# Noninvasive diagnosis of bronchiolitis oblitera

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CHEST RADIOLOGY
*RADIOLOGIA TORACICA*

# Noninvasive diagnosis of bronchiolitis obliterans due to sulfur mustard exposure: could high-resolution computed tomography give us a clue?

# *Diagnosi non-invasiva di bronchiolite obliterante dovuta alla esposizione a mostarde azotate (iprite): può la tomografia computerizzata ad alta risoluzione fornire una soluzione?*

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**Abstract**

***Purpose.*** Previous pathological investigations have reported bronchiolitis obliterans (BO) as the major long-term sequela of exposure to sulfur mustard. In this study, we investigated whether high-resolution computed tomography (HRCT) could be used as a noninvasive imaging modality to differentiate between mustard lung (as a subtype of BO) and other respiratory disorders.

***Materials and methods.*** Three groups of patients with sulfur-mustard-induced lung injury (BO), severe chronic asthma (resistant asthma) and smoking habit, respectively, were recruited. Also 30 nonsmoking participants were recruited randomly as the control group. Pulmonary function tests (PFT) and HRCT were performed. Images were viewed with a window level of –450 and window width of 1,400 HU. All images were evaluated by an expert radiologist who was blinded regarding the patients' diagnoses and clinical situations.

***Results.*** Airway involvement was higher and more frequent than parenchymal involvement in the groups with chemical-induced injury and asthma in comparison with smokers. On the other hand, parenchymal involvement was more frequent than airway involvement in the smokers' group in comparison with the other groups.

***Conclusions.*** HRCT can be a very useful method for differentiating between mustard lung, resistant asthma and lung injuries due to cigarette smoking.

**Keywords** HRCT · Resistant asthma · Bronchiolitis obliterans · Sulfur mustard · Smoking

***Abstract***

***Obiettivo.*** *Numerosi precedenti studi di anatomia patologica hanno dimostrato come la bronchiolite obliterante (BO) sia la conseguenza a lungo termine più frequente all'esposizione alle mostarde azotate (iprite). In questo studio abbiamo valutato se la tomografia computerizzata ad alta risoluzione (HRCT) possa essere impiegata come modalità di imaging non invasivo per la diagnosi differenziale tra il danno polmonare indotto da mostarde azotate (sottotipo di BO) ed altre patologie respiratorie.*

***Materiali e metodi.*** *Sono stati reclutati tre gruppi di pazienti, rispettivamente affetti da bronchiolite obliterante indotta da mostarde azotate (BO), affetti da asma cronica (asma refrattaria) e fumatori. Sono stati scelti casualmente ulteriori 30 soggetti non fumatori come gruppo di controllo.Tutti i pazienti sono stati tutti sottoposti a test di funzionalità respiratoria (PFT) e HRCT. Le immagini sono state visualizzate con un livello di finestra di –450 UH ed un'ampiezza di finestra di 1,400 UH. Tutte le immagini sono state visionate da un radiologo esperto all'insaputa della diagnosi e della situazione clinica dei pazienti.*

***Risultati.*** *Il coinvolgimento delle vie aeree è risultato maggiore e più frequente del coinvolgimento parenchimale nei gruppi di pazienti con danno polmonare chimicamente indotto e asmatici rispetto ai fumatori. D'altra parte il coinvolgimento parenchimale è risultato più frequente del coinvolgimento delle vie aeree nel gruppo di fumatori rispetto agli altri gruppi.*

***Conclusioni.*** *L' HRCT risulta essere un metodo utile per la diagnosi differenziale tra il danno polmonare da mostarde* *azotate, l'asma refrattaria ed il danno polmonare indotto dal fumo.*

***Parole chiave*** *HRTC · Asma · Bronchiolite obliterante · Mostarde azotate*

## Introduction

Mustard gas was extensively used against Iranian civilians and military forces during the Iran-Iraq war of the 1980s. It is well-documented that inhalation of sulfur mustard causes respiratory system injury. There is no common consensus about the pathophysiological basis of chronic pulmonary disease caused by mustard gas, but bronchiolitis obliterans (BO) has been proposed as the underlying cause [1].

