Detection of acute inhalation injury in fire victims by means of technetium-99m DTPA radioaerosol inhalation lung scintigraphy

Wan-Yu Lin, Chia-Hung Kao, Shyh-Jen Wang

Department of Nuclear Medicine, Taichung Veterans General Hospital, 160 Taichung Harbor Road, Sec. 3, Taichung 407, Taiwan

Received 2 August and in revised form 6 October 1996

Abstract. Mortality and morbidity in fire victims are largely a function of injury due to heat and smoke. While the degree and area of burn together constitute a reliable numerical measure of cutaneous injury due to heat, as yet no satisfactory measure of inhalation injury has been developed. In this study, we employed technetium-99m diethylene triamine penta-acetic acid (DTPA) radioaerosol lung scintigraphy (inhalation scan) to evaluate acute inhalation injury in fire victims. Ten normal controls and 17 survivors from a fire accident were enrolled in the study. All patients suffered from respiratory symptoms (dyspnoea and/or cough with sputum). ^{99m}Tc-DTPA aerosol inhalation lung scintigraphy was performed in all subjects, using a commercial lung aerosol delivery unit. The degree of lung damage was presented as the clearance rate (k; %/min) calculated from the time-activity curve over the right lungs. In addition, the distribution pattern of the radioactivity in the lungs was evaluated and classified into two groups: homogeneous distribution and inhomogeneous distribution. A plain chest radiograph (CxR) and pulmonary function test (PFT) were performed in the same group of patients. The results showed that 6/17 (35.3%) patients had inhomogeneous distribution of radioactivity in their inhalation scans, and 11/17 (64.7%) had homogeneous scans. Five of the six patients with inhomogeneous scans were admitted for further management, and all patients with homogeneous scans were discharged from the emergency department and needed no further intensive care. The clearance rates of the right lung were 0.73%±0.13%/min for normal controls and 1.54%±0.58%/min for fire victims. The difference was significant, with a P value of less than 0.01. Using a cut-off value of 0.9%/min (all normal subjects were below 0.9%/min), 14 (82.4%) patients had abnormal clearance rates of ^{99m}Tc-DTPA from the lung. In contrast, only three (17.6%) patients had abnormal CxR and three (17.6%) had abnormal PFTs. We conclude that (1) conventional CxR and PFT are not good modalities for evaluating inhalation injury in fire victims because of their low sensitivity, and (2) ^{99m}Tc-DTPA radioaerosol inhalation scintigraphy can provide an objective evaluation of inhalation injury during a fire accident and may be useful in therapeutic decision-making and disease monitoring.

Key words: Inhalation injury – Fire victim – Radioaerosol – Technetium-99m diethylene triamine penta-acetic acid – Lung scintigraphy.

Eur J Nucl Med (1997) 24:125–129

Correspondence to: Wan-Yu Lin

Introduction

Smoke inhalation has a major influence on the pulmonary complications that may occur after fires [1]. When smoke is inhaled, the lungs are injured directly by the heat from the flames and, more importantly, by the products of incomplete combustion [2, 3]. Significant inhalation injury probably adds 30%–40% to the mortality of extensive burns, with a high incidence of late-onset pneumonia [4, 5]. However, there is still a lack of a simple, sensitive and effective diagnostic modality for evaluating the lung condition in these patients. Early reports suggested that plain chest radiograph was of little value in the diagnosis and management of patients after acute smoke inhalation [6, 7].

Recently, the non-invasive measurement of the clearance rate of technetium-99m diethylene triamine penta-acetic acid (DTPA) aerosol has been used to investigate pulmonary epithelial permeability under different physiological conditions [8–11], in those who smoke [12, 13] and in various pulmonary disorders [14–16]. ^{99m}Tc-DTPA radioaerosol inhalation lung scintigraphy (inhalation scan) has proven to be a highly sensitive and useful modality for detecting early lung damage.

