# Comparison of virtual bronchoscopy with fiberoptic bronchoscopy findings in patients exposed to sulfur mustard gas

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# Comparison of virtual bronchoscopy with fiberoptic bronchoscopy findings in patients exposed to sulfur mustard gas

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## Abstract

**Background:** Fiberoptic bronchoscopy (FB) is the best modality for evaluation of tracheobronchial endoluminal lesions. Virtual bronchoscopy (VB) with the aid of computed tomography (CT) makes it possible to reconstruct endoscopic-like visualization of major airways. Sulfur mustard (SM) used during the Iraq–Iran war affects respiratory tracts and can lead to tracheobronchial stenosis.

**Purpose:** To compare VB with FB in SM-exposed patients suspected for airway stenosis.

**Material and Methods:** Thirty-one patients were evaluated with CT and bronchoscopic studies about 15 years after chemical attacks. The median age of patients was 40 years. Spiral CT scans were obtained and data were transferred to a workstation to generate VB images of major airways. Less than one week after CT scan, FB was performed.

**Results:** For the tracheal pathologies seen in FB, the sensitivity, specificity, and accuracy of VB was 90.9%, 95%, and 93.5% for tracheal stenosis, 40%, 96.2%, and 87.1% for vocal cord problems, 100%, 100%, and 100% for postoperative changes, and 100%, 96.7%, and 96.8% for intratracheal nodule. The inflammation of mucosal surface could not be assessed by VB. The bronchial pathologies seen in FB included eight cases of stenosis, and one case of nodule. Sensitivity, specificity, and accuracy of VB for detection of bronchial stenosis was 62.5%, 97.8% and 92.6%, respectively. Overall sensitivity, specificity and accuracy of VB in detecting tracheobronchial stenosis were 78.9%, 97.0%, and 92.9%, respectively.

**Conclusion:** Our study indicates that VB is an accurate method for evaluating stenoses, endoluminal nodules, and poststenotic areas within the tracheobronchial tree of SM-exposed victims. This complementary method could be helpful in revealing hidden post-stenotic lesions and also better depict the long tracheal strictures and their actual length.

**Keywords:** Fiberoptic bronchoscopy, virtual bronchoscopy, sulfur mustard, tracheal stenosis

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Fiberoptic bronchoscopy (FB) is one of the most common invasive diagnostic modalities for assessment of airway diseases. Regarding its high sensitivity, it remains the best modality for evaluation of tracheobronchial endoluminal and mucosal lesions (1). However, it poses potential risks of mortality (0.8%, especially in patients with advanced intrathoracic diseases) and morbidity (2, 3). Moreover, it is time-consuming and can lead to cardiac arrhythmias and cardiac arrest (4). FB provides no information about the presence and extent of extra luminal disease or the airway patency distal to severe stenoses (5).

With recent advances in computed tomography (CT) scan techniques, it is possible to generate three-dimensionally (3D) reconstructed images of the tracheobronchial tree. These 3D images are generally made in two basic types: (a) external rendering or CT bronchography (CTB) that reconstructs the external features of tracheobronchial tree; and (b) internal rendering or virtual bronchoscopy (VB) that makes it possible to reconstruct endoscopic-like visualization of major airways (6, 7) (Fig. 1). In recent years, VB plays a great role in imaging of airways (8) and its diagnostic accuracy for detection of airway stenosis has been proved

