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Diagnostic value of different patient positions during expiratory low-dose thin-layer MDCT for evaluating air trapping after allogeneic hematopoietic stem cell transplantation

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Abstract. – OBJECTIVE: To investigate the diagnostic value of different patient positions during expiratory low-dose thin-layer multidetector computed tomography (MDCT) for detecting air trapping after allogeneic hematopoietic stem cell transplantation (allo-HSCT).

PATIENTS AND METHODS: Expiratory lung MDCT scanning was done for 51 post-allo-HSCT patients in both the supine and prone positions to determine if they had air trapping lesions. We assessed the volume fraction of an air trapping region (CT value of ≤700HU at expiratory phase) against the whole lung area with a GE workstation and graded these results.

RESULTS: In the supine position, multiple air trapping lesions were found in 16 of 51 patients, which were scattered and mainly distributed in the dorsal sides of both lower lobes. In the prone position, in addition to these 15 patients, air trapping lesions were also found in 11 other patients, which were mainly distributed in the anterior load-bearing area of the lung lower lobes and lobe-connected areas. Compared with that in the supine position, the graded score of air trapping in the prone position was significantly different (*p* = 0.006).

CONCLUSIONS: When performing expiratory thin-layer MDCT for patients with chronic rejection reactions after allo-HSCT, scanning in the prone position should also be performed, not only to more accurately observe lesions, but also for a preliminary evaluation of air trapping severity. This provides a basis for an early clinical diagnosis and treatment.

Key Words:
Thin-layer MDCT, Air trapping, Supine position, Prone position, Expiratory phase.

Introduction

Allogeneic hematopoietic stem cell transplantation (allo-HSCT) is currently the most important treatment of hematologic malignancies, hematopoietic stem cell disease, immune deficiency diseases, and the other diseases. Pulmonary complications occur in approximately 50% of the patients after the treatment with HSCT, which result in a high mortality. Air trapping, which is closely related to the prognosis of the patients with HSCT treatment, is one of the most commonly happened pulmonary complications. Because symptoms of air trapping are usually non-specific (dry cough, shortness of breath, and dyspnea on exertion), early diagnosis can be quite difficult. Moreover, once symptoms and abnormalities were obvious, the air trapping was always severe, including resultant dyspnea, decreased quality of life, and increased mortality. If the air trapping in the lung can be found during the early stages of chronic rejection, the preventive treatment can be taken timely to slow the lung disease progression and reduce the mortality significantly[1]. However, as mentioned above, the clinical symptoms are always insidious in the early stage, which is easily misdiagnosed. Therefore, an early diagnosis of air trapping is crucial for clinical treatment.

In this study we scanned 51 post-allo-HSCT patients at expiratory phase using multidetector tomography (MDCT) in two different positions, supine and prone, to determine the air trapping conditions. These images were then compared and analyzed to explore the diagnostic value of

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the two positions on MDCT scans for lesion detection. Our aim was to establish a more accurate clinical imaging method, and to provide imaging evidence for early clinical diagnosis of air trapping.

Patients and Methods

Patients

Study Population

The patients with chronic rejection after allo-HSCT hospitalized from June 2010 to April 2012 in the hematology department of the Central Hospital of China Aerospace Corporation were enrolled in this study.

1) Equipment
2) GE 64-row VCT/XT machine (GE Healthcare, Milwaukee, WI, USA)
3) Post-Processing Software Life Technologies, Carlsbad, CA, USA)
4) GE/ADW4.4 Workstations (USA)

Methods

Inclusion Criteria

1) A well-documented allo-HSCT history;
2) Incidence of chronic rejection symptoms;
3) Results of inspiratory lung MDCT scan in the supine position were normal;
4) PFT examination results were normal, which included forced expiratory volume in one second/forced vital capacity (FEV_1/FVC) ratio > 70%, and $FEV_1 \geq 80\%$ of predicted.

Exclusion Criteria

1) A long history of smoking;
2) Any other cancer history except for blood cancer;
3) Obstructive pulmonary diseases and circulatory diseases, such as heart failure, pulmonary embolism, and others;
4) PFT results showed airflow limitation and FEV_1/FVC <70% and/or FEV_1 <80% of predicted;
5) Abnormal systemic immune diseases, such as rheumatoid arthritis, systemic lupus erythematosus, ankylosing spondylitis;
6) Any severe infection during the study, including clinical signs and radiological manifestations such as those on CT.