In this study, we evaluated the value of the inhalation scan for monitoring pulmonary damage in fire victims, and compared the results with those of chest X-ray films (CxR) and pulmonary function tests (PFT).

Materials and methods

Materials. Thirty-seven patients were sent to the emergency room following a closed-space explosive accident in a local power plant. Patients with a history of smoking or previous lung disease were excluded. Finally, 17 patients were enrolled in this study. The mean age of the subjects was 47.6 years (range 24–71 years). In addition, ten normal subjects were included as normal controls. CxR, PFT and inhalation scans were performed on all patients within 48 h after the accident, except in three patients who received the inhalation scan several days later (two on the 4th day and the other on the 12th day) because they were intubated in a critical condition.

Values of forced expiratory volume in 1 s (FEV_1), forced vital capacity (FVC) and FEV_1/FVC were calculated to evaluate pulmonary function. A value below 80% of the predicted value was considered abnormal.

^{99m}Tc-DTPA radioaerosol inhalation lung scintigraphy. The ^{99m}Tc-DTPA radioaerosol clearance speed, presented as a clearance rate (*k*; %/min) from lungs to blood, was measured in all individuals. The radioaerosols were generated from a commercial lung aerosol delivery unit (Aero/Vent, Medi Nuclear, USA) containing 7400 MBq (20 mCi) ^{99m}Tc-DTPA in 2–4 ml saline. The radioaerosol droplet size was measured by an inertial impactor (Model PC-2, California Measurement Inc, Calif., USA). The mass median aerodynamic diameter (MMAD) of the ^{99m}Tc-DTPA radioaerosol was smaller than 1 μm under a 6–7 l/min air flow rate. All subjects were positioned supine and told to inhale for 2–3 min from the aerosol delivery unit until the total radioactivity was over 200 000 counts. Data were collected for another 30 min by means of a large-field computerized gamma camera (Apex 609R, Elscint Ltd., Haifa, Israel), over the posterior view, which included the entire chest. Data were acquired as a series of 30 consecutive frames, one minute per frame, in a 64×64 matrix with word mode. Upon completion of the data acquisition, the first image in the series was displayed and further regions of interest were automatically created over both lungs. Radioactivity was corrected for radionuclide decay and background subtraction. Time-activity curves were generated over both lungs. A power exponential fitting routine was then used to calculate the clearance rate (*k*; %/min). However, only the right lung was used to analyse clearance, in order to avoid interference from stomach activity on the left side.

In addition, based on the first 1-min frame, distribution patterns of the radioactivity in the lungs were classified into two groups (homogeneous distribution and inhomogeneous distribution) by two observers.

Table 2. Detailed data of ten normal controls

No.	Age	Clearance rate (%/min)
1	54	0.53
2	44	0.54
3	48	0.64
4	42	0.64
5	52	0.76
6	56	0.76
7	66	0.77
8	49	0.83
9	47	0.88
10	48	0.90

Results

Detailed data are shown in Tables 1 and 2. Eight survivors had skin burns, all limited to their faces and hands. Of the 17 fire victims, 12 were discharged from the emergency department and five were hospitalized (in four cases due to respiratory problems and in one case

