: inspiratory capacity, FRC: functional residual capacity, IRV: inspiratory residual volume, TV: tidal volume, ERV: expiratory residual volume, RV: Residual volume

**Table 4.** The regional %lung volume of the nondependent lung in the four positions (N=8) (unit: %)

		Lt side lying (Rt lung)	Lt semi-prone (Rt lung)	Rt side lying (Lt lung)	Rt semi-prone (Lt lung)
MILV	ventral	24.9±2.9	24.6±2.0	22.6±3.7	20.3±3.1***†
	middle	43.9±1.8	43.7±1.8	44.0±1.5	42.4±2.6
	dorsal	31.1±2.8	31.7±2.3	33.3±4.0	37.3±4.9***††#
EELV	ventral	24.5±3.9	23.9±2.2	21.9±2.8	20.1±3.0*†
	middle	43.1±0.9	44.6±2.1	45.0±2.0	43.7±1.7
	dorsal	32.4±4.4	31.5±2.0	33.1±3.9	36.2±2.2*††#
MELV	ventral	25.3±3.8	23.8±3.8	22.7±3.6	20.1±3.2
	middle	44.9±1.9	44.8±2.3	45.6±1.5	44.8±2.0
	dorsal	29.8±4.5	31.4±2.7	31.7±4.0	35.0±3.6

Values are mean ±SE. \*p<0.05 vs. Lt SL (Rt lung), \*\*p<0.01 vs. Lt SL (Rt lung), † vs. Lt SP (Rt lung), ††p<0.01 vs. Lt SP (Rt lung), #p<0.05 vs. Rt SL (Lt lung)

Lt: left, Rt: right, SL: side lying, SP: semi-prone, MILV: maximum inspiratory lung volume, MELV: maximum expiratory lung volume, EELV: end of tidal expiratory lung volume

**Table 5.** The regional %lung volume for the dependent lung in the four positions (N=8) (unit: %)

		Lt side lying (Lt lung)	Lt semi-prone (Lt lung)	Rt side lying (Rt lung)	Rt semi-prone (Rt lung)
MILV	ventral	18.6±2.5	18.0±3.8	24.5±4.2***††	24.2±3.3***††
	middle	43.8±3.0	44.2±2.6	44.0±1.9	45.4±1.9
	dorsal	37.6±2.1	37.7±5.3	31.6±4.0***††	30.4±3.2***††
EELV	ventral	15.8±2.4	16.0±2.6	20.6±3.1***††	19.4±2.0*††
	middle	43.3±2.8	43.7±3.0	45.0±3.0	46.3±1.7*†
	dorsal	40.9±4.5	40.3±5.2	34.2±3.2*†	34.3±2.7***††
MELV	ventral	17.2±3.4	17.2±2.5	21.0±2.7*†	21.4±4.8*†
	middle	43.8±1.5	43.8±2.3	45.8±2.9	45.8±1.6
	dorsal	38.7±3.9	38.9±4.1	33.2±3.4***††	32.7±3.7***††

Values are mean ±SE. \*p<0.05 vs. Lt SP (Lt lung), \*\*p<0.01 vs. Lt SL (Lt lung), † vs. Lt SP (Lt lung), ††p<0.01 vs. Lt SP (Lt lung)

Lt: left, Rt: right, SL: side lying, SP: semi-prone, MILV: maximum inspiratory lung volume, MELV: maximum expiratory lung volume, EELV: end of tidal expiratory lung volume

## DISCUSSION

The present results show no significant differences in TLC and its subdivisions between the SL position and SP across both lungs. In addition, no significant differences in TLC and its subdivision were evident between the two positions in the comparison between the right and left lungs independently, with exception of the left lung in the right SL position and right SP. Under static or quasi-static conditions, regional lung volume depends on the intrinsic static pressure-volume characteristics of the lung and regional differences in pleural pressure<sup>10</sup>. Spatial variations in pleural pressure result from complex force interactions between the lung and other structures within the thorax. Gravity is one such force acting on these structures<sup>11</sup>. Gravity causes vertical gradients in pleural pressure and influences the regional distribution of ventilation in the lungs<sup>5, 6</sup>. Through the effect of vertical gradients on pleural pressure, the differences in lung volume between basal and apical segments became larger as the vertical direction of the length increased. In SP, which is tilted forward 45° from the SL position, the vertical length of the lung is about 70% that in the SL position. Therefore, lung volume differences between the nondependent and dependent lungs may be smaller in SP than in the SL position. However, except for the left lung in the right SL position and the right SP, no significant differences in TLC and its subdivisions was observed between the SL position and SP, indicating that differences in vertical length of the lung between the SL position and SP do not markedly affect TLC or its remaining subdivisions.

As the heart is present in the left pleural cavity, the left lung is smaller than the right lung. In the dependent lung, the TLC, FRC, and RV of the left lung were lower than those of the right lung. The TLC, FRC, RV of the left lung in the right SP were lower than those of the right lung in the left SL position and left SP, even when the lung was nondependent. The difference in size between the right and left lungs likely influenced this result. However, no significant differences in TLC and RV were seen observed between the left lung in the right SL position and right lung in the left SL position and left SP in the nondependent lung. Given these results, high negative pressure was considered to have occurred in the left pleural cavity in the right SL position. The reasons for this were considered twofold as follows: 1) as the heart is positioned higher in the right SL position than in the right SP, displacement of the heart and mediastinum to the underside readily occurs, and 2) the high negative pressure produced in the left chest cavity causes the left lung to expand.