Device Parameters

Tube voltage = 120 KV; tube current = 50 mA; collimator = 0.625 mm, speed= 39.4 mm/s, pitch = 0.984:1, reconstruction thickness = 0.625 mm, reconstruction interval = 0.625 mm, and a 512 × 512 matrix. A standard lung algorithm was used to reconstruct images (W: 1500 HU, C: -650-550 HU).

Scan Range

The scan range was from the apex to the diaphragm base of the lungs of patients. The Expiratory phase should meet the following conditions: when conducting TLC MDCT scans, the difference of the lower bounds between the inspiratory lung and the expiratory lung should be 4-6 cm (2 rib-units), the thorax should shrink and lung volume should be significantly reduced in the expiratory phase than those in the inspiratory phase. All the diagnostic requirements should be satisfied.

Scanning

Scan the whole lung at expiratory phase in the supine and prone positions respectively.

Image Analysis

The images were independently read by two highly-qualified senior radiologists. The CT respective images from the two positions were evaluated for each patient.

1) Evaluate lung conditions, including the location and shape of any lesions in the supine and prone positions at expiratory phase.
2) Identify any air trapping region on MDCT images by visual assessment. The junction of a lesion and the normal region was clear, smooth, and sharp.
3) Measure the volume of an air trapping region (CT values of ≤-700HU) with a GE workstation, and calculate the ratio of this region against the total lung volume. The air trapping level was graded on a 0-5 scale (2): no air trapping = 0; 1%-25% = 1; 26%-50% = 2; 51%-75% = 3; 76%-100% = 4.

Statistical Analysis

Kappa analysis was used to evaluate the consistency of the results between the two readers by (Kappa values ranging from -1 to 1): Kappa ≤ 0.40 indicated poor consistency; Kappa = 0.40-0.75 indicated moderate consistency; and Kappa ≥ 0.75 indicated good consistency.

McNemar paired χ^2 test was used to compare the air trapping volume fractions in the supine and prone positions at expiratory phase with SPSS 13.0 software (SPSS Inc., Chicago, IL, USA). $p < 0.05$ was considered significant.

For non-normal distribution of measurement data (volume fraction), two sample correlation rank sum test was used; expressed $p < 0.05$ was considered statistically significant.

Results

General Condition of Patients (Table I)

51 patients after allo-HSCT were scanned with thin-layer MDCT in supine and prone positions in our hospital, including 38 males and 13 females, aged between 5 and 53 years, whose mean age was 27.94 ± 11.99 years old, and the median time after transplantation was 15 months.

PFT examination of 51 patients were negative (FEV_1/FVC) ratio of > 70%, FEV_1 ≥ 80% predicted). MDCT at the expiratory phase in the supine position showed that 51 patients' lung were clear.

Comparison of MDCT Results in the Supine and Prone Positions at Expiratory Phase

MDCT images obtained in the supine position at expiratory phase showed that there were multiple air trapping lesions in 16 of these 51 patients, which were scattered and mainly distributed in the dorsal sides of both lower lobes (Figures 1B, 2B, 3B).

On MDCT images in the prone position, in addition to the 15 patients above, air trapping lesions were also found in 11 other patients. These air trapping lesions were mainly distributed in the anterior load-bearing area of the lung lower lobes and lobe-connected areas (Figures 1C, 2C, 3C), and were not detected in the supine position.

Paired χ^2 McNemar test was used to analyze the data obtained on the expiratory phase in the supine and prone positions. The lesion detection rates of the two positions were significantly different ($p = 0.006$). The rate from the prone position was higher (Table II).

The Kappa test results of the consistency of the two positions: the degree of agreement between the two positions were poor (Kappa = 0.533), which was statistically different ($p < 0.05$).