Airway remodelling is often considered to contribute to the element of irreversible airflow obstruction, which is a feature of some patients with asthma, BO and chronic obstructive pulmonary disease [2]. Lung diseases such as resistant asthma and cigarette smoking can change the structure of the small airways and cause irreversible airflow obstruction and thus interfere with proper diagnosis of mustard lung by causing similar clinical features. High-resolution computed tomography (HRCT) may reveal these abnormalities in symptom-free patients as well [3]. Different studies have reported HRCT findings, but these studies were limited to a single disease or compared the diseases with healthy individuals [4–6]. On the other hand, histopathological studies are invasive and may not be suitable for some patients.

In this study, we attempted to identify HRCT features that may help in differentiating between mustard lung (as a subtype of BO syndrome), resistant asthma and lung injuries due to cigarette smoking.

## Materials and methods

In an analytical cross-sectional study, we compared 90 cases (30 in each group) and 30 controls. The study was approved by the ethics committee of the university medical centre, and informed consent was obtained from all participants.

### Patients

Three groups of patients, each consisting of 30 individuals, were selected.

#### *Group 1: Sulfur-mustard-induced lung injury (bronchiolitis obliterans)*

Participants were patients suffering from pulmonary disorders due to previous exposure to a single high dose of sulfur mustard gas during the Iran-Iraq conflict in 1988. They were all from Sardasht, a city in western Iran, and were randomly selected from the medical records available at our university hospital that provides tertiary medical care and maintains a large database of patients exposed to chemical warfare agents during the war. Inclusion criteria were documented exposure to sulfur mustard and a diagnosis of chronic pulmonary disease due to mustard gas (histological evidence from previous biopsies). Exclusion criteria were pneumonia and/or acute bronchitis, cigarette smoking or substance abuse and a history of tuberculosis or resection of one or more lobes of lung.

#### *Group 2: Patients with severe chronic asthma (resistant asthma)*

Thirty consecutive patients with documented resistant asthma according to the American Thoracic Society definition [7] were chosen from our pulmonary clinic. Inclusion criterion was a need for permanent treatment (>50% in year) with high-dose orally administered or inhalant steroids to remain in a mild or moderate phase. Exclusion criteria were gastrooesophageal reflux disease and sinusitis.

#### *Group 3: Smokers*

This group consisted of patients referred to the pulmonary clinic with various respiratory problems, especially dyspnoea and cough, and a history of smoking. Exclusion criteria were exposure to sulfur mustard gas, receiving any medication for respiratory symptoms or corticosteroids, and substance abuse.

#### *Control group*

Thirty nonsmoking participants were recruited randomly as the control group. Exclusion criteria were a history of smoking or substance abuse, a history of any respiratory signs and symptoms and a history of allergy or pulmonary diseases.

### Study design and procedure

For the 90 patients in the three groups (BO, resistant asthma and smokers), a patient history, complete physical examination and pulmonary function tests (PFT) were performed on referral to the pulmonary clinic. These data were entered in the patients' files. PFT was performed without bronchodilator administration. The initial patient questionnaire contained demographic data, clinical manifestations and PFT results. Another form was created in which HRCT findings were documented.

All HRCT scans were obtained at near total lung capacity, with breath-holding rehearsed before commencement of the scan. Patients were imaged with a section thickness of 1.0 mm with 10 mm intervals in the supine position using a High Speed Advantage Scanner (General Electric Medical System, Milwaukee, WI, USA). Scans were performed with 120 kVp and 100 mA in 1 s without contrast agent. Images were reconstructed using the bone algorithm and were viewed at a window level of –450 and window width of 1,400 HU, which is the best choice for viewing lung images [8]. All images were evaluated by an expert radiologist blinded to the patients' diagnoses and clinical data. Intra- and interrater variability parameters were not measured, but error probability is assumed to be low due to high interobserver agreement of HRCT images. HRCT aspects investigated in this study were:

1. Bronchial wall thickness (BWT): For each patient, one or two bronchi with a diameter of 5–7 mm perpendicular to the surface section were chosen. Internal and external diameters of bronchi in inspiratory images were measured in 5× larger magnification by a ruler with an accuracy of 1 mm. Mean of the internal and external diameters (DO–DI) was measured for each patient and defined as the wall thickness index.
2. Evaluation of cylindrical bronchiectasis: A bronchus and its accompanying artery were chosen. The proportion of luminal diameter of bronchus and artery was measured (bronchiectasis index), and bronchiectasis was defined as luminal diameter greater than artery diameter.
3. Evaluation of small airways: The mosaic perfusion pattern on inspiratory images and air-trapping pattern on expiratory images were considered [9]. For these two patterns, both lungs were divided into three parts (upper, middle and lower), and in each part, images were separately observed in terms of extent of involvement (<25%=negative; ≥25%=positive).

Emphysema was categorised as centrilobular, panacinar and paraseptal. Other complications such as ground-glass pattern, mucoid impaction, bulla, atelectasis, narrowing and parenchymal nodule were evaluated subjectively and the results entered in the provided forms.

### Statistical analysis

Data were analysed using SPSS software version 15. All results were expressed as mean (standard deviation) and number (percentage). Continuous variables were compared with the Student's $t$ test. A $p$ value <0.05 was considered statistically significant.

## Results

Patient demographics are shown in Table 1. In all groups, patients were men, except for the asthma group, which contained four women (13.3%). Mean age of these four groups showed no significant differences ($p$>0.05). Mean disease duration in the asthma group was 5 years, and mean cigarette consumption among smokers was 27.2 pack years.

### Pulmonary function tests

The results of PFT in the four groups are shown in Table 2. Mean forced expiratory volume in 1 s (FEV1) in the group of asthmatic patients was obviously less than among smokers ($p$=0.001) and less than among controls ($p$<0.001). FEV1 in the BO group was less than in smokers ($p$=0.001). Forced vital capacity (FVC) in the group of asthmatic patients was lower than in the group of controls ($p$=0.003). The FEV1/FVC index in smokers was lower than in asthmatic patients ($p$=0.007), patients with chemical-induced injury ($p$<0.001) and controls ($p$=0.007).

To compare air-flow obstruction, the patients were divided into three groups according to FEV1 (Fig. 1). These groups were normal-to-mild obstruction (FEV1>80%), moderate obstruction (FEV1<80% but >60%) and severe obstruction (FEV1<60%)

### HRCT findings

1. Large airways: Indexes in the four groups are shown in Table 3.

**Table 1** Primary demographics of the four groups (mean ± standard deviation)
***Tabella 1*** *Caratteristiche epidemiologiche dei quattro gruppi di pazienti (media ± deviazione standard)*

| Patient characteristics | Bronchiolitis obliterans | Asthmatic | Smokers | Normal | Total | Significance |
|---|---|---|---|---|---|---|
| Number of cases | 30 | 30 | 30 | 30 | 120 | – |
| Age (years) | 43.5±8.2 | 44.3±11.2 | 42.8±13.6 | 44.3±12.8 | 43.7±11.5 | NS |
| Body mass index | 29.7±6.1 | 27.3±6 | 25.7±6.5 | 25.6±5.6 | 27.1±6.2 | NS |

**Table 2** Results of the pulmonary function test (PTF) in the four groups (mean ± standard deviation)
***Tabella 2*** *Risultati dei test di funzionalità respiratoria nei quattro gruppi di pazienti (media ± deviazione standard)*

| PFT | Bronchiolitis obliterans | Asthmatic | Smokers | Normal |
|---|---|---|---|---|
| FEV1 | 69.7±23.3 | 56.4±15.0 | 74.5±23.1 | 89.4±16.9 |
| FVC | 85.0±17.9 | 71.1±28.8 | 79.5±21.2 | 91.3±13.1 |
| FEV1/FVC | 87.0±14.9 | 82.2±10.4 | 70.2±13.7 | 82.2±8.2 |
| MMFE | 46.2±18.0 | 29.6±12.0 | 55.0±21.0 | 74.8±12.0 |

