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· Original article ·

Value of air trapping at inspiratory and expiratory low-dose CT in predicting early bronchiolitis obliterans syndrome after bone marrow transplantation

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[**Abstract**] **Objective** To determine whether bronchiolitis obliterans syndrome (BOS) after bone marrow transplantation can be predicted in light of air trapping. **Methods** Thirty-three cases of BOS (BOS group) and 111 normal patients (normal group) were comparatively reviewed for the CT characteristics (including frequency, dynamic change and diagnostic potency) of air trapping. The analysis was mainly based on the last CT scans before occurrence of BOS. **Results** The frequency of air trapping, especially mosaic air trapping or extensive air trapping, was higher in the BOS group than in the normal group ($P=0.03$). The median total air trapping score was higher in the BOS group than in the normal group ($P=0.01$). The increase of air trapping extent with the progress of disease was more common in the BOS group (50.0%, 9/18), whereas a decrease of air trapping extent, disappearance or intermittent appearance of air trapping was more common in the normal group (60.0%, 15/25) during the follow-up period. When mosaic air trapping or extensive air trapping was used as the diagnostic threshold, the specificity was high (90.5%, 96.7%), but the sensitivity was low (29.4%, 15.8%). **Conclusion** Occurrence of air trapping is a clue for development of BOS in patients receiving bone marrow transplantation. Mosaic air trapping and extensive air trapping are insensitive but specific CT findings.

[**Key words**] air trapping; X-ray computed tomography; bronchiolitis obliterans; bone marrow transplantation
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Bronchiolitis obliterans syndrome (BOS), a late complication after bone marrow transplantation, and an important cause for failure of bone marrow transplantation or death of patients, has been reported to occur in up to 10% of transplantation recipients [1]. The early diagnosis of BOS is a formidable challenge for hematologists because its symptoms are nonspecific (dry cough, shortness of breath, etc.). At present, the diagnosis of BOS is mainly based on pulmonary function tests. However, pulmonary function tests only reflect the overall lung function and do not differentiate BOS from other pulmonary complications that can also result in pulmonary dysfunction. Some invasive methods (such as transbronchial biopsy) have been used for the diagnosis of BOS after transplantation, but they are insensitive because the lesions always have a patchy distribution, and some patients are too sick to tolerate these invasive examination[2].

Inspiratory and expiratory CT has already been used for the diagnosis of BOS. In previous studies, it had been shown that air trapping was an early important indirect sign easily detected on expiratory thin-section CT[3-4]. The study by Gunn et al.[5] showed that for BOS developed after hematopoietic stem cell transplantation, air trapping was the principal finding on CT, and its severity was correlated with the degree of air flow obstruction as

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determined by pulmonary function test. However, inspiratory and expiratory CT scans would increase the exposure dose to the patients, which limited the value of this technique. In recent years, some studies have demonstrated that low-dose spiral CT scans can serve as an alternative scan mode for chest without decreasing the image quality[6-7]. Consequently, we believed that inspiratory and expiratory low-dose CT scans might be valuable in evaluating air trapping without increasing the exposure dose to patients. However, up to now, there has been no literature about application of inspiratory and expiratory low-dose CT in the evaluation of air trapping of BOS after bone marrow transplantation. Therefore, our study aimed to analyze the CT characteristics of air trapping before the development of BOS using inspiratory and expiratory low-dose CT and to determine the value of air trapping in predicting early BOS.

1　Materials and methods

1.1　Subjects　By reviewing the medical records of 300 sequential patients who had undergone bone marrow transplantation at our institution between May 30, 2003 and December 30, 2009, we identified 43 patients who had subsequently developed BOS. BOS was diagnosed according to the criteria established by revised criteria issued by The International Society for Heart and Lung Transplantation[8]. The severity of BOS is classified into BOS0, BOS0-p, BOS1, BOS2 and BOS3. Diagnostic criteria of BOS0-p is that the forced expiratory volume in one second (FEV_1) value is less than 81%-90% of the baseline value (defined as the average of the two highest measurements obtained postoperatively at least three weeks apart). BOS1 is defined as 66%-80%, BOS2 as 50%-65%, and BOS3 as less than 50% of FEV_1 baseline value[9-10]. In this study, BOS included BOS0-p, BOS1, BOS2 and BOS3.

