ORIGINAL ARTICLE

Annals of Nuclear Medicine Vol. 12, No. 5, 249–254, 1998

Evaluation by ventilation and perfusion scintigraphy in patients who developed postural hypoxemia in the supine position

Shigeru TOMINAGA,* Yoshinosuke FUKUCHI** and Yutaka MORI***

**Department of Internal Medicine, Juntendo University Urayasu Hospital*
***Department of Respiratory Medicine, Juntendo University School of Medicine*
****Department of Radiology, The Jikei University School of Medicine*

Ventilation and pulmonary perfusion scintigraphy were performed in 7 patients in whom postural change from the sitting position to the supine position decreased partial oxygen pressure in arteries (PaO_2) by 15 mmHg or more. Six of these 7 patients were obese. Five patients had organic pulmonary disease or space occupying lesions of the liver. On lateral supine-position images taken by using the continuous inhalation method for ^{81m}Kr ventilation scintigraphy, ventilation was reduced in the dorsal area corresponding to a gravity-dependent area, but on pulmonary perfusion scintigrams, there were no marked changes compared to normal adults. The mismatch of ventilation to perfusion may have caused hypoxemia. Reduced ventilation was correlated with reduced PaO_2. The distribution of ^{81m}Kr bolus gas inhalation suggested closure of the airway in the dorsal area at functional residual capacity (FRC), which means the resting expiratory level, in the supine position.

Key words: postural hypoxemia, obesity, ^{81m}Kr ventilation scintigraphy, ^{99m}Tc-MAA perfusion scintigraphy, lateral supine-position images

INTRODUCTION

THE MISMATCH of pulmonary ventilation to perfusion is an important factor that causes hypoxemia, but among patients excluding those with pulmonary thromboembolism, the incidence of morbid mismatch between pulmonary ventilation and perfusion visually detected on scintigrams is not high.

During the past 8 years, we examined 7 patients in whom postural change from the sitting position to the supine position decreased PaO_2 by 15 mmHg or more. In these patients, scintigraphy revealed that ventilation was abnormally reduced at some areas, suggesting a marked mismatch between ventilation and the distribution of pulmonary perfusion.

Ward et al.[1] reported that PaO_2 noticeably changed (by approximately 8 mmHg) during postural change to the supine position. Fifteen mmHg or greater decreases were considered extremely marked. To clarify the mechanism involved in these changes in PaO_2, the background of these 7 patients and findings on scintigraphy were examined.

SUBJECT PROFILE AND EXAMINATION METHOD

Profiles of 7 patients with a decrease of 15 mmHg or more decreases in PaO_2 during postural change from the sitting position to the supine position and results of spirography and arterial blood gas analysis are shown in Table 1. Patients' ages ranged from 38 to 66 years. There were 4 males and 3 females. Five of the 7 patients had organic pulmonary or hepatic diseases. One patient (Patient 1) had a lung tumor. The tumor was a solitary lung cancer measuring 3 × 2 cm in the posterior segment of the right upper lobe (S^2) (Fig. 1). Clinical staging was T1N0M0, but pathologically T4N1M0 by pleural dissemination after surgery. Two patients (Patients 2 and 3) had interstitial lung disease. Patient 2 had chronic hypersensitivity pneumonitis with positive Trichosporon cutaneum antibody (Fig. 2) and Patient 3 had local lung fibrosis in the

Received March 19, 1998, revision accepted July 21, 1998.
For reprint contact: Shigeru Tominaga, M.D., Department of Internal Medicine, Juntendo University Urayasu Hospital, Tomioka 2–1–1, Urayasu, Chiba 279–0021, JAPAN.