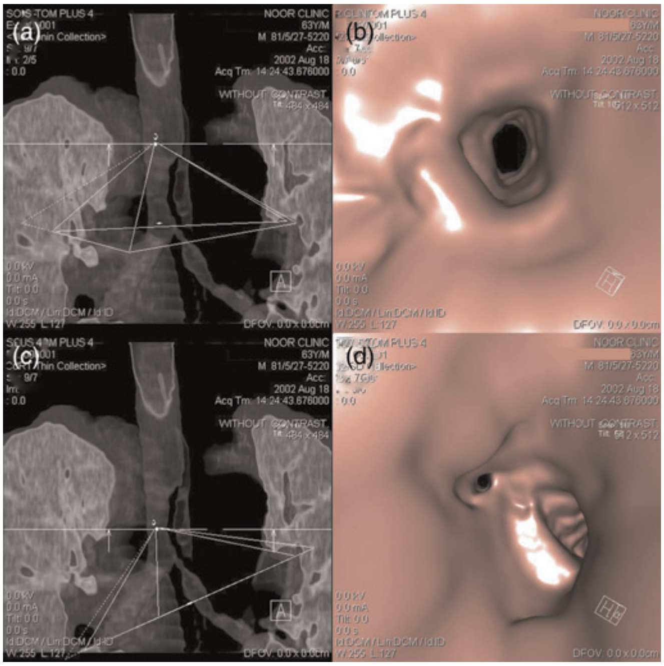

Fig. 1 A 63-year-old man with tracheobronchial stenosis. (a) CTB image of Grade I tracheal stenosis; (b) VB image of Grade I tracheal stenosis; (c) CTB image of Grade II left bronchial stenosis; (d) VB image of Grade II left bronchial stenosis

to be high (9). In addition, unlike FB, it is possible to evaluate the severe bronchial stenoses and post-stenotic regions with CTB and VB (10).

During the Iraq–Iran war (1981–1989), chemical warfare agents and specially sulfur mustard (SM) were used widely against the Iranian people (11–13). SM affects sensitive portions of respiratory tracts and may lead to latent morbidities (14). Previous studies have shown that SM exposure in its chronic phase could lead to deterioration of lung function, a major source of morbidity following exposure to this agent (15). A study on 197 Iranian veterans heavily exposed to SM showed development of various types of pulmonary involvements after 10 years, mostly chronic bronchitis (58%), asthma (10%), pulmonary fibrosis (12%), large airway stenosis (9%), and bronchiectasis (8%) (16).

Large airway stenosis develops subsequent to the direct damage of SM on the upper airways, which leads to scarring, fibrosis, and mucociliary malfunction as the causes of stenosis (15). Regarding their respiratory complaints and initial evaluations, many chemical warfare victims need to be checked with FB for suspected stenotic lesions. The current study assesses the diagnostic ability of non-invasive VB in comparison with FB in SM-exposed patients with clinical features suspected for airway stenosis.

## Material and Methods

During a three-year period, about 15 years after chemical attacks, 31 patients suspected for tracheobronchial stenosis who had documented exposure to SM during the Iran–Iraq war were selected for the study. Inclusion criteria included inspiratory stridor and/or unilateral wheezing in physical examination, unilateral decrease of lung volume and/or signs of localized bronchiectasis in chest X-ray, and flow limitation on maximal inspiratory or expiratory flow volume curves in pulmonary function test (PFT). Patients previously diagnosed with lung cancer, tuberculosis (TB), and burn injury, with history of intubation, intensive care unit (ICU) admission, or upper airway surgery before SM exposure, and who were unable to hold their breath during CT scanning were excluded from this study. In this retrospective study, CT data were retrieved from the PACS (Picture Archiving and Communication System) of our institution and the bronchoscopic findings were found in the archived documents of the patients.

All the patients were first evaluated by standard axial high resolution CT (HRCT) of the thorax and then contiguous spiral CT was performed to produce 3D reconstructions. FB was also performed for all of the patients as the gold standard test (17). Among the 31 patients, 26 were men (83.9%) and five were women (16.1%). The median age was 40 years (range 31–63 years).