*FEV1,* forced expiratory volume in one second; *FVC*, forced vital capacity; *MMFE,* modal method by Fourier expansion

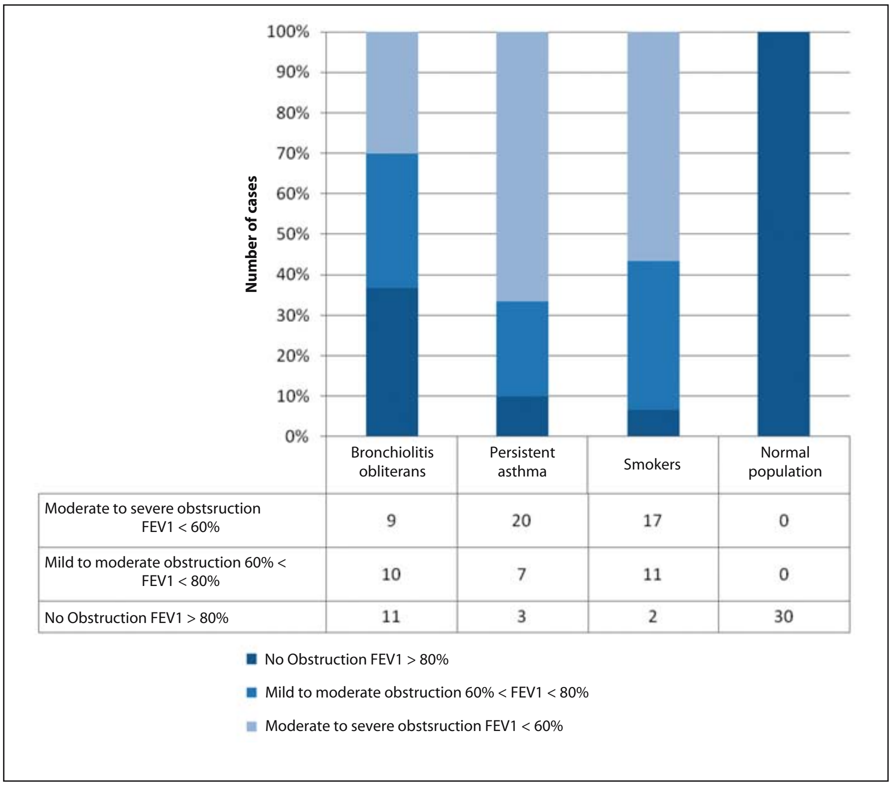


**Fig. 1** Level of airflow obstruction in the four groups (*p*<0.000).

***Fig. 1*** *Livello di ostruzione delle vie aeree nei quattro gruppi di pazienti (p<0,000).*

2. Small airways: Indexes are shown in Table 4. Neither the mosaic perfusion pattern nor the air-trapping pattern was seen in controls. In most cases, in the smokers' group, the mosaic perfusion pattern was seen in the lower lobe, especially in the left lung (11 cases, 36.3%). In patients with chemical lung injury, this pattern was seen in the lower lobe, especially in the left lung (23 patients, 76.7%), which was more than in the asthmatic group ($p$<0.001). The air trapping pattern was focal among smokers (eight patients, 26.4%) and located in the lower lobes among asthmatic patients.
3. Lung parenchyma findings*:* Indexes are shown in Table 5. Parenchymal involvement was more frequent than airway involvement in the smokers' group in comparison with the other groups. The cumulative frequency of all findings is summarised in Table 6.