Table 1 Profiles of 7 patients with the results of arterial blood gas analysis and spirography

Case	Age	Sex	Complications	Obesity index	Smoking history	PaO_2		$PaCO_2$		%VC	$FEV_{1.0}$%
						Sitting	Supine	Sitting	Supine		
1	56 yo	Female	Primary lung ca.	53%	−	86 mmHg	70 mmHg	42	38	80	76
2	38	Female	Hypersensitivity pneumonitis	40	−	70	55	35	34	103	79
3	66	Female	Interstitial pneumoma	28	+	85	69	36	37	74	88
4	39	Male	None	11	+	93	67	39	37	112	74
5	50	Male	Metastatic liver tumor	23	−	90	70	29	30	97	89
6	51	Male	Giant liver cyst	30	+	81	62	38	39	86	84
			Sleep apnea syndrome			SpO_2					
7	55	Male	Schizophrenia	36	+	96%	91%	not examined		not examined	

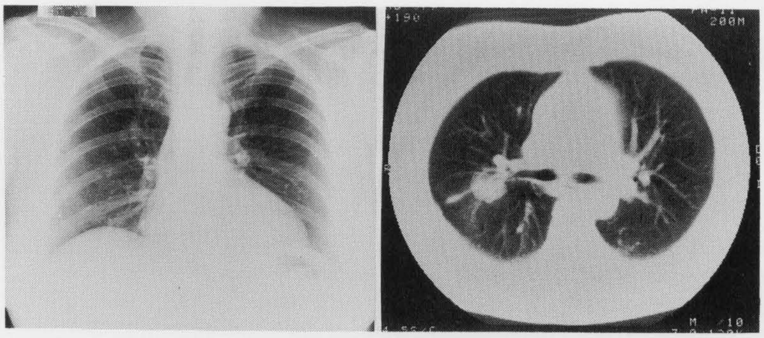
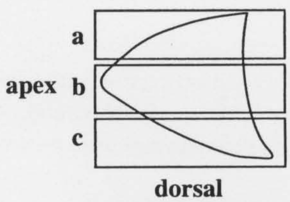


Fig. 1 Chest X ray and thoracic CT image in Patient 1. There was a solitary lung cancer in the right S^2.

Table 2 Ratio of radioactivity in the dorsal area to radioactivity in the entire lung field on lateral images during ventilation and perfusion scintigraphy



	^{81m}Kr (zone c/total)		^{99m}Tc-MAA (zone c/total)	
Subjects (n = 7)	0.17 ± 0.05	$p < 0.05$	0.31 ± 0.06	NS
Control (n = 5)	0.30 ± 0.05		0.32 ± 0.05	

The ratio of ventilation in the patient group was significantly reduced compared to that in the control group. There was no significant difference in pulmonary perfusion between the two groups

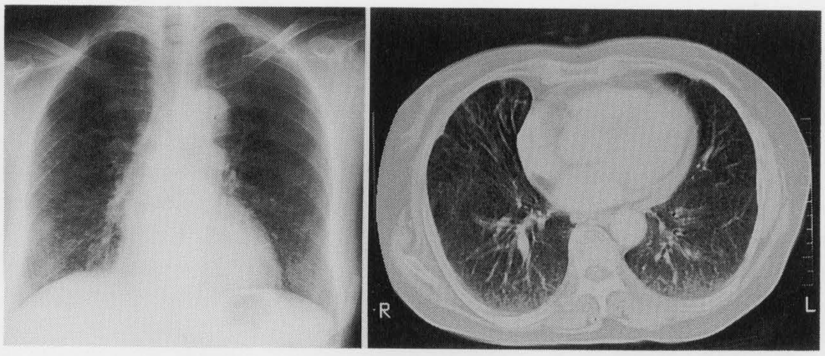


Fig. 2 Chest X ray and thoracic CT image in Patient 2. A ground glass opacity in the entire lung field and linear shadow in middle and lingular lobes were observed. The ground glass opacity was relatively prominent in the dorsal area. Mild pleural thickness was also observed in the right.