Patients initially underwent CT scanning. CT studies were obtained using a Somatom plus 4 CT scanner (Siemens Medical Systems, Erlangen, Germany). HRCT had thin 1-mm collimation (120 kVp, 200 mAs) at 10-mm intervals with scan time of 1–2 s and high spatial frequency reconstruction algorithm. Spiral scans had 3-mm collimation (120 kV, 200–250 mAs, subsecond 360° rotation and pitch of 1.5). The scanned segments were of 6–12 cm in length and the acquisition time was about 10–20 s, so that the study could be completed during a single breath-hold after a hyperventilation for about 1 min. Intravenous contrast material was not administered. Axial images were reconstructed using the kernel 50 algorithm. The CT examinations were performed at full inspiration.

Overlapped images were retrospectively reconstructed at 1.5 mm intervals with a linear interpolation algorithm (a standard algorithm) and in a narrow 20-cm field of view including trachea and proximal airways. Forty to 80 axial images were generated in 512 × 512 matrices. Axial images were transferred to a Syngo MultiModality Workplace (Siemens AG, Erlangen, Germany) and 3D volume-rendered images of the major airways were generated. The CT scans were blindly interpreted by two radiologists, both with an experience of about 10 years.

During the subsequent week after the CT scan, FB exams were performed in all the patients. All FB procedures were done by one pulmonologist with expertise in managing chemical warfare agent victims. After applying topical anesthesia (Lidocaine, aerosolized) to the patient's nasopharynx and larynx, approximately 5 mL of 1% lignocaine jelly was instilled into each nostril. The patients were then given small incremental doses of IV midazolam until judged to be lightly sedated. Supplemental oxygen at a rate of 3 L/min was provided continuously through nasal prongs until the patient was awake following the procedure. Patients were monitored for oxygen saturation, pulse rate, and possible arrhythmias in this period. The flexible FB (Olympus BF1T, Tokyo, Japan) was performed via the transnasal route.

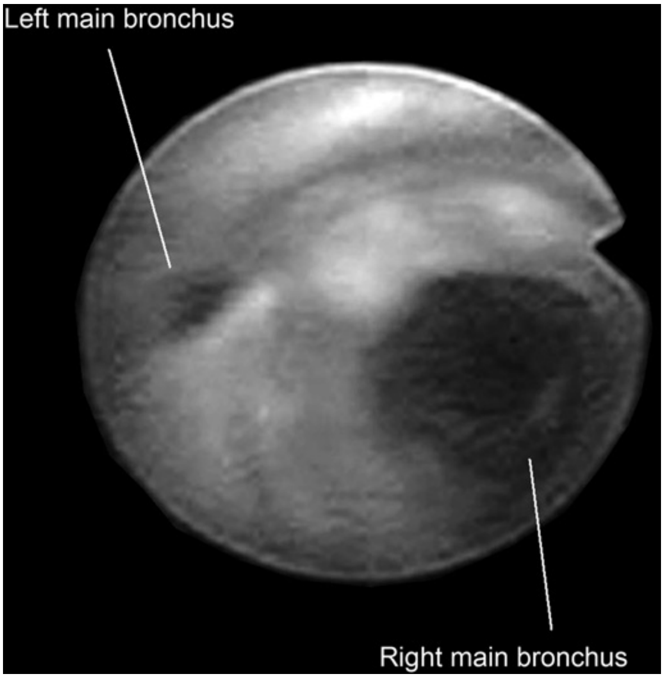


**Fig. 2** Bronchoscopic view of a 39-year-old man showing severe left main bronchial stenosis

During VB and FB reporting, the estimated grade of stenosis was recorded using a 3-point scale as follows: grade 0, no stenosis; grade 1, luminal narrowing of <50%; or grade 2, luminal narrowing of ≥50% (17) (Figs. 1–3). In the detailed evaluation of the patients, we considered two isolated anatomical locations: trachea (from vocal cords to carina) and main bronchi (from carina to the end of each main bronchus before branching). Because of technical problems, VB images of bronchi could not be interpreted in one patient. In three other patients with severe tracheal stenosis, evaluation of the trachea distal to the tracheal lesion was not possible by FB; thus the comparison between FB and VB was done for 54 bronchi only (sum of right and left bronchi in 27 patients).