## Discussion

Different studies have reported HRCT findings in several groups similar to our groups [10–12], but these studies were performed separately on a single disease or in comparison with healthy individuals. Our study was performed on three groups of patients and one control group. As mentioned, these three groups of patients could have the same clinical manifestations, leading to difficulties establishing the correct diagnosis and planning appropriate treatment if relying solely on the clinical manifestations and PFT. In this study, we collected all HRCT indexes that were used separately in previous studies and reviewed HRCT images of our patients and controls in terms of these indexes. We also evaluated three PFT indexes (FEV1, FVC, FEV1/FVC). The age variable was similar in the four groups. Mean body

**Table 3** Large airway indexes in the four groups [number (%)]
***Tabella 3*** *Caratteristiche delle vie aeree superiori analizzate nei quattro gruppi di pazienti [numero (%)]*

| | Bronchiolitis obliterans | Asthmatic | Smokers | Normal | Significance |
|---|---|---|---|---|---|
| Bronchiectasis | 22 (73.2) | 26 (86.7) | 12 (40) | 1 (3.3) | 0.000 |
| BWT | 29 (96.6) | 4 (13.2) | 2 (7.2) | 2 (7.2) | 0.000 |
| Mucoid impaction | 1(3.3) | 3 (10) | 13 (43) | 0 | 0.003 |
| Atelectasis | 0 | 0 | 0 | 0 | – |
| Narrowing | 6 (16.5) | 0 | 0 | 0 | – |

*BWT,* bronchial wall thickness

**Table 4** Small airway indexes in the four groups [number (%)][a]
***Tabella 4*** *Caratteristiche delle vie aeree inferiori analizzate nei quattro gruppi di pazienti [numero (%)][a]*

| | Bronchiolitis obliterans | Asthmatic | Smokers | Significance |
|---|---|---|---|---|
| Mosaic-perfusion pattern | | | | |
| RUL[a] | 3 (10) | 0 | 1 (3.3) | |
| RML[a] | 0 | 1 (3.3) | 2 (6.6) | |
| RLL[a] | 4 (13.2) | 0 | 2 (6.6) | |
| LUL[a] | 3 (10) | 0 | 4 (13.2) | |
| LLL[a] | 14 (46.2) | 1 (3.3) | 11 (36.6 | |
| Total | 23 (76.7) | 2 (6.6) | 20 (63.3) | 0.000 |
| Air-trapping pattern | | | | |
| RUL | 2 (6.6) | 3 (10) | 3 (10) | |
| RML | 1 (3.3) | 5 (16.5) | 0 | |
| RLL | 5 (16.5) | 2 (6.6) | 0 | |
| LUL | 3 (10) | 1 (3.3) | 4 (13.2) | |
| LLL | 14 (46.2) | 8 (26.4) | 1 (3.3) | |
| Total | 25 (83.3) | 19 (62.7) | 8 (26.4) | 0.000 |

*RUL,* right upper lobe; *RML*, right middle lobe; *RLL,* right lower lobe; *LUL,* left upper lobe; *LLL*, left lower lobe
[a]Fisher's exact test

**Table 5** Parenchymal indexes in the four groups [number (%)][a]
***Tabella 5*** *Caratteristiche parenchimali analizzate nei quattro gruppi di pazienti [numero (%)][a]*

| | Bronchiolitis obliterans | Asthmatic | Smokers | Normal | Significance |
|---|---|---|---|---|---|
| Emphysema | | | | | |
| Centrilobular | 1 (3.3) | 3 (10) | 28 (92.4) | 0 | 0.00 |
| Panlobular | 0 | 0 | 0 | 0 | – |
| Paraseptal | 0 | 0 | 0 | 0 | – |
| Ground glass | 2 (6.6) | 0 | 5 (17) | 0 | |
| Bulla | 0 | 0 | 0 | 0 | – |
| Parenchymal nodule | 2 (6.6) | 2 (6.6) | 16 (52.8) | 1 (3.3) | 0.01 |

Significant relationships are shown in bold
[a]Fisher's exact test

**Table 6** Frequency of the various high-resolution computed tomography (HRCT) findings in the three patient groups [number (%)]
***Tabella 6*** *Frequenza delle caratteristiche rilevate alla tomografia computerizzata ad alta risoluzione (HRCT) nei tre gruppi di pazienti [numero (%)]*

| | Bronchiolitis Obliterans | Asthma | Smokers |
|---|---|---|---|
| Bronchiectasis | ++++ | +++++ | ++ |
| Bronchial Wall Thickness | +++++ | + | + |
| Mucoid Impaction | + | + | +++ |
| Mosaic Perfusion | ++++ | + | ++++ |
| Air Trapping | +++++ | ++++ | ++ |
| Emphysema | + | + | +++++ |
| Parenchymal Nodule | + | + | +++ |

+: (1%–20%)
++: (21%–40%)
+++: (41%–60%)
++++: (61%–80%)
+++++: (81%–100%)

weight of patients in the chemically injured group was higher than patients in the smokers' group ($p$=0.002) and normal group ($p$=0.021).