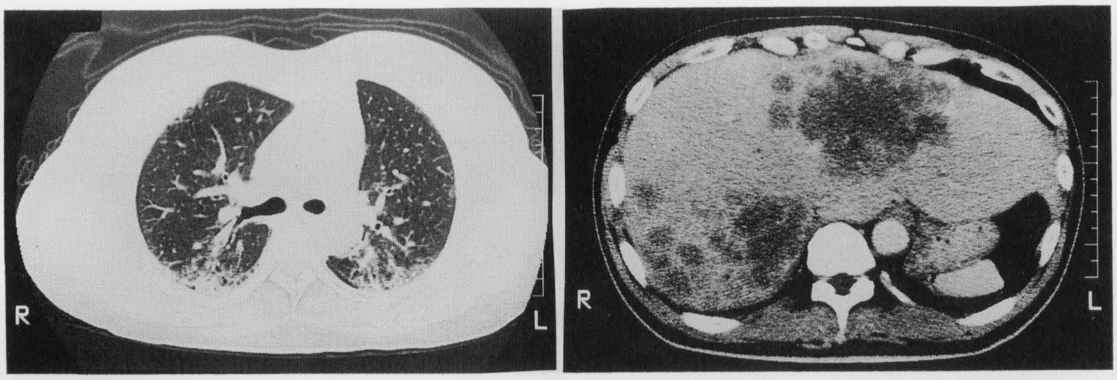


Fig. 3 Left: Thoracic CT image in Patient 3. Fibrosis was observed predominantly in the dorsal area. Right: Abdominal CT image in Patient 5. Large and multiple metastases were observed in the liver.

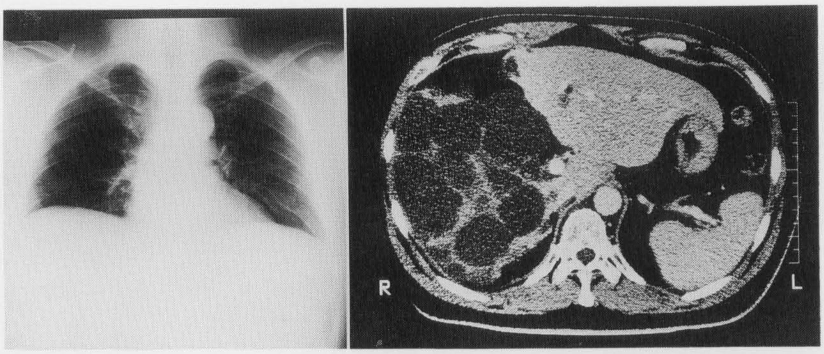


Fig. 4 Chest X ray and abdominal CT image in Patient 6. In the lung field, there were no abnormalities. However, the diaphragm was lifted. A huge cyst involved the right hepatic lobe.

subpleural area (Fig. 3 left). Patient 5 had multiple liver metastases from large intestinal cancer (Fig. 3 right) and Patient 6 had a huge benign liver cyst (Fig. 4). In Patients 4 and 7, chest X-ray did not reveal any abnormalities. There were 3 smokers (Patients 4, 6 and 7) and 4 non-smokers. The Brinkman smoking indexes were 400, 600 and 450.

Concerning the degree of obesity, standard body weight was calculated with Broca and Katsura's formula ((height − 100) × 0.9), and the degree of obesity was regarded as (actual body weight − standard body weight)/standard body weight. A patient with this index over 20% is obese. Six of 7 patients had 23% to 53% obesity. Patient 6 had sleep apnea syndrome (SAS) (apnea index, which means frequency of apnea over 10 seconds per hour, was 15).

In arterial blood gas analysis in the sitting position, PaO_2 was 80 mmHg or more in all patients except one. Hypercapnia was not detected in any patient. For arterial blood gas analysis in the supine position, blood was collected 10 minutes after postural change on the same day. Percent vital capacity (%VC) was normal in all patients except one, and the forced expiratory volume % in first second ($FEV_{1.0}$%) was normal in all patients. There were no patients with obstructive pulmonary disease. In Patient 1, FRC and closing capacity (CC) were measured in the two positions.

For pulmonary perfusion scintigraphy, 185 MBq/body of ^{99m}Tc-MAA was intravenously injected in the supine position. For ventilation scintigraphy, ^{81m}Kr with a half-life of 13 seconds was used. Continuous inhalation images in the supine position and bolus gas inhalation images at residual volume (RV), FRC and FRC + tidal volume (TV) were obtained in Patients 1, 2 and 3. These scintigrams were taken with a ZLC 7500 scinticamera (Siemens) from the right side in the supine position.