At the end, overall diagnostic sensitivity, specificity, and accuracy were calculated lesion by lesion and not by patient. The severity of stenosis was not important in calculating these indices. The data were analyzed with SPSS statistical software (SPSS for Windows, version 16.0; SPSS Inc, Chicago, IL, USA).

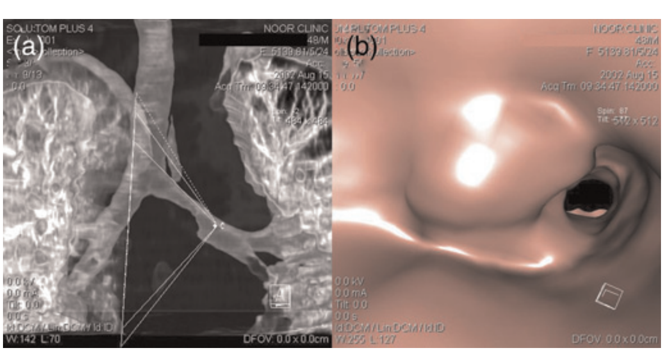


**Fig. 3** A 48-year-old man with bronchial stenosis. (a) CTB image of Grade I left bronchial stenosis; (b) VB image of Grade I left bronchial stenosis

**Table 1** Diagnostic indices of VB for different tracheal pathologies in comparison with FB

| Pathology | FB | VB Sensitivity (%) | VB Specificity (%) | VB Accuracy (%) |
|---|---|---|---|---|
| Stenosis | 11 (35.5%) | 90.9 | 95 | 93.5 |
| Vocal cord problems | 5 (16.1%) | 40 | 96.2 | 87.1 |
| Postoperative changes | 1 (3.2%) | 100 | 100 | 100 |
| Nodule | 1 (3.2%) | 100 | 96.7 | 96.8 |
| Mucosal inflammation | 8 (26.7%) | – | – | – |

## Results

The tracheal pathologies seen by FB included 11 cases (35.5%) with stenosis, five cases (16.1%) with vocal cord problems (including edema, local inflammation, and nodules), eight (26.7%) cases with mucosal inflammation, one case (3.2%) with an intratracheal nodule, and one case (3.2%) with postoperative changes (Table 1). In total, 21 patients (67.7%) had abnormal results in FB.

Among 11 cases with tracheal stenosis diagnosed by FB, four cases had grade-2 stenosis with more than 50% reduction of tracheal diameter and seven cases had grade-1 stenosis with reduction less than 50%. VB showed 11 cases with tracheal stenosis (10 of them had stenosis in FB); seven cases with grade-1 stenosis and four cases with grade-2 stenosis. For tracheal stenosis the sensitivity, specificity, and accuracy of VB in comparison with FB were shown to be 90.9%, 95%, and 93.5%, respectively.

VB showed three cases with vocal cord problems, two of them confirmed by FB. The only case of postoperative changes in FB was also shown by VB. VB showed two nodules in trachea, one of them confirmed by FB.

The bronchial pathologies seen by FB included eight cases of stenosis and one case with a nodule. Twenty patients had bronchial inflammation by FB. Six cases with bronchial stenosis by FB had grade-1 stenosis with less than 50% reduction of bronchial diameter and two other cases had grade-2 stenosis. On the other hand, VB showed six cases with bronchial stenosis, five cases of grade-1, and one case of grade-2. VB also showed the only bronchial nodule in the same location as shown by FB (Table 2).