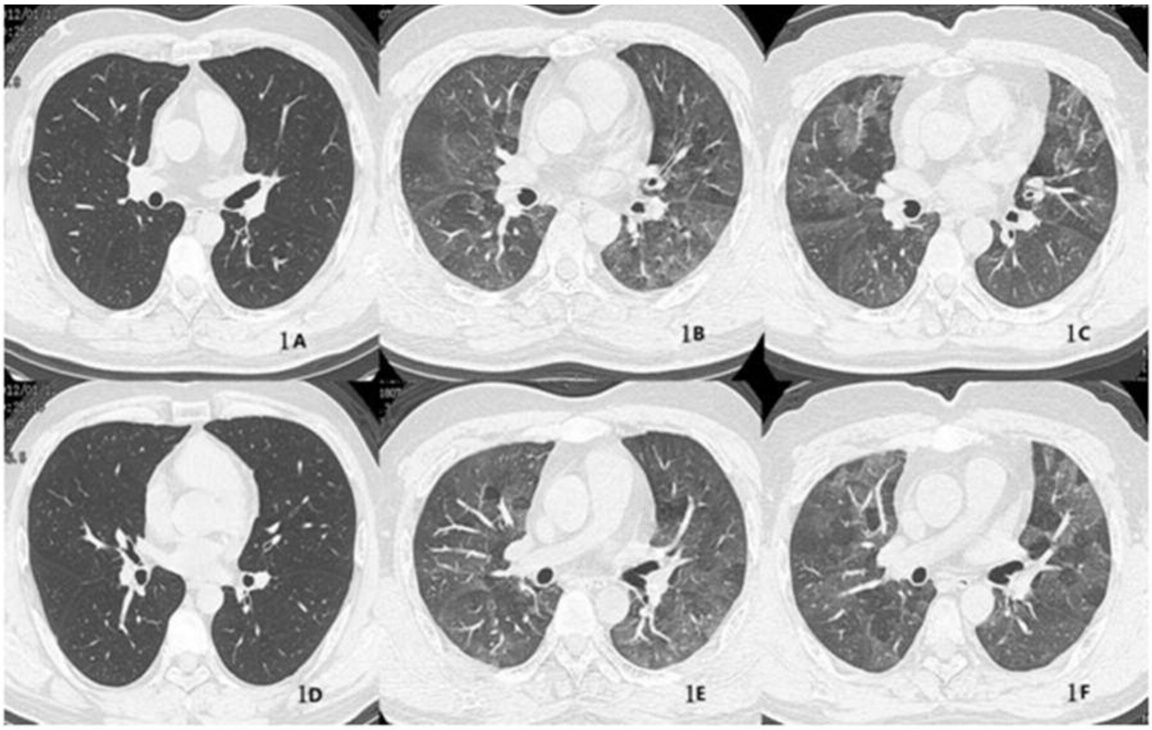

Figure 1. A34-year-old male; 36 months after transplantation; chronic graft-versus-host reaction had occurred; normal PFT results; when scanning at the inspiratory phase in the supine position (1A and 1D), no abnormalities were observed; when scanning at the expiratory phase in the supine position (1B and 1E), multiple air trapping lesions were observed in both lungs; when scanning at the expiratory phase in the prone position (1C and 1F), new air trapping lesions were observed.

Table I. Demographic and clinical characteristics of allo-HSCT patients.

Patient No.	Sex	Age	Months after transplantation	Volume fraction in supine position	Lesion location in supine position	Volume fraction in prone position	Lesion location in prone position
1	Male	34	36	2	Multiple in both lungs	2	Multiple in both lungs
2	Female	25	24	0		1	Anterior segments of the upper lobes of both lungs
3	Male	32	15	0		0	
4	Male	10	18	0		1	Tongue segments of the upper lobes of both lungs
5	Male	49	33	0		0	
6	Male	22	23	0		0	
7	Male	14	6	0		1	Anterior segments of the upper lobes of both lungs
8	Female	15	9	0		0	
9	Male	45	55	2	Multiple in both lungs	2	Multiple in both lungs
10	Male	17	22	0		0	
11	Female	21	27	0		0	
12	Female	15	14	0		0	
13	Male	38	42	0		0	
14	Male	43	38	0		0	
15	Male	26	39	2	Dorsal sides of the lower lobes of both lungs	2	Dorsal sides of the lower lobes of both lungs
16	Female	16	10	0		0	
17	Female	28	33	0		0	
18	Male	39	29	1	Multiple in both lungs	1	Multiple in both lungs
19	Male	45	26	0		0	
20	Male	28	18	1	Dorsal sides of the lower lobes of both lungs	1	Anterior segments and dorsal sides of the lower lobes of both lungs
21	Male	27	13	2	The lower lobes of both lungs	2	the lower lobes of both lungs
22	Male	28	12	0		0	
23	Male	47	20	0		0	
24	Male	23	7	0		1	Anterior segments of the upper lobes of both lungs
25	Female	23	15	0		0	
26	Male	46	13	0		1	Anterior segments of the upper lobes of both lungs
27	Male	19	11	1	The lower lobes of both lungs	0	
28	Male	31	12	0		0	
29	Male	33	5	0		1	Anterior segments of the upper lobes of both lungs

Table continued

Table I. *Continued.* Demographic and clinical characteristics of allo-HSCT patients.