As normal controls, 4 males and 1 female (age range from 28 to 66 years) with normal pulmonary function (%VC: 101.8 ± 12.2, $FEV_{1.0}$%: 84.6 ± 3.4) and normal chest X-ray findings were examined. Degrees of obesity of the 5 controls were 0, 13, 18, 58 and 84%. In all normal controls, PaO_2 was 85 mmHg or more in the supine position.

RESULTS AND CASE PRESENTATION

Lateral images of 7 patients and a normal control on ventilation and perfusion scintigrams are shown in Fig. 5. The left row indicates images taken during continuous inhalation of ^{81m}Kr gas. The right row indicates images taken with ^{99m}Tc-MAA pulmonary perfusion scintigra-

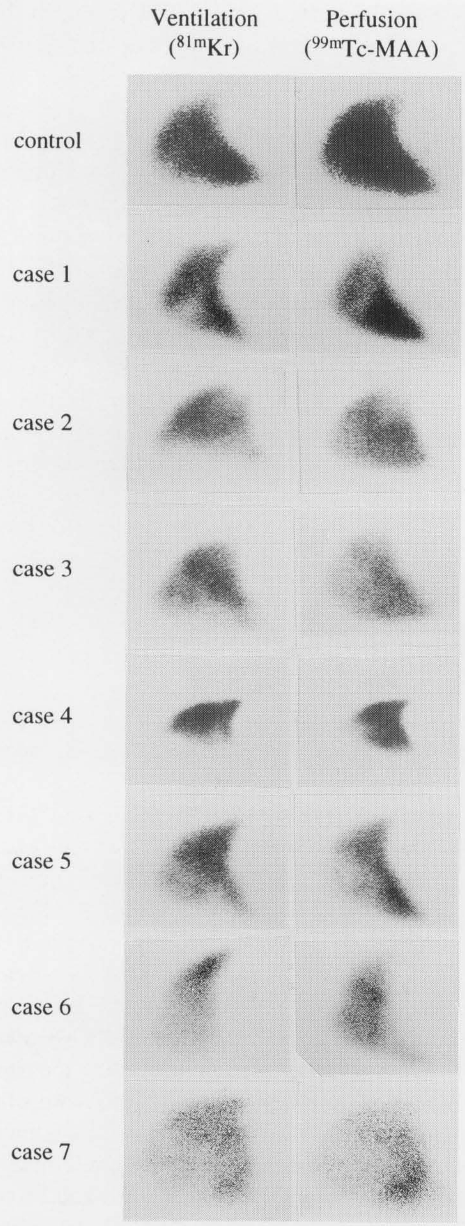


Fig. 5 Right lateral images in the supine position on pulmonary ventilation scintigraphy (left) and perfusion scintigraphy (right) in all patients and a control. For ventilation scintigraphy, continuous inhalation of ^{81m}Kr was administered. For perfusion scintigraphy, ^{99m}Tc-MAA was used. The distribution of ventilation in the dorsal area was markedly reduced in these patients, and markedly differed from that of pulmonary perfusion.

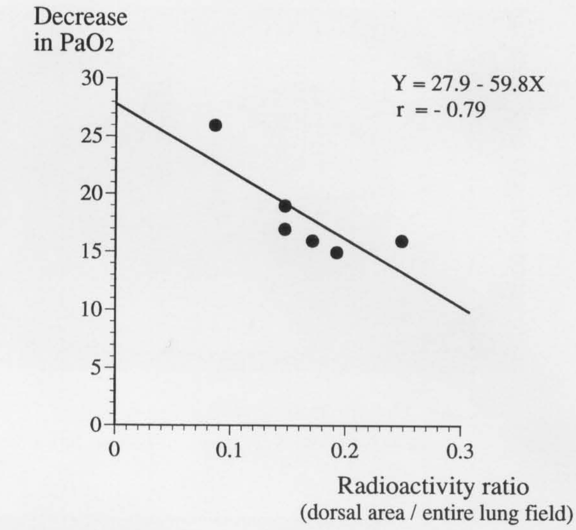


Fig. 6 Correlation between the dorsal area/entire lung field radioactivity ratio (abscissa) and postural change—related decrease in PaO_2 (ordinate). There was an inverse correlation between them. Radioactivity ratio in Patient 7 was 0.22.