**Table 2** Comparison of different bronchi pathologies in FB versus VB

| | Stenosis in VB | | |
|---|---|---|---|
| **Stenosis in FB** | Grade 2 | Grade 1 | Grade 0 |
| Grade 2 | 1 | 0 | 1 |
| Grade 1 | 0 | 4 | 2 |
| Grade 0 | 0 | 1 | 45 |
| | **Nodule in VB** | | |
| **Nodule in VB** | Yes | No | |
| Yes | 1 | 0 | |
| No | 0 | 53 | |

Sensitivity, specificity, and accuracy indices of VB in revealing bronchial stenoses in comparison with FB results were 62.5%, 97.8%, and 92.6%, respectively. Totally 13 patients (41.9%) had tracheal or bronchial stenosis diagnosed by FB or VB. Table 3 summarizes the sites of stenoses, accordant diagnostic methods, and the severity score for each method. Overall sensitivity, specificity, and accuracy of VB for detection of tracheal and bronchial stenoses were calculated to be 78.9%, 97.0%, and 92.6%, respectively.

McNemar test proved that the difference between the results of FB and VB in showing the presence or absence of stenosis in trachea or bronchi was insignificant ($P$ value = 1.0). Kappa test showed almost perfect grading agreement between two tests in the trachea (Kappa = 0.842, $P < 0.001$). The grading agreement of two tests was substantial for left bronchial stenosis (Kappa = 0.719, $P < 0.001$) and moderate for right bronchial stenosis (Kappa = 0.509, $P < 0.01$).

Some other lesions were shown only in HRCT survey and not by FB, including 11 cases of air trapping (35.5%), two cases of emphysema (6.5%), one parenchymal mass (3.2%), one mucosal plaque (3.2%), three cases of tracheal and bronchial wall calcification (9.7%), six cases of bronchiectasia (19.4%), and one case of brachiocephalic artery compression effect (3.2%).

## Discussion

Direct effects of SM on upper airway tracts can damage the trachea and bronchi, and the subsequent scarring, fibrosis, and mucociliary malfunction can then lead to stenosis (15); 41.9% of the patients in our study who were clinically suspected for airway stenosis proved to have such lesions by either VB or FB.

A few studies have been done with regard to central airway injuries of SM agent and its sequelae. A study by Beheshti *et al.* proved airway injuries in the tracheobronchial tree as a chronic effect of SM exposure (18). These findings are compatible with a chronic inflammatory response to the inhaled chemical agent. The chronic inflammation of central airways may result in stenosis (15, 19).

Currently in our country, FB is used as the standard mean for evaluating SM-exposed patients in whom