Table 1. Detailed data of 17 fire victims

No.	Sex	Age (yr)	Symptoms and signs	FEV_1	FVC	F/C	CR (%/min)	Hosp. (days)	Burn	Intub.	CxR	Pattern
1	F	24	Dyspnoea, ARDS	38	45	79	1.79	50	Y	Y	Pulm oedema	IH
2	M	50	Dyspnoea, cough	94	83	84	2.01	0	N	N	N	H
3	M	48	Cough, dyspnoea	108	107	82	1.26	0	Y	N	N	IH
4	M	56	Cough, sputum	89	83	83	2.15	0	N	N	N	H
5	M	58	Cough, sputum	98	84	85	1.95	0	Y	N	N	H
6	M	71	Cough, sputum	102	99	85	1.21	0	N	N	N	H
7	M	70	Dyspnoea, cough	61	62	67	0.87	35	Y	Y	Inter. infiltr.	IH
8	M	34	Dyspnoea, sputum	96	91	85	1.14	0	N	N	Normal	H
9	M	27	Cough, sputum	115	96	97	2.63	10	Y	N	Normal	IH
10	M	38	Cough	84	85	81	2	0	N	N	Normal	H
11	M	63	Cough, sputum	110	107	89	1.12	0	Y	N	Normal	H
12	M	62	Cough, dyspnoea	91	89	86	1.05	0	N	N	Normal	H
13	M	30	Cough, red eye	50	60	65	0.67	12	Y	N	Normal	IH
14	F	50	Dyspnoea, red eye	93	91	84	1.25	7	Y	Y	Inter. infiltr.	IH
15	F	41	Dyspnoea, cough	105	101	86	0.86	0	N	N	Normal	H
16	M	39	Cough	86	84	81	2.05	0	N	N	Normal	H
17	M	48	Dyspnoea	98	92	84	2.19	0	N	N	Normal	H

F/C, FEV_1/FVC; CR, clearance rate; Intub., endotracheal intubation; Int. infiltr., interstitial infiltration; Hosp., hospitalization; H, homogeneous; IH, inhomogeneous

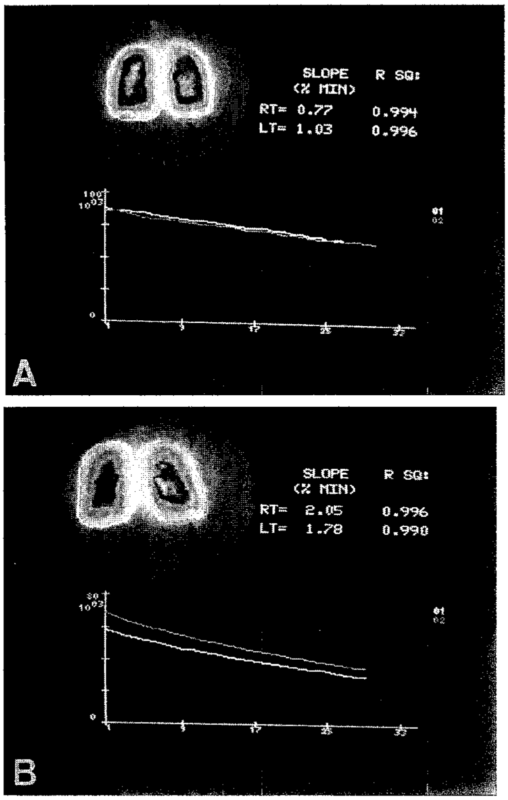

Fig. 1. A A time-activity curve of a normal subject shows a normal clearance rate of ^{99m}Tc-DTPA. **B** A time-activity curve of a fire victim (patient no. 16) shows a faster clearance rate of ^{99m}Tc-DTPA

Fig. 2. The inhalation scan (anterior view) of patient no. 7 shows inhomogeneous distribution of radioactivity in both lungs

due to skin burn) for periods ranging from 7 to 50 days. Three required endotracheal intubation and one required ventilation for 17 days as a result of adult respiratory distress syndrome. The clearance rates of the right lung were 0.73%±0.13%/min for normal controls and 1.54%±0.58%/min for fire victims (Fig. 1). The difference was significant, with *P* values of less than 0.01. Using a cut-off value of 0.9%/min (all normal subjects were below 0.9%/min), 14/17 (82.4%) patients had an abnormal clearance rate of ^{99m}Tc-DTPA from the lung, while only three (17.6%) patients had abnormal PFT and three (17.6%) had abnormal CxR findings. Comparisons between these diagnostic modalities are tabulated in Table 3, according to hospitalization or non-hospitalization of the patients.