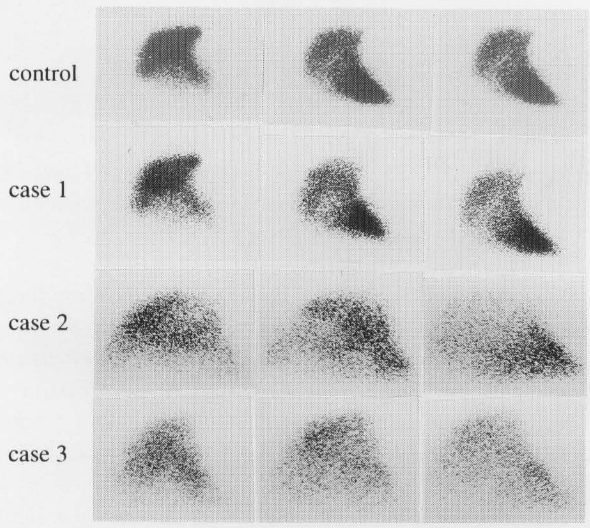


Fig. 7 Lateral images on ^{81m}Kr bolus gas inhalation at RV, FRC and FRC + TV in the supine position. In controls, the entire lung was imaged on inhalation at FRC. However, in Patients 1, 2 and 3, the dorsal area was not sufficiently imaged during inhalation at FRC. The dorsal area was imaged on inhalation at FRC + TV.

phy. In all patients, the distribution of ventilation in the dorsal area was noticeably reduced when compared to the distribution of perfusion. There were no such findings in the controls.

Lateral scintigraphic images were divided into 3 regions of interest (ROI) involving the abdominal and dorsal sides. The radioactivity in the dorsal area/radioactivity in the entire lung field ratio was calculated (Table 2). In 7 patients, the ventilation in the dorsal area/ventilation in the entire lung field ratio was 0.17 ± 0.05 (mean $\pm$ SD). This value was significantly lower than that in controls, but the pulmonary perfusion in the dorsal area/pulmonary perfusion in the entire lung field ratio was 0.31 ± 0.06. There was no significant difference compared to the control value. Furthermore, in 7 patients, there was a linear correlation between the dorsal area/entire lung field radioactivity ratio (X) and postural change-related decrease in PaO_2 (Y); $Y = 27.9 - 59.7X$ ($r = -0.79$) (Fig. 6).

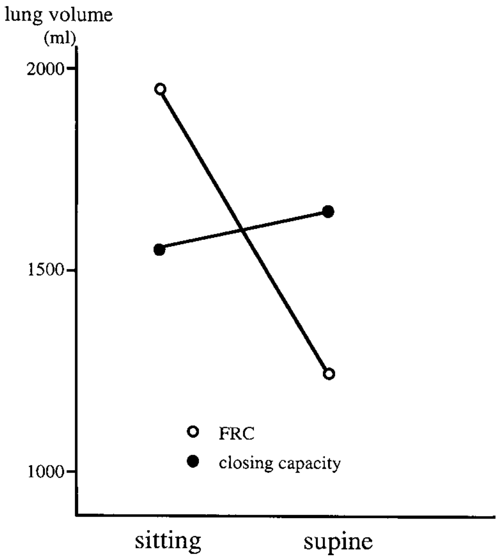


Fig. 8 FRC and CC in Patient 1 in the sitting and supine positions. In the supine position, CC exceeded FRC.

There was no correlation between the obesity index and postural change related to PaO_2.

