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SURGICAL ENDOSCOPY
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Fiber-optic bronchoscopic classification of inhalation injury

Prediction of acute lung injury

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Abstract
Background: Fiber-optic bronchoscopy is widely used for the early diagnosis of inhalation injury. However, there is no current bronchoscopic classification of inhalation injury for the prediction of acute lung injury (ALI). Our goal was to devise such a classification.
Methods: Between February 1993 and January 2002, 167 patients with highly suspicious inhalation injuries were collected. All patients received fiber-optic bronchoscopy within 24 h after their accident. In total, 108 patients were diagnosed as positive under direct inspection. The patients were divided into three groups (G_1, G_2, and G_3) according to the depth of mucosal damage. Six patients were found to be positive by biopsy and were assigned to group Gb. Of these 114 positive cases, 27 developed ALI. Meanwhile, 53 patients were diagnosed as negative; these patients were assigned to group G_0.
Results: After analysis, the following results were noted: G_0 (n = 53), two ALI (3.8%); G_1 (n = 49), two ALI (4%); G_2 (n = 46), 15 ALI (33%); G_3 (n = 13),10 ALI (77%); Gb (n = 6), no ALI. We discovered that the deeper the mucosal injuries, the higher the rate of ALI. There were no deaths related to the procedure.
Conclusions: Fiber-optic bronchoscopy is a safe and effective method for the early diagnosis of inhalation injuries. Also, it is a good predictor of ALL.We hope that in the near future, this classification will serve as a treatment guideline for the early prevention of ALI. The more severe the damage, the more alert clinicians need to be to improve the patient's chances for survival.

Key words: Fiber-optic bronchoscopy — Classification — Inhalation — Acute lung injury

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Inhalation injury is a major cause of death in burn patients. Many of the victims remain "silent" for 3–4 days before fatal pulmonary complications occur [7]. Even chest radiography [6, 12] and arterial blood gas analysis [13] provide few indications of the extent of the damage within the first few days.

Fiber-optic bronchoscopy has been widely used in the early diagnosis of inhalation injury [11] in an attempt to reduce morbidity and mortality as much as possible. However, we still do not know how effective the procedure really is. Also, there is currently a lack of a bronchoscopic classification for the prediction of the incidence of acute lung injury (ALI).

From 1993 to 2002, we conducted a prospective study. All patients highly suspicious for inhalation injury (due to explosions in confined areas, burns of the head and neck, expectoration of carbon soot, and singed nasal hair) underwent fiber-optic bronchoscopy within 24 h of injury. Afterward, the bronchoscopic findings were analyzed and correlated with their clinical course. The study showed that early bronchoscopy is effective in early diagnosis. Moreover, our results suggested a bronchoscopic classification that could after be an effective prognostic predictor and treatment guideline.

Materials and methods

Between February 1993 and January 2002, all patients (male, 113; female; 54; age range, 17–86 years) highly suspicious for inhalation injury received fiber-optic bronchoscopy within 24 h of injury. Eighty-four percent had facial burns as a result of explosions or fire in a confined area. The procedure was performed by two experienced fiber-optic bronchoscopists (S.-H.C. and Y.-J.C.) using an Olympus BF P200 (Olympus Optical Co., Ltd.; Tokyo, Japan). The following findings were considered to be positive: mucosal edema or reddening, ulcerations, necrosis, and carbon soot over the vocal cord, larynx, trachea, main bronchi, or smaller bronchial divisions. Absence of cough reflex and absence of bronchial secretions were regarded as signs of severe injury [7].

Table 1. Findings of fibre-optic bronchoscopy by group

Group	Finding
G_0	Negative
Gb	Positive, confirmed by biopsy
G_1	Mild edema and hyperemia, with or without carbon soot
G_2	Severe edema and hyperemia, with or without carbon soot
G_3	Ulcerations, necrosis, absence of both cough reflex and bronchial secretions (dry)

In the event that the macroscopic findings were controversial, bronchial biopsies were performed over both the main bronchi and lobar bronchi, and the conclusion was made by a pathologist. Patients deemed to be positive were divided into four different of groups as follows:

Group b (Gb): Confirmed positive by biopsy
Group 1 (G_1): Mild mucosal edema and hyperemia, with or without carbon soot
Group 2 (G_2): Severe mucosal edema and reddening, with or without carbon soot
Group 3 (G_3): Ulcerations, necrosis, and absence of both cough reflex and bronchial secretionsPatients deemed to be negative, were classified as group 0 (G_0).

This classification was applied according to the depth of mucosal damage (Table 1).

The results were correlated with the patients' clinical course over their entire hospital stay. Analysis of the results showed a correlation between the different groups and the rate of ALI.

ALI was diagnosed in patients without septicemia, with bilateral diffuse pulmonary infiltrates, with PaO_2 (partial pressure of oxygen in arterial blood)/FiO_2 (inspired percentage of oxygen) <300 mmHg, and pulmonary wedge pressure <18 mmHg. Patients who had the same pulmonary conditions (i.e., bilateral infiltrates, PaO_2/FiO_2 < 300 MmHg and pulmonary wedge pressure < 18 mmHg) after 4 days of injury were not included in the study for other reasons—for example, septicemia may contribute to the condition.