Table 3. Comparison between different diagnostic modalities according to hospitalization or non-hospitalization of the patients

		Inhalation scintigraphy						
		Distribution pattern		Clearance rate (%/min)	PFT		CxR	
	No.	Even	Uneven		N	abN	N	abN
Hospitalization	5	0	5	1.44	2	3	2	3
Non-hospitalization	12	11	1	1.58	12	0	12	0

N, Normal; abN, abnormal

Table 4. Comparison between different diagnostic modalities according to the distribution pattern of inhalation scintigraphy

Distribution pattern	No.	Clearance rate (%/min)	Hospitalization		PFT		CxR	
			Yes	No	N	abN	N	abN
Homogeneous	11	1.61	0	11	11	0	11	0
Inhomogeneous	6	1.41	5	1	3	3	3	3

N, Normal; abN, abnormal

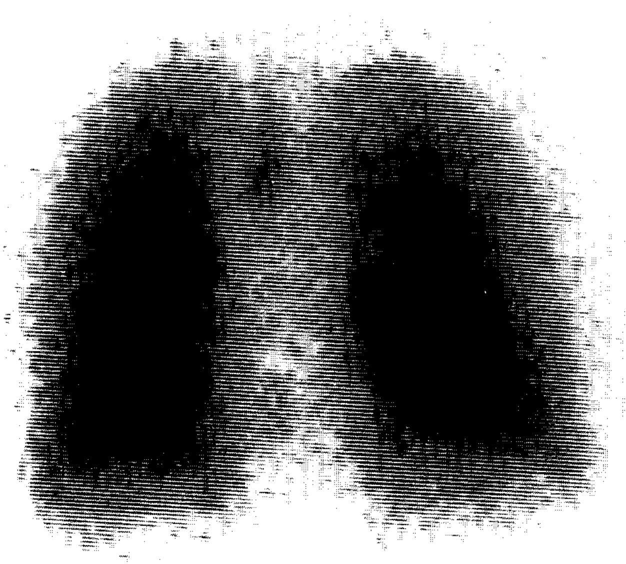

Fig. 3. The inhalation scan (anterior view) of patient no. 16 shows homogeneous distribution of radioactivity in both lungs

In Table 4, the results of different diagnostic modalities and clinical findings are shown according to the distribution pattern of radioactivity in the inhalation scintiscan. Six of the 17 (35.3%) patients showed inhomogeneous distribution of radioactivity in their inhalation scans (Fig. 2) while 11/17 (64.7%) had homogeneous scans (Fig. 3). Five of the six patients with inhomogeneous scans were admitted for further management, and all patients with homogeneous scans were discharged from the emergency department and needed no further intensive care. Both PFT and chest X-ray showed less sensitivity in detecting lung injury than the inhalation scan.

Discussion

Significant damage may be caused both to the airways and to the lung parenchyma following acute smoke and heat inhalation. In the upper and major airways, heat injury and acute smoke inhalation cause oedema, necrosis and sloughing of the mucosa, bronchospasm, and cessation of ciliary movement of the bronchial epithilium. These conditions often lead to airway obstruction and atelectasis [17, 18]. In the lung parenchyma, smoke causes parenchymal injury to the alveolar epithilium. This results in pulmonary capillary permeability, pulmonary oedema and interference with gas exchange [19, 20]. This often leads to acute pulmonary insufficiency, which is a major cause of morbidity and mortality in burn victims [20].

The most striking abnormality in the lungs after smoke inhalation is airway obstruction, because of particulate debris and irritant volatile vapours from synthetic polymers from materials used in construction, furniture and decoration [21]. In addition, heat injury also causes mucosal oedema of the major airways and can result in airway obstruction. In the inhalation scan, obstruction of small airways will block the entry of ^{99m}Tc-DTPA into the lung parenchyma and present an area with hyporadioactivity or without radioactivity in the lung (inhomogeneous distribution). Therefore, evaluating the distribution pattern of radioactivity after inhalation of the radioaerosol should be a useful and direct way to monitor the existence and severity of small airway obstruction. In our study, the five victims who had to be hospitalized showed inhomogeneous distribution of radioactivity in the lung, while almost all the patients who needed no hospitalization showed a homogeneous distribution pattern. The results suggest that the inhomogeneous distribution of radioactivity in an initial inhalation scan may indicate a more serious inhalation injury, and further treatment may be necessary for these patients.