Figure 7 shows lateral images on inhalation of ^{81m}Kr bolus gas for Patients 1, 2 and 3 and for a control. On inhalation images at RV, distribution in the dorsal area was reduced in these 3 patients and a control, but on inhalation images at FRC, the entire lung was imaged in controls, but the dorsal area was incompletely imaged in Patients 1, 2 and 3. On inhalation images at FRC + TV, the dorsal area was sufficiently imaged. These findings suggest that closure of the airway persisted in the dorsal area at the FRC level in the patient group, and that the entire airway was opened at the lung capacity between FRC and FRC + TV.

Figure 8 shows changes in FRC and CC in the sitting and supine positions in Patient 1. Due to reduced FRC, CC exceeded FRC in the supine position. This was consistent with findings on images on bolus gas inhalation.

DISCUSSION

Even in healthy adults, it has been reported that PaO_2 in the supine position is slightly decreased compared to that in the sitting position.[2] This tendency was also found in some regression formulae.[3,4] Fukuchi et al.[5] compared PaO_2 in the two positions, and reported that PaO_2 in the supine position was slightly decreased by approximately 2 mmHg. Ward et al.[1] noted a relatively marked 8 mmHg reduction in PaO_2. When compared to these studies, the 7 patients in our study had 15 mmHg or more decreases in PaO_2 during postural change, which were extremely abnormal. The mechanism involved in these decreases was speculated to be as follows: ventilation at gravity-dependent areas was reduced in the supine position, causing a mismatch between ventilation and perfusion. In these patients, this mechanism was visually demonstrated on scintigrams.

The direction of gravity is from the pulmonary apex toward the base of the lung in the sitting position. In the supine position, the direction of gravity is ventrodorsal. Therefore, lateral images may be appropriate for evaluating the distribution of pulmonary ventilation and perfusion in the gravity direction in the supine position. As shown in Fig. 5, scintigraphy revealed that the distribution of ventilation in the gravity-dependent area, that is, dorsal area, was abnormally reduced on lateral supine-position images in the patient group with noticeable decreases in PaO_2. The dorsal area/entire lung field radioactivity ratio was also significantly reduced compared to that in controls. Concerning pulmonary perfusion, there was no significant difference between patients and controls in the distribution of perfusion in the dorsal area. Therefore, the mismatch of ventilation to perfusion at the dorsal area in the supine position may have caused hypoxemia. Reduced ventilation in the dorsal area was correlated with reduced PaO_2.

The distribution of bolus gas inhalation reflected the slope of the regional pressure-volume curve at the lung capacity when inhalation was started. It is generally regarded that closure of the airway in the dependent zone is noted at RV.[6] Therefore, the dorsal area was not imaged on bolus gas inhalation at RV on lateral supine-position images from normal controls and patients, as shown in Fig. 7. But in the patient group, images on inhalation at FRC and FRC + TV showed that closure of the airway in the dependent zone persisted at FRC in the supine position, suggesting that the airway was opened between FRC and FRC + TV, so that ventilation in the dependent zone may be reduced during resting ventilation in the supine position.

Leblanc et al. reported that such findings of CC exceeding FRC were noted among normal adults aged 44 years or older in the supine position.[7] It is speculated that such findings induce a slight reduction in PaO_2 related to postural change.[8] In the 7 patients we examined, hypoxemia might also be caused by a similar mechanism. Several factors may have made this condition as severe as could be detected on a scintigram, noticeably reducing PaO_2. Based on the background of 7 patients, it is assumed that these factors include obesity, liver tumor and organic pulmonary disease.

Some studies have reported that ventilation in the dependent zone in the sitting position is reduced in some obese patients.[9] It has been shown that FRC in the supine position is decreased compared to that in the sitting position[10] and that this tendency is more noticeable in obese patients.[11] Therefore, postural change-related decreases in PaO_2 are more noticeable in obese patients.[12] Fukuchi et al.[5] found that PaO_2 in obese patients was reduced by approximately 5 mmHg, which was 3 mmHg greater than the rate of decrease in non-obese patients. Furthermore, Ward et al.[1] reported noticeable decreases in PaO_2. In their study, body weight was not described, and their series may have included obese patients.

But a more noticeable reduction in PaO_2 in our patients during postural change is not consequent on obesity alone.