Inclusion criteria included: (1)the patients underwent consecutive follow-up CT scans and pulmonary function tests; (2)the patients were younger than 60 years old. Exclusion criteria included: (1)the patients had concurrent pulmonary complications (such as fungal or bacterial infection); (2) the patients could not inhale or exhale under the instruction of doctor; (3)the records of the patients' pulmonary function tests or CT scans were too incomplete to meet the requirements of study.

Of the 43 patients who had subsequently developed BOS, 10 patients were excluded for various reasons including imaging failure ($n=2$), incompleteness of follow-up CT scans or pulmonary function tests ($n=3$), no written informed consent ($n=1$), being transferred to another hospital ($n=2$) or death due to various reasons ($n=2$). Totally, the study group consisted of 33 patients (19 males and 14 females), of whom there were 30 allogeneic bone marrow transplantation recipients and three autologous bone marrow transplantation recipients. Their age ranged from 14 to 54 years old (mean age, 34 years).

For all these patients, BOS was histopathologically proven by bronchoalveolar lavage or transbrochial biopsy. The time interval between the biopsy or bronchoalveolar lavage and CT scan was 0-7 d (mean 4 d), and the time interval between the biopsy or bronchoalveolar lavage and pulmonary function test was 0-10 d (mean 6 d).

Of the 257 patients without BOS after bone marrow transplantation, 146 patients were excluded from the normal group for various reasons, including incompleteness of follow-up CT scans or pulmonary function tests ($n=12$), loss to follow-up ($n=24$), no written informed consent ($n=14$), or occurrence of other pulmonary complications ($n=96$). Eventually, 111 patients without BOS (and without other pulmonary complications) after bone marrow transplantation were included in the normal group. The follow-up schedules of these patients were the same as that of the BOS group.

The clinical information (including smoking history, gender, age and weight) was compared between the two groups and no significant difference was found ($P>0.05$).

This study was approved by the institutional review board of Air Force General Hospital of PLA, and all the patients in this study provided written informed consent.

1.2 Inspiratory and expiratory low-dose CT technique CT scans were performed on a Lightspeed 16 Spiral CT scanner (GE Medical Systems, American). The helical scans were obtained both at the end inspiration and end expiration by using an 8-mm collimation and a pitch of 1 120 kV, 50 mAs and were reconstructed at 2-mm collimation and 2-mm interval with a high-frequency algorithm. The scan scope ranged from the apex of lung to the diaphragm. Examination was performed during breath holding at fully suspended inspiration and fully suspended expiration. Before scanning, breath holding at fully suspended inspiration and at fully suspended expiration was rehearsed for all the patients to ensure that the amplitude of exhalation was the same as the amplitude of inhalation.

The serial follow-up CT scans were performed every three months during the first year, and then every six months afterwards. The longest follow-up lasted two and half a year. All the patients in our study underwent CT examination and pulmonary function test during the same week.

1.3 Interpretation of CT image First, a radiologist, who did not participate in the analysis of CT images and did not reveal the information to others, selected the last CT images before occurrence of BOS and the first CT images for the normal group. The selected CT images were evaluated independently by two other chest radiologists who had more than ten years' experience of thoracic image interpretation. They were blinded to each other's interpretation and to the patients' clinical and functional information. The images were viewed with the lung window (window width 1 500 HU, level −700 HU). For each patient, the inspiratory scans were reviewed first, with the expiratory scans of the same patient reviewed immediately afterwards. In addition, the CT images at other time points were also observed in order to review the periodic change of air trapping during the follow-up period.