Interestingly, the clearance rates of ^{99m}Tc-DTPA from the lungs in patients who had to be admitted for further treatment were not higher than those in patients who needed no further treatment. Actually, they were slightly lower. The hospitalized patients should have had obstructions of small airways, since all of them had an inhomogeneous distribution scan. Our explanation is that in cases with airway obstruction, the airflow is decreased and a relatively large amount of radiotracer could deposit in the airway instead of the alveoli. The clearance rate of the radiotracer in the small airways is surely slower than in the alveoli. Therefore, in cases with inhomogeneous distribution of radioactivity, the clearance rate is not a reliable criterion for the detection of pulmonary injury in fire victims. In our study, of the six patients with inhomogeneous distribution, two (33%) (nos. 7 and 13) who needed admission for further treatment had normal clearance rates. By contrast, of the 11 patients with homogeneous distribution, only one (9%) had a clearance rate lower than 0.9. We suggest that interpretation of inhalation scintigraphy in fire victims should focus on the distribution pattern of radioactivity first, and then use the clearance rate to evaluate the integrity of the alveoli.

The value of the CxR in evaluation of the respiratory system in fire victims is debatable. Stone et al. [6] and Eaton et al. [7] suggested that the value of CxR in the diagnosis and management of patients after acute smoke inhalation is limited [6, 7], whereas Teixidor et al. [22] and Lee and O'Connell [23] stressed the importance of the CxR in the early post-exposure period. In our study, only three patients had positive radiographic findings, but all three needed endotracheal intubation. We conclude that the CxR is not a sensitive modality in evaluating lung damage after smoke inhalation. Abnormality on chest films may not be seen until a severe complication such as atelectasis, alveolar oedema or bronchopneumonia develops. However, the initial CxR is still an important predictor (especially in significant smoke inhalation injuries) and enables selection of patients likely to need endotracheal intubation.

Assessment of the effects of smoke inhalation on respiratory function is difficult because pre-exposure lung function is unlikely to be known unless the subject has had a pre-existing lung disease and has come to the hospital for help. Therefore, we could only compare the PFT of patients with a normal database, and considered it to be abnormal when the values were below 80% of normal predicted values. However, these criteria seemed only able to detect serious cases of pulmonary injury in fire victims. In our study, only the three patients with long hospitalization had abnormal PFT. In addition, measurements of PFT requiring cooperation from severely ill persons could yield spurious results. Our data suggest that PFT may be not a sensitive test in detecting pulmonary injury in fire victims.

Although the number of patients in our study was small, there was a striking incidence of airway obstruction after smoke inhalation. The findings of abnormal inhalation scintigraphy in most of the fire victims suggest that smoke inhalation may lead to more damage to the respiratory system than has previously been recognized. We conclude that the conventional chest X-ray and pulmonary function test are not good modalities for evaluating inhalation injury in fire victims because of their low sensitivity. In contrast, ^{99m}Tc-DTPA radioaerosol inhalation scintigraphy can provide an objective evaluation of inhalation injury during a fire accident and, therefore, may be useful in therapeutic decision-making and disease monitoring.