Patient No.	Sex	Age	Months after transplantation	Volume fraction in supine position	Lesion location in supine position	Volume fraction in prone position	Lesion location in prone position
30	Female	12	4	1	Dorsal sides of the lower lobes of both lungs	1	Anterior segments and dorsal sides of the lower lobes of both lungs
31	Male	22	13	0		1	Anterior segments of the upper lobes of both lungs
32	Male	53	21	0		0	
33	Male	28	15	0		0	
34	Male	17	4	0		1	
35	Female	23	5	1	The lower lobes of both lungs	1	Anterior segments and dorsal sides of the lower lobes of both lungs
36	Male	22	23	0		1	Anterior segments of the upper lobes of both lungs
37	Male	18	7	0		1	Anterior segments of the upper lobes of both lungs
38	Male	20	14	0		1	Anterior segments of the upper lobes of both lungs
39	Female	45	21	0		0	
40	Female	38	10	0		0	
41	Male	35	18	2	Multiple in both lungs	2	Multiple in both lungs
42	Male	8	19	1	Dorsal sides of the lower lobes of both lungs	1	Anterior segments and dorsal sides of the lower lobes of both lungs
43	Female	39	9	0		0	
44	Male	24	8	1	Dorsal sides of the lower lobes of both lungs	1	Anterior segments and dorsal sides of the lower lobes of both lungs
45	Male	42	4	0		0	
46	Male	7	15	1	Dorsal sides of the lower lobes of both lungs	1	Anterior segments of the upper lobes of both lungs
47	Female	5	14	1	The lower lobes of both lungs	1	Anterior segments of the upper lobes of both lungs
48	Male	41	18	0		0	
49	Male	27	37	0		0	
50	Male	27	9	1	Dorsal sides of the lower lobes of both lungs	1	Anterior segments and dorsal sides of the lower lobes of both lungs
51	Male	33	3	1	The lower lobes of both lungs	1	Anterior segments of the upper lobes of both lungs

Air trapping volume fraction: 0 = no air trapping; 1 = 1%-25%; 2 = 26%-50%; 3 = 51%-75%; 4 = 76%-00%.

Table II. Statistical analysis of expiratory lung MDCT results in different positions.

		Prone position		
		Negative	Positive	Total
Supine position	Negative	24	11	35
	Positive	1	15	16
Total		25	26	51
p-value				0.006

$p < 0.05$ indicates significant difference.

Inter-observer Agreement

The results arrived at by the two readers showed good consistency for their agreement (Kappa = 0.89).

Statistical Analysis of Air Trapping Scores in the Supine and Prone Positions

The score for the total air trapping volume fraction for the 16 patients in the supine position was 23, and the score for the 26 patients in the prone position was 44. These two results were significantly different ($p < 0.05$), indicating that scan in the prone position had a higher sensitivity for detecting air trapping lesions (Table III).

Discussion

HSCT is an important treatment for hematological malignancies. It has been reported that infectious and non-infectious pulmonary complications occurred in approximately 40%-60% of patients after allo-HSCT and that 10%-40% of these patients died, of which 65% died from non-infec-

