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Computed tomographic assessment of airflow obstruction in smoke inhalation injury: Relationship with the development of pneumonia and injury severity

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ABSTRACT

Purpose: The prediction of pulmonary deterioration in patients with smoke inhalation injury is important because this influences the strategy for patient management. We hypothesized that narrowing of the luminal bronchus due to bronchial wall thickening correlates to respiratory deterioration in smoke inhalation injury patients.

Methods: In a prospective observational study, all patients were enrolled at a single tertiary trauma and critical care center. In 40 patients, chest computed tomographic images were obtained within a few hours after smoke inhalation injury. We assessed bronchial wall thickness and luminal area % on chest computed tomographic images. Airway wall thickness to total bronchial diameter (*T*/*D*) ratio, percentage of luminal area, and clinical indices were compared between patients with smoke inhalation injury and control patients.

Results: The *T*/*D* ratio of patients with smoke inhalation was significantly higher than that of control patients ($p < 0.001$), and the luminal area of these patients was significantly smaller than that of control patients ($p < 0.001$). The number of mechanical ventilation days correlated with the initial infusion volume, *T*/*D* ratio, and luminal area %. ROC analysis showed a cut-off value of 0.26 for the *T*/*D* ratio, with a sensitivity of 79.0% and specificity of 73.7%, and a value of 23.4% for luminal area %, with a sensitivity of 68.4% and specificity of 84.2%.

Conclusions: These data revealed the utility of computed tomography scanning on admission to show that the patients with smoke inhalation injury had airway wall thickening compared to control patients without smoke inhalation injury. Airflow narrowing due to airway wall

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Abbreviations: SII, smoke inhalation injury; ARDS, acute respiratory distress syndrome; CT, computed tomography; PaO_2/FIO_2, arterial partial pressure of oxygen to inspired oxygen fraction ratio; CO-Hb, carboxyhemoglobin; ICU, intensive care unit; PEEP, positive end-expiratory pressure; OL, overall long diameter; OS, overall short diameter; IL, internal long diameter; IS, internal short diameter; T, wall thickness; Ai, Luminal area; Ao, total airway area; *T*/*D*, airway wall thickness to total bronchial diameter; LA, (Luminal area (A_i) in mm^2 / total airway area (A_o))×100; AIS, Abbreviated Injury Score; SD, standard deviation; ROC, receiver operating characteristic.

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thickening was related to the development of pneumonia and the number of mechanical ventilation days in patients with smoke inhalation injury. Airflow narrowing is one important factor of respiratory deterioration in smoke inhalation injury.

1. Introduction

Smoke inhalation injury (SII) contributes to the development of pulmonary edema, pneumonia, and acute respiratory distress syndrome (ARDS) [1]. In a burn patient, if SII is present, treatment strategy needs to be revised because of the present respiratory deterioration [2]. The prediction of pulmonary deterioration in patients with SII using presently available examinations such as bronchoscopy, laboratory data, and chest X-rays is difficult [3–9]. Recently, Kwon et al. reported that virtual bronchoscopy by computed tomography was useful in the determination of SII severity [10]. Previously, we measured bronchial wall thickness using chest computed tomography (CT) scans obtained shortly after admission. Bronchial wall thickness was measured at the dorso-lateral side of the right main trachea 2 cm distal from the tracheal bifurcation. Bronchial wall thickness was found to be predictive of the total number of ventilator days, duration of intensive care unit (ICU) stay, and the development of pneumonia in SII patients. This bronchial wall thickening in SII is a reversible change of the airway wall [11]. We hypothesized that narrowing of the luminal bronchus due to bronchial wall thickening correlates to respiratory deterioration in patients with SII.

2. Materials and methods

2.1. Patient selection

We enrolled 40 patients admitted to the Critical Care Unit in Osaka City University Hospital from January 2008 to December 2013 in this prospective study. SII was suspected on the basis of smoke exposure within a confined space or the presence of soot on the nares, pharynx, or larynx. The suspicion of SII was confirmed by the bronchoscopic findings in these patients. The inclusion criterion was an AIS score above 1, according to the bronchoscopy results at admission. Exclusion criteria included age younger than 18 years and presence of chronic obstructive pulmonary disease, bronchial asthma, malignancy, or burn surface area >20%. We evaluated as the control group 15 volunteers who were all undergoing evaluation by medical examination. Findings from chest CT scans of the control group patients were interpreted by a radiologist as being within normal range.

2.2. Measurements

The clinical data recorded included age, sex, total surface area of the burn, associated injury, inhalation injury grade by bronchoscopy, lung injury score, initial arterial partial pressure of oxygen to inspired oxygen fraction (*P*/*F*) ratio, *P*/*F* ratio at 24 h after admission, initial arterial blood gas analysis, initial plasma carboxyhemoglobin (CO-Hb) level, time between smoke inhalation and CT, initial 24-h fluid volume, total number of ventilator days, duration of ICU stay, development of pneumonia, and patient outcome. We analyzed the predictive value of objective variables having ventilation days as the explanatory variable. We defined pneumonia as consolidation on the chest X-ray film, body temperature of >38 °C or <36 °C, white blood cell count of ≥12,000 cells/mm^3 or ≤4000 cells/mm^3, and positive culture of sputum except for normal respiratory/oral flora or mixed respiratory/oral flora or the equivalent. Extubation criteria were adequate mentation and the capacity to maintain an adequate *P*/*F* ratio of >200 with the use of simple oxygen delivery devices ($F_IO_2 < 0.4$ and with a low level of positive end-expiratory pressure [PEEP] of <5 cm H_2O).

2.3. CT assessment

A thoracic high-resolution CT scan was obtained in each patient within a few hours of admission to our hospital. CT images were obtained on a SOMATOM CT system (Siemens, Germany). All CT images were non-contrast-enhanced 1.5-mm helical scans taken at 120 kV and 150 mA. Scans were obtained at end-inspiration by using a 1-s scan time and a high spatial frequency. Airway wall dimensions were calculated using a validated method (11). The images of each bronchus examined were approximately perpendicular to the bronchial axis from the top of the aortic arch to 2 cm above the right hemi-diaphragm. The images were viewed on a workstation using a magnification of 5, and measurements of the overall long diameter (OL) and short diameter (OS) and the internal long diameter (IL) and short diameter (IS) of the bronchi were made using electronic calipers, with wall thickness (T) being derived from these measurements using the formula $T = (OL - IL)/2 + (OS - IS)/2)/2$ (Fig. 1). All bronchi of more than 1.5 mm in diameter clearly seen in cross-section were measured, and a total 15 bronchi were measured per subject.

Luminal area (A_i) in mm^2 and total airway area (A_o) were calculated from overall bronchial and lumen diameters, respectively, using the formula $A = \pi r^2$. We assessed both the ratio of airway wall thickness to total bronchial diameter (*T*/*D* ratio) and the percentage luminal area ($LA\% = (A_i/A_o) \times 100$).

2.4. Bronchoscopy and scoring system

Bronchoscopy was performed according to a standardized protocol within 12 h of admission in all SII patients. The degree of bronchial mucosal injury was evaluated using a standardized