References

1. Clark CJ, Reid WH, Gilmour WH, Campbell D. Mortality probability in victims of fire trauma: revised equation to include inhalation injury. *Br Med J* 1986; 292: 1303–1305.
2. Cahalane M, Demling RH. Early respiratory abnormalities from smoke inhalation. *JAMA* 1984; 251: 771–773.
3. Stephenson SF, Esrig BC, Polk HC Jr, et al. The pathophysiology of smoke inhalation injury. *Ann Surg* 1975; 182: 652–660.
4. Herndon DN, Langer F, Thompson P, et al. Pulmonary injury in burned patients. *Surg Clin North Am* 1987; 67: 31–46.
5. Shirani KZ, Pruitt BA, Mason AD. The influence of inhalation injury and pneumonia on burn mortality. *Am Surg* 1987; 205: 82–87.
6. Stone H, Rhome DW, Corbett JD, Given KS, Martin JD Jr. Respiratory burns: a correlation of clinical and laboratory results. *Ann Surg* 1967; 165: 157–159.
7. Eaton RJ, Senior RM, Pierce JA. Aspects of respiratory care pertinent to the radiologist. *Radiol Clin North Am* 1973; 2: 93–107.
8. Jones JG, Berry M, Hulands GH. The time course and degree of change in alveolar-capillary membrane permeability induced by aspiration of hydrochloric acid and hypotonic saline. *Am Rev Respir Dis* 1978; 118: 1007–1013.
9. Newhouse MI, Jordana M, Dolovich M. Evaluation of lung epithelial permeability. *Eur J Nucl Med* 1987; 13: S58–S62.
10. Meignan M, Rosso J, Leveau J, Katz A, Cinotti L, Madelaine G, Galle P. Exercise increases the lung clearance of inhaled technetium-99m-DTPA. *J Nucl Med* 1986; 27: 274–280.
11. Meignan M, Rosso J, Robert R. Lung epithelial permeability to aerosolized solutes: relation to position. *J Appl Physiol* 1987; 62: 902–911.
12. Jones JG, Minty BD, Lawler P, Hulands G, Crawley JC, Veall N. Increased alveolar epithelial permeability in cigarette smokers. *Lancet* 1980; I: 66–68.
13. Mason GR, Ulzer JM, Effros RM, Reid E. Rapid reversible alteration of pulmonary epithelium permeability induced by smoking. *Chest* 1983; 83: 6–11.
14. Lin WY, Kao CH, Wang SJ, Yeh SH. Lung toxicity of chemotherapeutic agents detected by Tc-99m DTPA radioaerosol inhalation lung scintigraphy. *Neoplasma* 1995; 42: 113–115.
15. Rosso J, Guillon JM, Parrot A, Denis M, Akoun G, Mayaud C, Scherrer M, Meignan M. Technetium-99m-DTPA aerosol and gallium-67 scanning in pulmonary complications of human immunodeficiency virus infection. *J Nucl Med* 1992; 33: 81–87.
16. Fanti S, Monetti N, DeFabritiis A, Aloisi D, Cavalli A, Corbelli C, Marengo M, Dondi M. Detection of subclinical pulmonary involvement in systemic sclerosis by means of 99mTc-DTPA clearance. *Eur J Nucl Med* 1993; 20: 827.
17. Clark CJ, Kinsella J, Reid WH, Campbell D. The role of fibreoptic bronchoscopy in early diagnosis of smoke inhalation injury. *Thorax* 1988; 43: 828.
18. Clark CJ, Pollock AJ, Reid WH, Campbell D, Gemmell C. Role of pulmonary alveolar macrophage activation in acute lung injury after burns and smoke inhalation. *Lancet* 1988; II: 872–874.
19. Fein A, Leff A, Hopewell PC. Pathophysiology and management of the complications resulting from fire and the inhaled products of combustion. *Crit Care Med* 1980; 8: 94–98.
20. Peitzman AB, Shires GT III, Corbett WA, Curreri PW, Shires GT. Measurement of lung water in inhalation injury. *Surgery* 1981; 90: 305–312.
21. Trunkey D. Inhalation injury. *Surg Clin North Am* 1978; 135: 250–263.
22. Teixidor MS, Rubin E, Novick GS, Alonso DR. Smoke inhalation: radiological manifestations. *Radiology* 1983; 149: 383–387.
23. Lee MJ, O'Connell DJ. The plain chest radiograph after acute smoke inhalation. *Clin Radiol* 1988; 39: 33–37.