Large airways

1. Bronchiectasis: Bronchiectasis was significantly more frequent in BO and asthmatic patients. The prevalence of this finding in the BO group was similar to that reported by Ghanei et al. [13]. In contrast, two other studies reported a prevalence of 32% and 26%, respectively [14, 15]. In another study [16], the mean FEV1 in asthmatic patients was 85%, which was similar to our study. FEV1 value in Carr et al.'s study [17] was lower, but they showed that there is a direct relationship between the prevalence of bronchiectasis and asthma severity. In our study, the prevalence of bronchiectasis in the smokers' group was lower than in the groups with BO and asthma, which was confirmed by previous similar studies [18]. The prevalence of bronchiectasis in the BO and asthmatic groups was higher than in the smokers' group due to greater pulmonary involvement.
2. BWT: BWT is seen often with bronchiectasis and is expected to be more frequent in the asthmatic and BO groups. In our study, BWT frequency was significantly higher in the BO group ($p$ <0.05), which was similar to previous studies [13]. Patients with refractory asthma and status asthmaticus may have hypertrophy of the airway smooth muscles and distended mucus plaque and small and large airway inflammation, which can result in BWT. In our asthmatic group, however, BWT frequency was lower than in previous similar studies. For example, in the study by Lynch et al. [19], BWT was seen in 92% of patients and in study by Harmanci et al. [20] in 100% of patients. The lower value of BWT in our study may be an underestimation of BWT due to lack of accurate computerised instruments.
3. Mucoid impaction: The frequency of mucoid impaction in our study was higher in the smokers' group. This may be due to the underlying pathology, which is chronic bronchitis, airway degeneration and mucus accumulation in the airways [21].

Small airways

Bronchiolar involvement was observed in the three patient groups. HRCT images showed changes such as air trapping, mosaic perfusion and small centrilobular opacities.

1. Air trapping: Air trapping is well-diagnosed on images taken in the expiration phase. Chronic airway diseases, asthma, BO, pulmonary cystic diseases and bronchiectasis could be the causes of such a pattern. In normal cases the lung shows increased attenuation in the expiration phase, but when air trapping exists, the more translucent areas in expiration are seen in low attenuation. This pattern is often seen in some lobes or the whole lung, with generalised involvement of the small airways, but if it is seen as focal involvement, it may be related to small-airway abnormality [22]. This pattern is a special and sensitive finding for diagnosing BO [23]. The frequency of air trapping was significantly higher in the BO and asthmatic groups ($p$=0.00), which confirms the findings of previous studies (Fig. 2) [13]. The air trapping pattern was found in lower parts of the lung, especially the left lung. This may be due to gravity force, which results in a greater accumulation of chemical substances at the lung base.
2. Mosaic perfusion*:* Differences in the perfusion of airway vessels may be seen in pulmonary diseases that cause focal air trapping or weak ventilation. In these patients vascular contraction reflex or vascular bed limitation results in decreased perfusion, which is common in patients with BO caused by sulfur mustard gas. The mosaic perfusion index was significantly higher in the

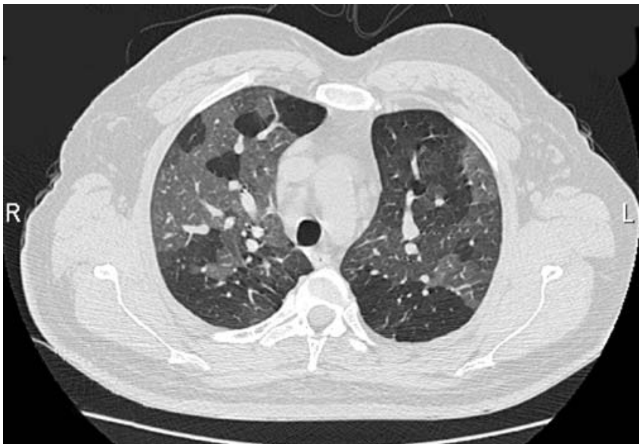


**Fig. 2** High-resolution computed tomography (HRCT) of a 43-year-old man exposed to mustard gas 20 years earlier. The image demonstrates expiratory air trapping.