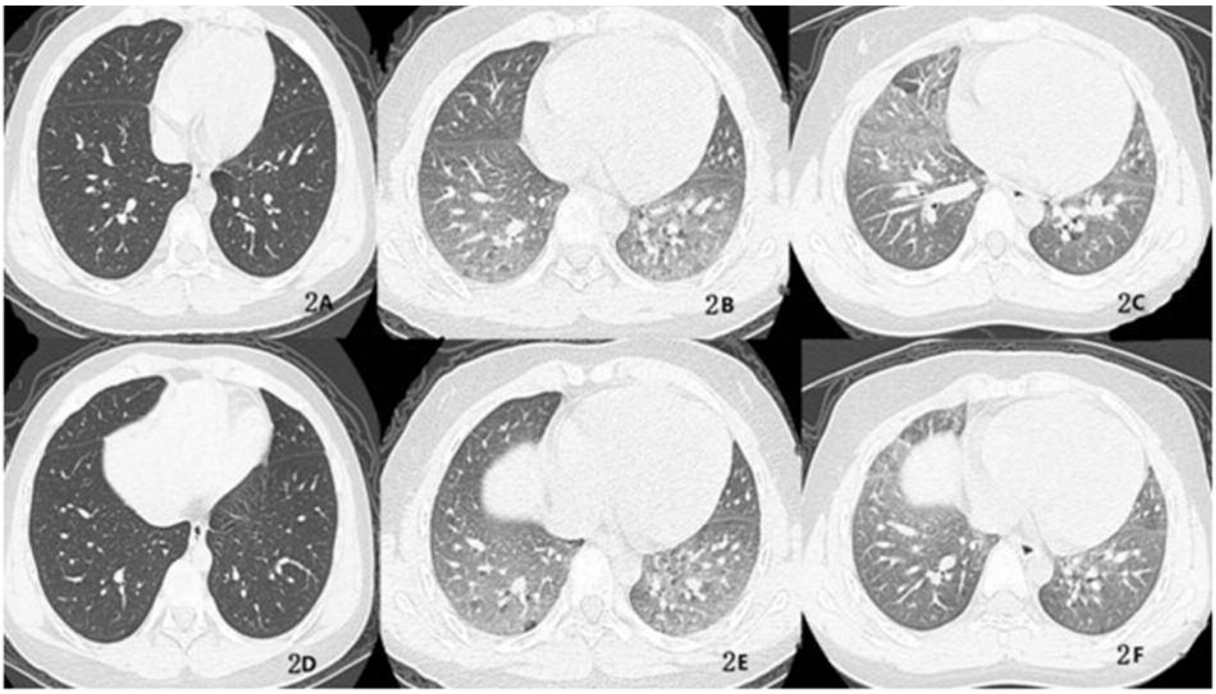

Figure 2. A 14-year-old male; 35 months after transplantation; chronic graft-versus-host reaction had occurred; normal PFT results; when scanning at the inspiratory phase in the supine position (2A and 2D), no abnormalities were observed; when scanning at the expiratory phase in the supine position (2B and 2E), some air trapping lesions were observed in the dorsal sides of the lower lobes of both lungs; when scanning at the expiratory phase in the prone position (2C and 2F), the area of air trapping lesions in the dorsal sides of the lower lobes of both lungs were narrowed down, some had even disappeared, and new lesions were observed in the anterior segments of the upper lobes of both lungs.

Table III. Comparison of lesion volume fractions in different positions at the expiratory phase.

	Volume fraction	Air trapping	
		Positive	Negative
Supine	23	16	35
Prone	44	26	25
Z			-4.583
p-value			0.000

$p < 0.05$ indicates significant difference.

tious pulmonary disease[2]. These complications may have been related to immunodeficiency, graft-versus-host disease, and other factors due to the use of immunosuppressive agents. Among these complications, air trapping in the lungs is most common after allo-HSCT, the clinical signs and symptoms of which are often non-specific, and may even have no symptoms at the early stage. Thus, a diagnosis is usually delayed, which results in a poor prognosis and a significantly high mortality rate among patients after allo-HSCT. Therefore, early diagnosis and treatment is important for a favorable prognosis, which can block the progression of this disease reported on the diagnostic value of thin-layer CT for assessing air trapping in obstructive airways disease[3], and found that MDCT was very valuable for diagnosing air trapping caused by obstructive disease, which can be used as the preferred imaging method to identify air trapping lesions. In another study[4], also confirmed that performing low-dose MDCT scanning (tube current: 80 mAs-20 mAs) not only had no effect on detecting air trapping lesions, but could also significantly reduce the radiation dose. Therefore, we used a tube current of 50 mAs for MDCT scanning in our study.