Air trapping was defined as the areas of subnormally decreased attenuation on expiratory CT images. The pattern of air trapping was classified into no air trapping, lobular, mosaic and extensive air trapping. Lobular air trapping was defined as small areas of hypoattenuation that corresponded to one or two adjacent secondary pulmonary lobes in one or two regions per lung level. Mosaic air trapping was when three or more areas of lobular air trapping were observed to alternate with areas of normally attenuating lung, usually in a multilobular distribution. Extensive air trapping was a contiguous area of air trapping that was larger than three adjacent pulmonary lobules and was subsegmental, segmental, or lobular in distribution[10]. Before viewing the study images, the two observers reviewed several actual examples of lobular, mosaic, and extensive air trapping as reference images.

The assessment of the severity of air trapping was semi-quantitative, similar to methods used in the previous studies[11-12]. Each lobe of the lung was scored on a scale of 0-4 for air trapping, depending on the percent of each lobe involved: a score of 0 means no visible air trapping, 1 means 1%-25% of the cross-sectional area was affected, 2 means 26%-50% of the cross-sectional area was affected, 3 means 51%-75% of the cross-sectional was affected, and a score of 4 means that 76%-100% of the cross-sectional area was affected. For each subject, dynamic expiratory images were compared with inspiratory images at three anatomic levels: (1) the upper lung zone, defined as the level of the superior aspect of the aortic arch; (2) the

middle lung zone, defined as the level of the carina; (3) the lower lung zone, defined as the level 2 cm lower than the carina. The degree of air trapping was assessed by comparing inspiratory and expiratory images at similar anatomic levels. To obtain a total air trapping score for CT examination, the scores for all three anatomic levels at each examination were added. The range of possible total air trapping scores was 0-12[9-11].

1.4 Pulmonary function tests Pulmonary function tests were performed with a Ganshorn Powercube Ergo Spirometer (Ganshorn Medizin Electronic, Germany). Measurement parameters included forced vital capacity (FVC), FEV_1 and the ratio of FEV_1 to the forced vital capacity (FEV_1/FVC). All the patients underwent serial follow-up pulmonary function tests once a month after bone marrow transplantation. The longest follow-up lasted two and half a year.

1.5 Statistical analysis Statistical analysis was performed with the SPSS 13.0 soft package. Agreement between the two observers was assessed using agreement analysis. Kappa values of less than 0.40 were regarded as poor agreement, 0.40-0.75 as moderate, and greater than 0.75 as excellent agreement. For the cases with poor agreement, the CT images were read by two observers together with a third thoracic radiologist and the final interpretation was made by consensus.

The frequencies of air trapping with different patterns and periodic change of air trapping between two groups were compared with the χ^2 test. Air trapping scores of the two groups were compared using nonparametric the Wilcoxon's rank sum test. A $P<0.05$ was considered statistically significant. In order to evaluate the impact of time interval between last CT scan and diagnosis of BOS on the change of air trapping, the univariate regression analysis was performed when the time interval served as independent variable and change of air trapping as dependent variable. Sensitivity, specificity, positive predictive value and negative predictive value were computed when air trappings with different patterns served as the diagnostic threshold.

2 Results

2.1 Patterns of air trapping The frequencies of air trapping in the two groups are summarized in Tab 1. There was a significant difference in the frequency of air trapping between two groups ($P=0.03$). The frequency of air trapping was higher in the BOS group than in the normal group. For both the BOS group and the normal group, the distribution of air trapping was heterogeneous. Air trapping was mostly located in the lower lung, followed by medial lung and upper lung. In addition, air trapping was mostly located in the dependent area of the lung.