***Fig. 2*** *Tomografia computerizzata ad alta risoluzione (HRCT) di un uomo di 43 anni esposto a mostarde azotate 20 anni prima. L'immagine dimostra l'intrappolamento d'aria in espirazione.*

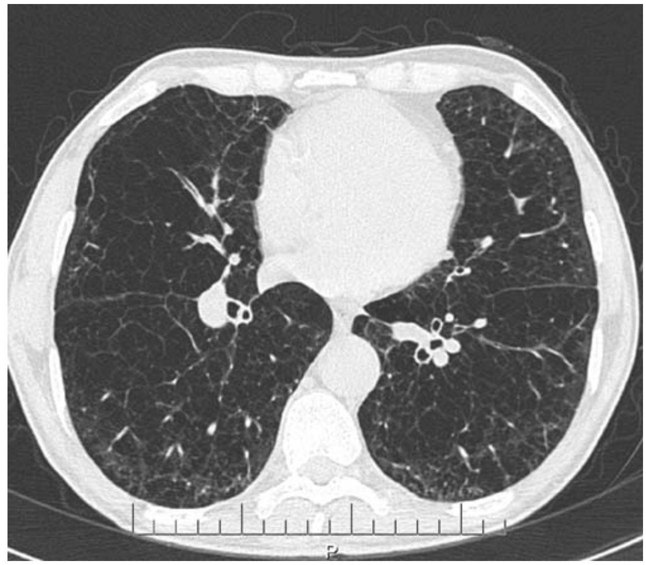

**Fig. 3** High-resolution computed tomography (HRCT) of a 48-year-old man with a smoking history of 25 pack years. Emphysema is visible.

***Fig. 3*** *Tomografia computerizzata ad alta risoluzione (HRCT) di un uomo di 48 anni con una storia di fumo di 25 anni. Si noti l'enfisema polmonare.*

chemically injured group and the smokers' group. The important point in this study is the high frequency of the mosaic perfusion pattern in the smokers' group, a finding rarely reported in previous studies.

Pulmonary parenchymal findings

Centrilobular emphysema was significantly more frequent in the smokers' group ($p$=0.001, Fig. 3), as reported by previous studies [11]. In some other studies, the frequency of emphysema was reported to be higher among asthmatic patients in comparison with healthy populations [24]. Centrilobular and subpleural parenchymal nodules were seen on HRCT images of smokers. These nodules are the reflection of bronchiolectasis and peribronchial fibrosis and signs of parenchymal or terminal bronchiolar involvement [22]. The frequency of parenchymal nodules in our study was significantly higher in the smokers' group ($p$=0.01).

## Conclusion

Airway involvement was greater and more frequent than parenchymal involvement in the chemically injured and asthmatic group in comparison with smokers. On the other hand, parenchymal involvement was more frequent than airway involvement in the smokers' group in comparison with other groups. Significant air trapping at expiration is the most frequent radiological finding in chemically injured patients and could be used as a diagnostic criterion. Bronchiectasis and increased BWT may also be detected. Overall, HRCT can be used as a noninvasive method for differentiating between mustard lung (as a subtype of BO syndrome), resistant asthma and lung injuries due to cigarette smoking.