Results

In this study, 167 cases were collected. There were no instances of morbidity or mortality during the bedside procedure. In total, there were 53 G_0 patients, 49 G_1, 46 G_2, 13 G_3, and six Gb. The incidence of ALI was as follows: G_0, ALI 3.8% (two of 53); G_1, ALI 4% (two of 49); G_2, ALI 33% (15 of 46); G_3, ALI 77% (10 of 13); Gb, ALI 0% (no cases) (Table 2).

The differences among the five groups were analyzed using Fisher's exact test and the Mantel-Haenszel chi-square test. The results, $p < 0.001$ and $p = 0.001$, respectively, were statistically significant. We found that the deeper the damage, the higher the rate of ALI.

The percentage of ALI cases in G_3 (77%) was the highest; and G_2 (33%) was the second highest. However, the percentages of G_0, Gb, and G_1 were significantly lower than that of G_2. Thus, a threshold effect likely appeared between G_1 and G_2.

Discussion

With the increasing indoor use of gaseous fuels, plastics, synthetic products, and volatile chemicals, the chances of explosion in a confined area have grown concomitantly, thereby also increasing the risk of toxic gaseous smoke and hot steam injury to the respiratory tract. The degree of injury depends on the duration of inhalation, the temperature, and the toxicity of the gas [16]. Injury usually occurs during a sudden explosion in a confined area. Victims are foiled to inhale large amounts of smoke in an environment low in oxygen or while unconscious.

Table 2. Correlation of acute lung injury (ALI) and mortality by group

	No. of patients	ALI (n, %)	Mortality (%)
Go	53	2 (3.8)	0
Gb	6	0	0
G_1	49	2 (4%)	2
G_2	46	15 (33%)	15
G_3	13	10 (77%)	62
Total	167	29	14

Fisher's exact test $p < 0.001$
Mantel-Haenszel chi-square test for trend, $p = 0.001$

Clinically, the patients appear to have facial burns, swollen lips, singed nasal hair, and carbon soot–tinged respiratory secretions. However, some do not present with the classic appearance. They often appear normal, even chest radiography [6, 12] on and blood gas analysis [13]. Two to three days later, however, ALI may develop.

The mortality rate after inhalation injury ranges from 45% to 78% [3]. Inhalation injury is one of three significant predictors of death after thermal injury [8, 17, 18, 20]. Thus, early diagnosis and management of inhalation injury is critical. Since the 1975 report of Moylan et al. [11], bronchoscopy has been widely used for the early detection of airway injury.

Although a xenon^{133} ventilation perfusion scan is another good means of diagnosis [6], its limitations are quite extensive. In patients with preexisting lung disease—for example, chronic obstructive pulmonary disease (COPD) or bronchiectasis—a false-positive scan is likely [1, 10]. Moreover, moving a critically ill patient to the scanning room entails, substantial risk and great expense.

Fiber-optic bronchoscopy can be done at bedside, and the risks are minimal. In our series, there was no morbidity or mortality related to the procedure. Most important, we were able to make the diagnosis much more rapidly under direct visual observation and inspection.

Over the past 9 years, we performed fiber-optic bronchoscopy on 167 patients who were highly suspicious for inhalation injury. Of these, 114 were diagnosed positive, while 53 were diagnosed negative. Twentyseven positive patients developed ALI, for a rate of 23.7%, or almost a fourth.

When we analyzed our data further (Fisher's exact test, $p < 0.001$; Mantel-Haenszel chi-square test for trend, $p = 0.001$), we recognized that there was a different rate for ALI depending on the specific bronchoscopic findings: G_3 had the worst outcome, whereas G_0 had the best. Accordingly, we also noticed that the deeper the mucosal damage, the higher the rate of ALI. Using this classification, not only could we predict the patient's outcome, we also had a treatment guideline that could be applied in our future patients.

Death is not an uncommon outcome in patient with inhalation injury [8, 17, 18, 20]. However, in this study the overall mortality rate related to ALI was only 14%. The incidence of mortality related to ALI is listed in Table 2 for each group. When we compared our results to other studies [2, 3, 15, 18, 19], which have reported a $\leq 60\%$ rate of mortality, we found them highly encouraging. These results were likely due to our protocol for pulmonary care, which follows three important principles: (a) Immediately after the diagnosis of inhalation injury by fiber-optic bronchoscopy, preventive ventilatory support was given [14]—for example, in G_1, G_2, and G_3. For Gb patients, deterioration in the blood-gas value was the indication for assisted mechanical ventilation. (b) Increased fluid resuscitation support was given to maintain stable hemodynamics [4, 5]; i.e., maintenance fluid supply was administered to patients with only inhalation injury, whereas 2 ml/kg/%-of-burn of additional fluid was given to patients with inhalation injury plus burn. (c) Finally, intensive pulmonary toilet was provided.

Interestingly, in most studies [4] there was an attempt to eliminate the carbon soot via bronchoscopy. However, we do not think that there is any need to take deliberate measures to clean out the soot. In our experience, with follow-up bronchoscopy 3–5 days after the initial examination, the soot nearly disappears. It may be removed during the intensive respiratory toilet.

In conclusion, any burn patient highly suspicious for inhalation injury should receive an early bronchoscopy. If the results are positive, prompt and aggressive measures, including preventive ventilation, should be undertaken.

Fiber-optic bronchoscopy is a safe, effective, and economical procedure for the early diagnosis of inhalation injury. It enables the prediction of ALI and improves the prognosis of the patient.

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