Tab 1 The frequency of air trapping after bone marrow transplantation

n (%)

Group	*N*	Patterns of air trapping			
		No	Lobular	Mosaic	Extensive
BOS	33	15 (45.5)	9 (27.3)	4 (12.1)	5 (15.2)
Normal	111	86 (77.5)	19 (17.1)	3 (2.7)	3 (2.7)

BOS: Bronchiolitis obliterans syndrome. Air trapping was included for analysis only when it was showed on at least one scan of serial follow-up CT scans before and after occurrence of BOS. There was a significant difference in the frequency of air trapping between the two groups ($P=0.03$)

2.2 The severity of air trapping The severity of air trapping is summarized in Tab 2. There were significant differences in air trapping scores at the level of the middle lung and lower lung between the BOS group and the normal group ($P=0.03$ and $P=0.01$, respectively). There was no significant

difference in air trapping scores at the level of the upper lung ($P=0.12$). There was a significant difference in the mean total trapping scores between the two groups ($P=0.01$). The median total air trapping score in the BOS group was 6 (range, 3-12 points), whereas the median total air trapping score in the normal group was 3 (range, 1-5 points). According to score measurements, the widest involvement of a lobe was most common in extensive air trapping, followed by mosaic air trapping and lobular air trapping.

Tab 2 The severity of air trapping after bone marrow transplantation (air trapping score)

$\bar{x}\pm s$

Group	n	Upper lung zone	Middle lung zone	Lower lung zone	Total
BOS	18	2±1	3±3*	4±2*	6±6*
Normal	25	1±1	1±2	2±1	3±2

BOS: Bronchiolitis obliterans syndrome. The range of air trapping score at the level of each plane was 0-4; the range of the total air trapping score was 0-12. * $P<0.05$ vs normal group

2.3 Periodic changes of air trapping during the follow-up period The periodic changes of air trapping during the follow-up period are summarized in Tab 3. There was a significant difference in the periodic change of air trapping between the two groups ($P=0.02$). An increase of air trapping extent with the progress of disease was more common in the BOS group (50.0%, 9/18) than in the normal group (12.0%, 3/25), and a decrease of air trapping extent, disappearance or intermittent appearance of air trapping during the follow-up period was more common in the normal group (60.0%, 15/25) than in the BOS group (22.2%, 4/18).

Tab 3 Periodic change of air trapping during the follow-up period

n(%)

Group	n	Progress	Stable	Decrease or disappearance	Intermittent
BOS	18	9(50.0)	5(27.8)	2(11.1)	2(11.1)
Normal	25	3(12.0)	7(28.0)	7(28.0)	8(32.0)

BOS: Bronchiolitis obliterans syndrome. There was a significant difference in the periodic change of air trapping between the two groups ($P=0.02$)

The time interval between occurrence of air trapping and development of BOS is summarized in Tab 4. The univariate regression analysis showed that the time interval between last scan and diagnosis of BOS had no statistical impact on the extent or pattern of air trapping. Most air trapping occurred before the development of BOS, with only one case of lobular air trapping occurring after the development of BOS.

Tab 4 The time interval between occurrence of air trapping and BOS after bone marrow transplantation

n

Patterns of air trapping	Before occurrence of BOS t/month			Concomitant with occurrence of BOS	After occurrence of BOS t/month		
	<3	3-6	>6		<3	3-6	>6
Lobular	4	3	0	1	1	0	0
Mosaic	2	2	0	0	0	0	0
Extensive	4	1	0	0	0	0	0

BOS: Bronchiolitis obliterans syndrome. $N=18$

2.4 Diagnostic potency of air trapping The diagnostic potency of air trapping with different patterns is summarized in Tab 5. When lobular air trapping (Fig 1) was used as a diagnostic threshold, the sensitivity and specificity were 56.4% and 65.8%, respectively, and the positive predictive value and negative predictive value were 55.6% and 65.6%, respectively. When mosaic air trapping (Fig 2) or extensive air trapping (Fig 3) was used the diagnostic threshold, the specificity was very high (90.5% or 96.7%), but the sensitivity was low (29.4% or 15.8%).