The findings of this study suggest that the increase in the lung volume of the dorsal segment was greater in the right SP than in the right SL. However, no significant difference was observed between the left SL position and left SP. This is attributed to the displacement of the heart in SP and the SL position. The heart was displaced ventrally by gravity in SP but not in the SL position and leaned on the ventral parapet. Ball<sup>12</sup> performed the first computed tomographic investigation of the effects of postures and noted that the heart and great vessels moved ventrally and caudally and a larger area of the heart came into contact with the anterior chest wall in the prone position. Therefore, the spaces for expansion of the ventral and dorsal segments of the lung were decreased and increased in SP, respectively. As a result, when the left lung was the nondependent lung, the increase in the %lung volume of the dorsal segment was greater in SP than in the SL position.

With regard to the dependent lung, the %lung volume of the dorsal segment was significantly higher in the left lung than in the right lung in SP and the SL position. However, the %lung volume of the dorsal segment did not differ significantly between the SL position and SP. Displacement of the heart by gravity is considered to have influenced this result. Chang<sup>13</sup> suggested that displacement of the heart and mediastinum to the underside by gravity causes distortion of the lung in the SL position. The heart, which is located ventrally in the pleural cavity, compresses the ventral segment of the dependent lung. The %lung volume of the dorsal segment is thus increased in the left SP and SL position.

The present study has one primary limitation. As lung volume was measured based on MRI results, this means that not only air but also moisture and pulmonary tissue were included in the measurements. In the postures used, moisture was moved to the dependent lung by gravity, reducing the compliance of the dependent lung. This effect could not be taken into consideration in the MRI technique applied in this study.

## REFERENCES

- 1) Ota H, Kawai H, Sato M, et al.: Effect of early mobilization on discharge disposition of mechanically ventilated patients. *J Phys Ther Sci*, 2015, 27: 859–864. [[Medline](#)] [[CrossRef](#)]
- 2) Brooks DJ, Kelsey CJ, Lacy JB, et al.: A clinical practice guideline on peri-operative cardiorespiratory physical therapy. *Physiother Can*, 2001, 53: 9–25.
- 3) Tsubaki A, Deguchi S, Tonedo Y, et al.: Influence of posture on respiratory function and respiratory muscle strength in normal subjects. *J Phys Ther Sci*, 2009, 21: 71–74. [[CrossRef](#)]
- 4) Tomita K, Sakai Y, Monma M, et al.: Analysis of diaphragmatic motion with prone positioning using dynamic MRI. *J Phys Ther Sci*, 2004, 16: 85–89. [[CrossRef](#)]
- 5) Anthonisen NR, Milic-Emili J: Distribution of pulmonary perfusion in erect man. *J Appl Physiol*, 1966, 21: 760–766.

[\[Medline\]](#)

- 6) Dickinson S, Park PK, Napolitano LM: Prone-positioning therapy in ARDS. *Crit Care Clin*, 2011, 27: 511–523. [\[Medline\]](#) [\[CrossRef\]](#)
- 7) Guérin C, Reignier J, Richard JC, et al. PROSEVA Study Group: Prone positioning in severe acute respiratory distress syndrome. *N Engl J Med*, 2013, 368: 2159–2168. [\[Medline\]](#) [\[CrossRef\]](#)
- 8) Gattinoni L, Carlesso E, Taccone P, et al.: Prone positioning improves survival in severe ARDS: a pathophysiologic review and individual patient meta-analysis. *Minerva Anesthesiol*, 2010, 76: 448–454. [\[Medline\]](#)
- 9) Guerin C, Gaillard S, Lemasson S, et al.: Effects of systematic prone positioning in hypoxemic acute respiratory failure: a randomized controlled trial. *JAMA*, 2004, 292: 2379–2387. [\[Medline\]](#) [\[CrossRef\]](#)
- 10) Milic-Emili J: Ventilation distribution. In: Hamid Q, Shannon J, Martin J, (ed.) *Physiologic Basis of Respiratory Disease*, 1st ed. Hamilton: BC Decker, 2005.
- 11) Lai-Fook SJ, Rodarte JR: Pleural pressure distribution and its relationship to lung volume and interstitial pressure. *J Appl Physiol* 1985, 1991, 70: 967–978. [\[Medline\]](#)
- 12) Ball WS, Wicks JD, Mettler FA Jr: Prone-supine change in organ position: CT demonstration. *AJR Am J Roentgenol*, 1980, 135: 815–820. [\[Medline\]](#) [\[CrossRef\]](#)
- 13) Chang H, Lai-Fook SJ, Domino KB, et al.: Spatial distribution of ventilation and perfusion in anesthetized dogs in lateral postures. *J Appl Physiol* 1985, 2002, 92: 745–762. [\[Medline\]](#) [\[CrossRef\]](#)