When a large abdominal tumor lifts the diaphragm, as found in Patients 5 and 6, the tumor may more noticeably reduce FRC in the supine position, causing airway closure even at FRC. Generally, both lung capacity and FRC are decreased in patients with interstitial lung disease.[13]

Interstitial lesions in our patients were relatively prominent in the dorsal area. In patient 1, the tumor occupied the posterior segment and ventilation decreased in the peripheral area, that is the dorsal area of the tumor, on scintigram. The distribution of these lesions may contribute in part to the airway closure of the dorsal area. Smoking and aging may contribute to the phenomenon slightly, because of the increase in closing capacity.[14] But the mechanism of the airway closure is not entirely clear.

In this study, there was only one non-obese patient among the patients showing marked decreases in PaO_2 related to postural change. Five of 7 patients were not only obese but also had organic pulmonary disease or liver tumors. It was speculated that several factors that reduce FRC, such as postural change, obesity and organic pulmonary or liver tumors, further reduced ventilation in the dependent zone.

CONCLUSION

We encountered patients with severe hypoxemia in the supine position. It was shown that hypoxemia was caused by a mismatch between pulmonary ventilation and perfusion related to reduced ventilation in the gravity-dependent area, that is, the dorsal area. In most patients, obesity was complicated by lung disease or liver tumor. These factors reduced FRC and caused airway closure at FRC in the supine position. This finding was detected on lateral supine-position images during ventilation and perfusion scintigraphy. Reduced ventilation was correlated with reduced PaO_2.

REFERENCES

1. Ward RJ, Tolas AG, Benveniste RJ, Hansen JM, Bonica JJ. Effect of posture on normal arterial blood gas tensions in the aged. *Geriatrics* 21: 139–143, 1966.
2. June MR, Bishpop JM. A—a difference in O_2 tension and physiological dead space in normal man. *J Appl Physiol* 18: 284–288, 1963.
3. Sorbni CA, Grassy V, Solinas E. Arterial oxygen tension in relation to age in healthy subject. *Respiration* 25: 139, 1966.
4. Mellemgaard K. The alveolar—arterial oxygen difference: Its size and components in normal man. *Act Physiol Scand* 67: 10–20, 1966.
5. Fukuchi Y, Harasawa M. Arterial blood gas in the aged with particular reference to its normal value and postural change in relation to obesity. *Jpn J Geriatrics* 10: 59–65, 1973.
6. Milic-Emili JM, Henderson JA, Dolovich MB, Trop D, Kaneko K. Regional distribution of inspired gas in the lung. *J Appl Physiol* 21: 749–759, 1966.
7. Leblanc P, Ruff F, Milic-Emili J. Effect of age and body position on airway closure in man. *J Appl Physiol* 28: 448–451, 1970.
8. Don HF, Craig DB, Wahba WM, Couture JG. The measurement of gas trapped in the lungs at functional residual capacity and the effects of posture. *Anesthesiology* 35: 582–590, 1971.
9. Holley HS, Milic-Emili J, Becklake MR, Bates DV. Regional distribution of pulmonary ventilation and perfusion in obesity. *J Clin Inves* 46: 475–481, 1967.
10. Agostoni E, Mead J. Statics of the respiratory system. *In* Handbook of Physiology Section 3 Respiration, Fenn WO, Rahn H (ed.), Washington DC, Physiol Soc, pp. 387–409, 1964.
11. Tucker DH, Sieker HO. The effect of change in body position on lung volumes and gas mixing in patients with obesity, heart failure and emphysema. *Am Rev Respir Dis* 82: 787–791, 1960.
12. Vaugham RW, Engelhard RC, Wise L. Postoperative hypoxemia in obese patients. *Ann Surg* 180: 877–882, 1974.
13. Weinberg SE. Overview of the interstitial lung disease. *In* Principal of Pulmonary Medicine. Saunders WB Company, Philadelphia, pp. 122–131, 1986.
14. Buist AS, Van Fleet DL, Ross BB. A comparison of conventional spirometric tests and the test of closing volume in an emphysema screening center. *Am Rev Respir Dis* 107: 735–743, 1973.