Tab 5 Diagnostic potency of air trapping

%

Visual scores of air trapping[a]	Sensitivity (95% confidence interval)	Specificity (95% confidence interval)	Positive predictive value	Negative predictive value
Lobular	56.4(39.4-65.5)	65.8(54.3-79.8)	55.6	65.6
Mosaic	29.4(20.3-47.3)	90.5(82.4-93.5)	70.2	62.1
Extensive	15.8(10.4-33.4)	96.7(93.2-98.5)	84.3	60.1

[a]: Equal to or greater than this pattern. $N=18$

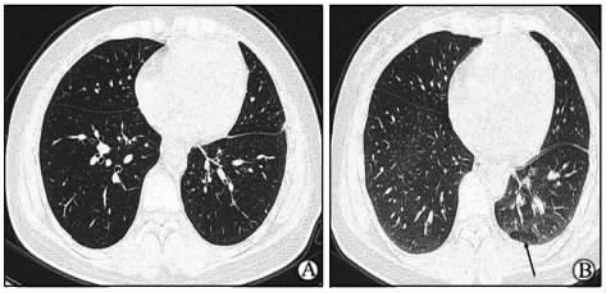

Fig 1 A 23-year-old man with BOS after bone marrow transplantation

BOS: Bronchiolitis obliterans syndrome. A: There was no abnormal change in bilateral lower lung on the inspiratory axial CT scan; B: The attenuation in left lower lung increased and there was lobular air trapping (arrow) in the subpleural region on the expiratory axial CT scan

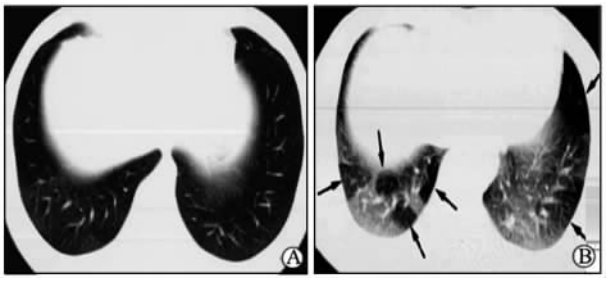

Fig 2 A 42-year-old woman with BOS after bone marrow transplantation

BOS: Bronchiolitis obliterans syndrome. A: There was no abnormal change in bilateral lower lung on the inspiratory axial CT scan; B: There was mosaic air trapping (arrows) in the bilateral lower lung on the expiratory axial CT scan

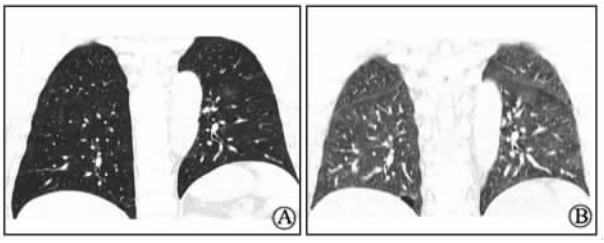

Fig 3 A 37-year-old man with BOS after bone marrow transplantation

BOS: Bronchiolitis obliterans syndrome. A: There was a bulla in the subpleural region of right lower lung and there was no other abnormal change on the inspiratory coronal CT scan; B: There was extensive air trappings in bilateral lungs and a bulla in the subpleural region of right lower lung on the exspiratory coronal CT scan

3 Discussion

This is the first study to evaluate the value of air trapping in predicting early BOS after bone marrow transplantation using inspiratory and expiratory low-dose CT scans. In this study, we provided a comprehensive description of CT characteristics of air trapping before the development of BOS, and showed that air trapping, especially mosaic or extensive air trapping, was more common in the BOS group than in the normal group.