**Table 3** Summary of clinical date of patients with tracheal or bronchial stenosis due to SM

| Patient | Age | Sex | Site of tracheal stenosis | VB | FB |
|---|---|---|---|---|---|
| 1 | 33 | Male | – | Trachea: Grade 0<br>LMB: Grade 0<br>RMB: Grade 1 | Trachea: Grade 0<br>LMB: Grade 0<br>RMB: Grade 0 |
| 2 | 32 | Male | Proximal trachea | Trachea: Grade 2<br>LMB: Grade 0<br>RMB: Grade 0 | Trachea: Grade 2<br>LMB: Not possible<br>RMB: Not possible |
| 3 | 34 | Male | Proximal trachea | Trachea: Grade 1<br>LMB: Grade 0<br>RMB: Grade 0 | Trachea: Grade 1<br>LMB: Grade 0<br>RMB: Grade 0 |
| 4 (Fig. 2) | 39 | Male | Proximal trachea | Trachea: Grade 0<br>LMB: Grade 0<br>RMB: Grade 0 | Trachea: Grade 1<br>LMB: Grade 2<br>RMB: Grade 1 |
| 5 (Fig. 3) | 48 | Male | Proximal trachea | Trachea: Grade 1<br>LMB: Grade 1<br>RMB: Grade 0 | Trachea: Grade 1<br>LMB: Grade 1<br>RMB: Grade 1 |
| 6 | 60 | Male | Proximal trachea | Trachea: Grade 2<br>LMB: Grade 0<br>RMB: Grade 0 | Trachea: Grade 2<br>LMB: Not possible<br>RMB: Not possible |
| 7 | 32 | Female | Distal trachea | Trachea: Grade 1<br>LMB: Grade 0<br>RMB: Grade 1 | Trachea: Grade 1<br>LMB: Grade 0<br>RMB: Grade 1 |
| 8 | 34 | Female | Distal trachea | Trachea: Grade 1<br>LMB: Grade 0<br>RMB: Grade 0 | Trachea: Grade 0<br>LMB: Grade 0<br>RMB: Grade 0 |
| 9 | 34 | Male | Distal trachea | Trachea: Grade 1<br>LMB: Grade 0<br>RMB: Grade 0 | Trachea: Grade 1<br>LMB: Grade 0<br>RMB: Grade 0 |
| 10 | 47 | Female | Distal trachea | Trachea: Grade 1<br>LMB: Grade 1<br>RMB: Grade 1 | Trachea: Grade 1<br>LMB: Grade 1<br>RMB: Grade 1 |
| 11 | 62 | Male | Distal trachea | Trachea: Grade 2<br>LMB: Grade 0<br>RMB: Grade 0 | Trachea: Grade 2<br>LMB: Grade 0<br>RMB: Grade 0 |
| 12 (Fig. 1) | 63 | Male | Distal trachea | Trachea: Grade 1<br>LMB: Grade 2<br>RMB: Grade 0 | Trachea: Grade 1<br>LMB: Grade 2<br>RMB: Grade 0 |
| 13 | 38 | Male | All part of trachea | Trachea: Grade 2<br>LMB: Grade 2<br>RMB: Grade 0 | Trachea: Grade 2<br>LMB: Not possible<br>RMB: Not possible |

LMB = Left main bronchus; RMB = Right main bronchus tracheobronchial stenosis is suspected. In this study, we depicted tracheobronchial stenosis with virtual bronchoscopic (VB) images in SM exposed Iran–Iraq war victims and the diagnostic accuracy based on these images was calculated comparing with the findings of the gold standard test, flexible bronchoscopy.

Indeed VB provides accurate information regarding the obstructing lesions and the anatomy distal to an obstruction (10); it also helps to visualize the extraluminal lesions and with the aid of axial and reformatted CT scan slices, assessment of the lung parenchyma at the same time is possible (17). This method plays a role in assessment of airway patency distal to high-grade stenoses where the bronchoscope cannot pass (20). On the other hand, it has been shown that VB is unreliable in diagnosing dynamic airway pathologies or mucosal lesions (9). Moreover, retained secretions and artifacts may result in false-positive findings (10).

In this study, previously-performed CT data were retrieved from the PACS of our institution. CT exams had been done with a single slice CT scanner machine. Using a single slice CT could be considered as a limitation in this study. Although virtual bronchoscopy with single-detector helical CT scanning is reported to have excellent sensitivity and specificity for detecting central airway stenosis (21, 22), it is limited by the relatively long scanning times needed for a narrowly collimated exam. This may produce breathing and motion artifacts, especially in patients with an airway disease that may restrict their ability to hold breath for a sufficient length of time (23). The result could be misinterpretation of the tracheobronchial lumen and false-positive findings (17). In comparison with single slice CT, multislice CT scan would provide faster speed, greater coverage, and improved spatial resolution along with its unique ability to create thick and thin sections from the same data-set (8, 23). Besides using a single slice CT, some other limitations could be considered for our study. For example, we could not confirm VB cases of poststenotic tracheobronchial stenosis by FB. Moreover, adding an expiratory phase to the CT examination might have revealed some other pathologic conditions like tracheobronchomalacia.