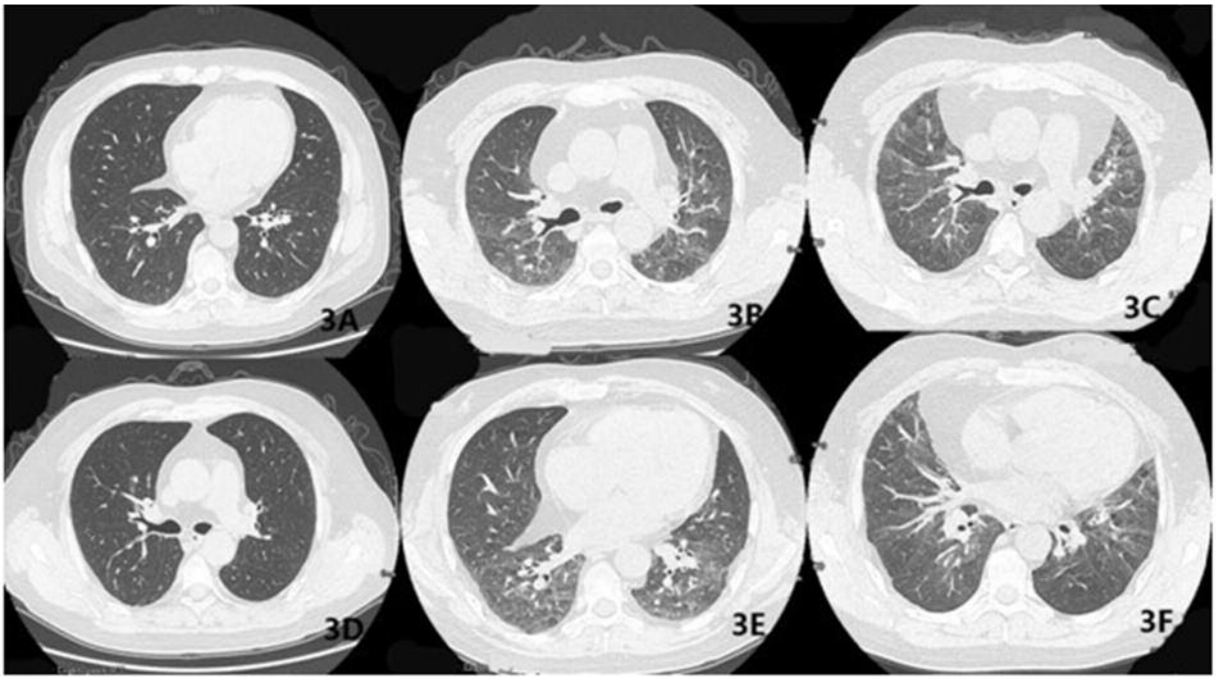

Figure 3. A 45-year-old male; 55 months after transplantation; chronic graft-versus-host reaction had occurred; normal PFT results; when scanning at the inspiratory phase in the supine position (3A and 3D), no abnormalities were observed; when scanning at the expiratory phase in the supine position (3B and 3E), some air trapping lesions were observed in the dorsal sides of the lower lobes of both lungs; when scanning at the expiratory phase in the prone position (3C and 3F), the area of air trapping lesions in the dorsal sides of the lower lobes of both lungs were narrowed down, some had even disappeared, and new lesions were observed in the anterior segments of the upper lobes of both lungs.

In addition, in previous studies that compared HRCT and MDCT for detecting diffuse lung disease, it was shown that MDCT had a higher positive detection rate compared to HRCT. Besides, the results reported by MDCT readers were more consistent[5,6] and it was easier to identify small airway disease related to bronchiolitis obliterans by MDCT at expiratory phase[7]. Argued that continuous MDCT multi-scanning could reduce the rate of missed diagnosis and measure the air trapping volume fraction more accurately. The scan speed of thin-layer MDCT is notably faster than that of HRCT, which makes it easier for examining those patients with poor breathing and can greatly reduce artifacts and the radiation dose used.

The scanning method used in this study included multiple high-resolution image reconstruction techniques with a standard lung algorithm. Compared with MDCT performed at the inspiratory phase, MDCT at the expiratory phase can more readily identify early air trapping lesions, which can increase the detection rate for small airway disease and can accurately observe the whole lung condition. This aids in determining the underlying cause of air trapping in advance demonstrated that air trapping, as the common sign of small airway disease, was detected by MDCT at the expiratory phase and which occurred earlier than findings of pulmonary function abnormalities[2,8,9]. Previous studies have confirmed that only when the lung destruction area is more than 30% can PFT detect an abnormality, at which time the condition is mostly irreversible. Thus, MDCT with its high sensitivity and specificity is recommended for detecting air trapping lesions. In our study, patients with chronic rejection symptoms after allo-HSCT were examined by PFT and inspiratory MDCT, and those with normal results were enrolled and further examined by expiratory MDCT in the supine and prone positions to evaluate their lung lesion conditions.