This study was supported by the previous

study which showed that air trapping was the principal finding on CT for the patients with BOS after bone marrow transplantation and the occurrence of air trapping might indicate this disease [5]. The results from our study were not consistent with those reported by Lee et al. [14]. They analyzed the incidence of air trapping in patients after lung transplantation, and found that there was no significant difference in the mean air trapping score between two groups; consequently, they thought that expiratory thin-section CT was of limited accuracy in diagnosing early BOS after lung transplantation. The possible reasons for the discrepancy between the two studies included: (1)there was a difference in grouping method. In their study, the patients were classified into the BOS group and the normal group according to histological results, and the patients with the normal biopsy were further classified into abnormal and normal group in light of a pulmonary function test. However, in our study, the patients were grouped into two groups of BOS and the normal group according to histological results. (2) The subjects of our study were bone marrow transplantation recipients whereas the subjects of their study were lung transplantation recipients, which might influence the results of the two studies.

Several previous studies investigated the severity of air trapping after transplantation. For example, Bankier et al. [15] evaluated the severity of air trapping after heart-lung transplantation and found that, at the threshold of 32%, air trapping was sensitive, specific, and accurate for diagnosing BOS. Konen et al. [9] assessed the thin-section CT features of BOS in lung transplant recipients before the clinical appearance, and demonstrated that when an air trapping score of three or higher was used to define abnormal air trapping, the sensitivity and specificity for the diagnosis of BOS were 33% and 92%, respectively. To our knowledge, there has been no study that assessed the severity of air trapping before the development of BOS after bone marrow transplantation. Therefore, we assessed the severity of air trapping semi-quantitatively before the development of BOS after bone marrow transplantation and found that the air trapping score at the level of the middle lung or lower lung and the total air trapping score were higher in the BOS group than in the normal group. Therefore, we believe that air trapping scores are helpful for the diagnosis of BOS. However, according to our experience, this semi-quantitative assessment method is relatively complex and its reproducibility needs to be further researched.

Regarding occurrence time of air trapping, our study showed that most of the air trappings occurred before the development of BOS, which was helpful for the diagnosis of early BOS because it became possible to predict BOS before occurrence of this disease in light of air trapping seen on CT[16-17]. But Berstad et al. [18] demonstrated that most cases of air trapping were detected concomitantly with or later than the development of BOS. The possible reasons for the discrepancy between these two studies include: (1) in their study, the extent of air trapping was evaluated with a minimum-intensity-projection technique, and only two levels (carina, the midway between the right diaphragm and the carina) were selected when expiratory CT scans were performed. In contrast, in our study the air trapping was assessed using inspiratory and expiratory low-dose CT scans, and the scan scope covered the total lung so that it was possible to detect more air trapping. (2)The follow-up time was longer in our study than in their study, which was advantageous to detect more air trapping.

A few authors [14,18-19] have analyzed the periodic changes of air trapping of BOS after lung transplantation and demonstrated that the extent of air trapping increased with the progress of BOS, but they did not compare the further change of air trapping between the BOS group and the normal

group. We compared the periodic changes of air trapping between two groups and found that the increase of the extent of air trapping with the progress of disease was more common in the BOS group. This finding might be related to many factors. Jung et al. [20] thought that the mechanism of BOS after bone marrow transplantation included graft versus host disease (GVHD), viral infection, decrease of IgA level and other factors, of which GVHD was the most possible contributor to initial injury of the mucous membrane of the bronchiole. All these factors might result in dysfunction of ventilation of bronchioles and thus air trapping usually progressed with the aggravation of disease. For the normal group, air trapping frequently decreased, disappeared or intermittently appeared because the mechanism of air trapping in this group was different from that in the BOS group and probably related to compliance of the lung and mutual interdependence with the adjacent lung regions, thus there was not a gradual progress in the course of disease [20-21]. Therefore, the periodic change of air trapping was helpful for the diagnosis of BOS.