Using the same single-detector CT scanner as ours, Rapp-Bernhardt *et al.* found sensitivity, specificity, and accuracy of 93.8%, 99.7%, and 99% for VB, respectively (21). In another study by single detector CT scan, Ferretti *et al.* reported a sensitivity of 95% for VB in depicting tracheobronchial stenoses (22). In the central airways, a study by Hoppe *et al.* showed a sensitivity of 90%, specificity of 96.6%, and accuracy of 95.5% for VB with a multidetector scanner (17). In another study with the aid of multidetector CT, Finkelstein *et al.* reported that VB had a sensitivity of 100% for detection of obstructive lesions and 83% for detection of endoluminal non-obstructive lesions (24). A meta-analysis by Jones *et al.* on 13 studies with 454 patients proved that technical parameters including scanner type (multidetector vs. single-detector) do not have any significant effects on diagnostic accuracy indices of VB in patients with suspected airway stenosis. They showed pooled sensitivity and specificity of 85% and 87%, respectively (9). In the above mentioned studies, diagnostic accuracy indices of the VB were not separately presented for trachea and bronchial stenoses.

In this study we have shown that the sensitivity of VB for stenotic lesions was 91% in trachea and 62.5% in bronchi. The overall sensitivity was 78.9%. Lower sensitivity in bronchies could be due to their special courses in comparison to the straight pathway of the trachea that decrease the accuracy of VB in bronchi. As in our series, it is also shown by other studies that the VB false-negative cases of central airway stenosis occur mostly in bronchi distal to the trachea (17, 22). The specificity of our method for detection of tracheobronchial stenosis was high compared with other studies (17, 23). Although stenosis is a rare complication of SM exposure (25), we had cases with severe tracheal stenosis (4 out of 13 patients with airway stenosis), which made the evaluation of the distal-to-stenosis airways difficult or impossible by FB. In addition, several cases of airway stenosis due to SM exposure had multiple affected sites in their respiratory tracts (6 out of 13 patients in this study). VB would be effective for visualizing obstructive lesions in post-stenotic sites. VB was also effective at detecting peripheral obstructive lesions beyond the size limits of endoscope in 2 patients. The bronchial stenosis of these two patients were distal to the main bronchi and were not statistically calculated as positive results. Another advantage of VB in SM-exposed patients is its capability of revealing extraluminal and parenchymal pathologies as happened for 11 cases in this series. Like a few previous studies, in contrast to stenosis caused by prolonged intubations, we encountered no predilection for right main bronchus in SM-exposed patients (25, 26).

In conclusion, our study indicates that VB is an accurate and non-invasive method for evaluating stenosis, endoluminal nodules, and post-stenotic areas within the tracheobronchial tree of SM-exposed victims. Although FB remains the best method for evaluating the airway patency and mucosal lesions, VB may be used as a complementary mean to assess possible post-stenotic lesions and also for better depiction of long tracheal strictures and their actual length, especially in SM victims who may have multiple synchronous airway stenoses.

**Conflict of interest:** None.

## REFERENCES

1 Masanes MJ, Legendre C, Lioret N, *et al.* Fiberoptic bronchoscopy for the early diagnosis of subglottal inhalation injury: comparative value in the assessment of prognosis. *J Trauma* 1994;**36**:59–67

2 Pue CA, Pacht ER. Complications of fiberoptic bronchoscopy at a university hospital. *Chest* 1995;**107**:430–2

3 Rogalla P, Ruckert JC, Schmidt B, *et al.* [Virtual bronchoscopy]. *Radiologe* 2001;**41**:261–8

4 Moylan JA, Adib K, Birnbaum M. Fiberoptic bronchoscopy following thermal injury. *Surg Gynecol Obstet* 1975;**140**:541–3

5 Aquino SL, Vining DJ. Virtual bronchoscopy. *Clin Chest Med* 1999;**20**:725–30, vii–viii

6 Finkelstein SE, Summers RM, Nguyen DM, *et al.* Virtual bronchoscopy for evaluation of airway disease. *Thorac Surg Clin* 2004;**14**:79–86

7 Xiong M, Zhang W, Wang D, *et al.* CT virtual bronchoscopy: imaging method and clinical application. *Chin Med J (Engl)* 2000;**113**:1022–5