Conclusions

Our results showed that multiple air trapping lesions were found in 16 patients during expiratory MDCT scan in the supine position. The distributions of these lesions were scattered and mainly located in the dorsal sides of the lower lobes of both lungs. In the prone position, total 26 patients were observed with multiple air trapping lesions: the new air trapping lesions appeared in the anterior segments of the lower lobes of both lungs, and some of the lesions found in the supine position were reduced or even disappeared at different levels, which indicated that these lesions were mild; thus, they changed with a change in body position. The positive rate detected in the prone position was higher than that in the supine position. The lesions in the newly-added 11 patients were mainly located in anterior segments of the upper lobes of both lungs, which may have been associated with gravitational effects: load-bearing areas change with postural changes. These results were presumably due to the following reasons.

1) Compression of the heart: in the supine position, the dorsal side of a lung is below the heart. When compressed by the heart, lung expansion is affected[10]. In the prone position, the lung area affected by the heart is reduced, which is beneficial for lung expansion. As a result, the lesions in the dorsal sides of the lower lobes of both lungs are greatly alleviated, whereas in anterior segments, the number of obstructive lesions is increased.
2) Physical anatomical effects: bronchus upper segments consist of "C" shaped tracheal rings, smooth muscle, and connective tissue, so that there is a bare area without covering cartilage, which is easily pressed by expiratory pressure concomitant with arteries and veins. In the prone position, the arterial and venous pressures in anterior segments of both lungs are increased and the diameter expands, so that bronchial compression is more obvious, and those bronchi with mild stenosis are more easily shown as bronchial obstruction.
3) Hypostatic effects: in the prone position, anterior segments are located in a lower location and are influenced by gravity, which results in increased airway pressure; thus, a mildly obstructive airway can also be manifested as air trapping. In contrast, there is no air trapping sign in a mild obstructive airway in the dorsal sides. The results of our study showed that due to hypostatic effects and heart compression, air trapping lesions in the dorsal sides of both lungs were more easily found in the supine position. While in the prone position, lesions in the anterior segments of the lower lobes of both lungs were more easily identified. If lesions appear in both positions, it can be considered that the small airway obstructive condition in this area is severe, which cannot be changed with postural changes.

Conflict of Interest

The Authors declare that they have no conflict of interests.

References

1) Chien JW, Martin PJ, Gooley TA, Flowers ME, Heckbert SR, Nichols WG, Clark JG. Airflow obstruction after myeloablative allogeneic hematopoietic stem cell transplantation. Am J Respir Crit Care Med 2003; 168: 208-214.
2) Wakayama K, Kurihara N, Fujimoto S, Hata M, Takeda T. Relationship between exercise capacity and the severity of emphysema as determined by high resolution CT. Eur Respir J 1993; 6: 1362-1367.
3) Bankier AA, Mehrain S, Kienzl D, Weber M, Estenne M, Gevenois PA. Regional heterogeneity of air trapping at expiratory thin-section CT of patients with bronchiolitis: potential implications for dose reduction and CT protocol planning. Radiology 2008; 247: 862-870.
4) Bankier AA, Schaefer-Prokop C, De Maertelaer V, Tack D, Jaksch P, Klepetko W, Gevenois PA. Air trapping: comparison of standard-dose and simulated low-dose thin-section CT techniques. Radiology 2007; 242: 898-906.
5) Dodd JD, de Jong PA, Levy RD, Coxson HO, Mayo JR. Conventional high-resolution CT versus contiguous multidetector ct in the detection of bronchiolitis obliterans syndrome in lung transplant recipients. J Thorac Imaging 2008; 23: 235-243.
6) Siegel MJ, Bhalla S, Gutierrez FR, Hildebolt C, Sweet S. Post-lung transplantation bronchiolitis obliterans syndrome: usefulness of expiratory thin-section ct for diagnosis. Radiology 2001; 220: 455-462.
7) Lee ES, Gotway MB, Reddy GP, Golden JA, Keith FM, Webb WR. Early bronchiolitis obliterans following lung transplantation: accuracy of expiratory thin-section ct for diagnosis. Radiology 2000; 216: 472-477.
8) Gunn ML, Godwin JD, Kanne JP, Flowers ME, Chien JW. High-resolution ct findings of bronchiolitis obliterans syndrome after hematopoietic stem cell transplantation. J Thorac Imaging 2008; 23: 244-250.
9) Muller NL, Miller RR. Diseases of the bronchioles: CT and histopathologic findings. Radiology 1995; 196: 3-12.
10) Webb WR, Stern EJ, Kanth N, Gamsu G. Dynamic pulmonary CT: findings in healthy adult men. Radiology 1993; 186: 117-124.