Compared with pulmonary function tests, inspiratory and expiratory CT scans allow for indirect evaluation of airway obstruction before BOS. These quantitative methods are based on the detection of air trapping, including the distribution, extent or pattern of air trapping, which reflects the retension of excess gas in all or part of the lung. Therefore, the evaluation of air trapping is useful for the detection or diagnosis of early BOS[22]. The clinical value of this study is that BOS may be predicted in light of air trapping before the development of this disease, and thus these patients could receive treatment as early as possible. When lobular trapping was used as diagnostic threshold, sensitivity was 56.4%, and specificity was 65.8%. When mosaic air trapping and extensive air trapping were used as the diagnostic threshold, the specificity was high at 90.5% and 96.7%, but the sensitivity was low at 29.4% and 15.8%. BOS0-p served as the diagnostic criteria of BOS in this study, and these criteria for BOS might have contributed to the low sensitivity of air trapping. However, this classification of BOS is believed to be more sensitive for the detection of early-stage BOS. In the clinical practice, there were false positives and false negatives when BOS was predicted in light of air trapping. Some cases of BOS had no air trapping, and because of this the disease might has other signs; such as tree-in-bud pattern, bronchodilation, or thickening of the bronchial wall. In addition, when air trapping appeared as diffused, some cases of air trapping might be missed [22-23]. Some normal patients might have air trapping, even mosaic air trapping or extensive air trapping, which might be related to the compliance of the lung and mutual interdependence with the adjacent lung regions [20-21]. de Jong et al. [23] compared the value of composite CT scoring system and air trapping scores in the early detection of bronchiolitis obliterans after lung transplantation. Composite CT scoring system was based on combination of air trapping and various CT signs, such as bronchiectasis, mucus plugging, airway wall thickening, and consolidation. It was found that combined manifestations of both air trapping and other CT signs (such as bronchiectasis, thickening of bronchial wall, mucus plug) were more valuable for diagnosis of the early BOS, but a further comparable study is necessary.

Our study had several limitations. First, although low-dose CT scans would greatly decrease the exposure dose to patients, repeated follow-up CT scans would lead to the slight increase in the total exposure dose to the patients eventually. Second, if BOS was to progress, although only a few cases showed the change of pattern of air trapping during the follow-up period in our study, the pattern of air trapping of BOS might change from lobular to extensive air trapping, which undermined

the diagnostic potency of air trapping of different patterns.

In conclusion, there are significant differences in frequency and temporal changes of air trapping between the BOS group and the normal group. The median total air trapping score is higher in the BOS group than in the normal group. Therefore, air trapping is helpful for predicting early BOS after bone marrow transplantation. When mosaic air trapping or extensive air trapping is used as the diagnostic threshold, the specificity is very high, but the sensitivity is low.

4 Conflict of interest

The authors declare that there is no conflict of interest.

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吸呼气低剂量动态 CT 显示的空气滞留在预测骨髓移植术后早期阻塞性细支气管炎中的价值

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[**摘要**] **目的**　使用吸呼气低剂量动态 CT 扫描评价在骨髓移植术后阻塞性细支气管炎(BOS)发生前的空气滞留特点和分级，探讨能否根据空气滞留预测 BOS 的发生。**方法**　对 33 例骨髓移植术后 BOS 患者(BOS 组)和 111 例骨髓移植术后正常人群(正常对照组)进行对照性分析，BOS 组的 CT 图像主要依据在 BOS 发生前的最后一次扫描结果。评价内容包括空气滞留的发生率、动态变化及诊断效能。**结果**　BOS 组的空气滞留(尤其马赛克和广泛性空气滞留)的发生率高于正常对照组($P=0.03$)。BOS 组的总体空气滞留评分的平均值高于正常对照组($P=0.01$)。随疾病的发展而加重的空气滞留多见于 BOS 组(50.0%，9/18)，而空气滞留范围减少、消失或间断出现多见于正常对照组(60.0%，15/25)。当把马赛克空气滞留或广泛性空气滞留作为诊断标准时，诊断特异度较高(90.5%，96.7%)，敏感度较低(29.4%，15.8%)。**结论**　空气滞留征象可以为骨髓移植术后 BOS 的发生提供一定的预测信息，马赛克空气滞留和广泛性空气滞留是特异性较高但是不敏感的 CT 征象。

[**关键词**] 空气滞留；X 线计算机体层摄影术；阻塞性细支气管炎；骨髓移植

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