8 Boiselle PM. Multislice helical CT of the central airways. *Radiol Clin North Am* 2003;**41**:561–74
9 Jones CM, Athanasiou T, Nair S, *et al.* Do technical parameters affect the diagnostic accuracy of virtual bronchoscopy in patients with suspected airways stenosis? *Eur J Radiol* 2005;**55**:445–51
10 Boiselle PM, Ernst A. Recent advances in central airway imaging. *Chest* 2002;**121**:1651–60
11 Abbas F. Report of the specialists appointed by the Secretary-General of the United Nations to investigate allegations by the Islamic Republic of Iran concerning the use of chemical weapons. *Arch Belg* 1984;**42**(Suppl):302–10
12 Abolghasemi H, Radfar MH, Rambod M, *et al.* Childhood physical abnormalities following paternal exposure to sulfur mustard gas in Iran: a case-control study. *Confl Health* 2010;**4**:13
13 Hosseini-khalili A, Haines DD, Modirian E, *et al.* Mustard gas exposure and carcinogenesis of lung. *Mutat Res* 2009;**678**:1–6
14 Sohrabpour H. Clinical manifestations of chemical agents on Iranian combatants during Iran–Iraq conflict. *Arch Belg* 1984;**42**(Suppl):291–7
15 Rowell M, Kehe K, Balszuweit F, *et al.* The chronic effects of sulfur mustard exposure. *Toxicology* 2009;**263**:9–11
16 Emad A, Rezaian GR. The diversity of the effects of sulfur mustard gas inhalation on respiratory system 10 years after a single, heavy exposure: analysis of 197 cases. *Chest* 1997;**112**:734–8
17 Hoppe H, Dinkel HP, Walder B, *et al.* Grading airway stenosis down to the segmental level using virtual bronchoscopy. *Chest* 2004;**125**:704–11
18 Beheshti J, Mark EJ, Akbaei HM, *et al.* Mustard lung secrets: long term clinicopathological study following mustard gas exposure. *Pathol Res Pract* 2006;**202**:739–44
19 Ghanei M, Mokhtari M, Mohammad MM, *et al.* Bronchiolitis obliterans following exposure to sulfur mustard: chest high resolution computed tomography. *Eur J Radiol* 2004;**52**:164–9
20 Koletsis EN, Kalogeropoulou C, Prodromaki E, *et al.* Tumoral and non-tumoral trachea stenoses: evaluation with three-dimensional CT and virtual bronchoscopy. *J Cardiothorac Surg* 2007;**2**:18
21 Rapp-Bernhardt U, Welte T, Doehring W, *et al.* Diagnostic potential of virtual bronchoscopy: advantages in comparison with axial CT slices, MPR and mIP? *Eur Radiol* 2000;**10**:981–8
22 Ferretti GR, Knoplioch J, Bricault I, *et al.* Central airway stenoses: preliminary results of spiral-CT-generated virtual bronchoscopy simulations in 29 patients. *Eur Radiol* 1997;**7**:854–9
23 Hoppe H, Walder B, Sonnenschein M, *et al.* Multidetector CT virtual bronchoscopy to grade tracheobronchial stenosis. *Am J Roentgenol* 2002;**178**:1195–200
24 Finkelstein SE, Summers RM, Nguyen DM, *et al.* Virtual bronchoscopy for evaluation of malignant tumors of the thorax. *J Thorac Cardiovasc Surg* 2002;**123**:967–72
25 Ghanei M, Akhlaghpoor S, Moahammad MM, *et al.* Tracheobronchial stenosis following sulfur mustard inhalation. *Inhal Toxicol* 2004;**16**:845–9
26 Balali-Mood M, Hefazi M. The pharmacology, toxicology, and medical treatment of sulphur mustard poisoning. *Fundam Clin Pharmacol* 2005;**19**:297–315