**Conflict of interest** None

## References/*Bibliografia*

1. Ghanei M, Tazelaar HD, Chilosi M et al (2008) An international collaborative pathologic study of surgical lung biopsies from mustard gas-exposed patients. Respir Med 102:825–830
2. Saglani S, Papaioannou G, Khoo L et al (2006) Can HRCT be used as a marker of airway remodelling in children with difficult asthma? Respir Res 7:46
3. Teel GS, Engeler CE, Tashijian JH, duCret RP (1996) Imaging of small airways diseases. Radiographics 16:27–413
4. Yilmaz S, Ekici A, Ekici M, Keles H (2006) High-resolution computed tomography findings in elderly patients with asthma. Eur J Radiol 59:238–243

5. Worthy SA, Park CS, Kim JS, Müller NL (1997) Bronchiolitis obliterans after lung transplantation: high-resolution CT findings in 15 patients. Worthy AJR 169:673–677
6. Gupta PP, Yadav R, Verma M et al (2009) High-resolution computed tomography features in patients with chronic obstructive pulmonary disease. Singapore Med J 50:193–200
7. Boskabady MH, Kolahdooz GH (2002) Prevalence of asthma symptoms among the adult population in the city of Mashhad (north-east of Iran). Respirology 7:267–272
8. Niimi A, Matsumoto H, Amitani R et al (2000) Airway wall thickness in asthma assessed by computed tomography. Relation to clinical indices. Am J Respir Crit Care Med 162:1518–1523
9. Jensen SP, Lynch DA, Brown KK et al (2002) High-resolution CT features of severe asthma and bronchiolitis obliterans. Clin Radiol 57:1078–1085
10. Cho SH, Seo JY, Choi DC et al (1996) Pathological changes according to the severity of asthma. Clin Exp Allergy 26:1210–1219
11. Clark KD, Wardrobe-Wong N, Elliott JJ et al (2001) Patterns of lung disease in a "normal" smoking population: are emphysema and airflow obstruction found together? Chest 120:743–747
12. Ghanei M, Fathi H, Mohammad MM et al (2004) Long-term respiratory disorders of claimers with subclinical exposure to chemical warfare agents. Inhal Toxicol 16:491–495
13. Ghanei M, Mokhtari M, Mohammad MM, Aslani J (2004) Bronchiolitis obliterans following exposure to sulfur mustard: chest high resolution computed tomography. Eur J Radiol 52:164–169
14. Hefazi M, Attaran D, Mahmoudi M, Balali-Mood M (2005) Late respiratory complications of mustard gas poisoning in Iranian veterans. Inhal Toxicol 17:587–592
15. Bagheri MH, Hosseini SK, Mostafavi SH, Alavi SA (2003) High resolution CT in chronic pulmonary changes after mustard gas exposure. Acta Radiol 44:241–245
16. Paganin F, Séneterre E, Chanez P et al (1996) Computed tomography of the lungs in asthma: influence of disease severity and etiology. Am J Respir Crit Care Med 153:110–114
17. Carr DH, Hibon S, Rubens M, Chung KF (1998) Peripheral airways obstruction on high-resolution computed tomography in chronic severe asthma. Respir Med 92:448–453
18. Vignola AM, Paganin F, Capieu L et al (2004) Airway remodelling assessed by sputum and high-resolution computed tomography in asthma and COPD. Eur Respir J 24:910–917
19. Lynch DA, Newell JD, Tschomper BA et al (1993) Uncomplicated asthma in adults: comparison of CT appearance of the lungs in asthmatic and healthy subjects. Radiology 188:829–833
20. Harmanci E, Kebapci M, Metintas M, Ozkan R (2002) High-resolution computed tomography findings are correlated with disease severity in asthma. Respiration 69:420–426
21. Deveci F, Murat A, Turgut T et al (2004) Airway wall thickness in patients with COPD and healthy current smokers and healthy non-smokers: assessment with high resolution computed tomographic scanning. Respiration 71:602–610
22. Webb R, Muller N (2001) High-resolution CT of the lung, 3rd edn. Lippincott Williams & Wilkins, New York
23. Bankier AA, Van Muylem A, Scillia P et al (2003) Air trapping in heart-lung transplant recipients: variability of anatomic distribution and extent at sequential expiratory thin-section CT. Radiology 229:737–742
24. Yorgancio lu A, Sakar A, Tarhan S et al (2003) High resolution CT findings in patients with asthma. Tuberk Turaks 51:5–10