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● *Original Contribution*

PERFORMANCE OF LUNG ULTRASOUND IN DETECTING PERI-OPERATIVE ATELECTASIS AFTER GENERAL ANESTHESIA

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Abstract—The aim of this prospective observational study was to evaluate the performance of lung ultrasound (LUS) in detecting post-operative atelectasis in adult patients under general anesthesia. Forty-six patients without pulmonary comorbidities who were scheduled for elective neurosurgery were enrolled in the study. A total of 552 pairs of LUS clips and thoracic computed tomography (CT) images were ultimately analyzed to determine the presence of atelectasis in 12 prescribed lung regions. The accuracy of LUS in detecting peri-operative atelectasis was evaluated with thoracic CT as gold standard. Levels of agreement between the two observers for LUS and the two observers for thoracic CT were analyzed using the κ reliability test. The quantitative correlation between LUS scores of aeration and the volumetric data of atelectasis in thoracic CT were further evaluated. LUS had reliable performance in post-operative atelectasis, with a sensitivity of 87.7%, specificity of 92.1% and diagnostic accuracy of 90.8%. The levels of agreement between the two observers for LUS and for thoracic CT were both satisfactory, with κ coefficients of 0.87 ($p < 0.0001$) and 0.93 ($p < 0.0001$), respectively. In patients in the supine position, LUS scores were highly correlated with the atelectasis volume of CT ($r = 0.58$, $p < 0.0001$). Thus, LUS provides a fast, reliable and radiation-free method to identify peri-operative atelectasis in adults. (E-mail: ouyangwen133@vip.sina.com)

Key Words: **Lung ultrasound, Thoracic computed tomography, Atelectasis, General anesthesia.**

INTRODUCTION

Atelectasis, one of the most prevalent post-operative pulmonary complications of general anesthesia, occurs mainly in the dependent parts of the lung in 85%–90% of patients undergoing general anesthesia (Martin et al. 2015). The development of atelectasis can impair gas exchange, leading to hypoxemia (Hedenstierna and Rothen 2012) and possibly other pulmonary complications, including pneumonia and acute lung injury (Duggan and Kavanagh 2007; Restrepo and Braverman 2015), which are associated with increased in-hospital mortality and length of stay in the intensive care unit (ICU) (Lawrence et al. 1995; Serpa Neto et al. 2014). However, atelectasis is rarely detected early partially because of the lack of sensible and practical bedside methods for lung imaging.

Although thoracic computed tomography (CT) has been the gold standard for lung imaging, radiation exposure and the risks associated with transporting unstable patients make this approach suboptimal for routine examination. Lung ultrasound (LUS) has been proven to outperform chest radiography (CXR) in diagnosing common pulmonary pathologic abnormalities, such as pneumothorax, pleural effusion and inter-stitial syndrome (Xirouchaki et al. 2011). Indeed, LUS provides a rapid, reliable and radiation-free approach to evaluation of critically ill patients with dyspnea at the bedside (Manson and Hafez 2011). As LUS is easy to perform and can be repeated, it may be useful for both diagnostic imaging and the dynamic evaluation of pathologic abnormalities (Bouhemad et al. 2010).

The aim of this prospective observational study was to evaluate the application of LUS in the detection of post-operative atelectasis in adult patients undergoing

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general anesthesia, with thoracic CT as the reference standard.

METHODS

Ethics, registration and informed consent

This study was approved by the institutional review board of The Third Xiangya Hospital of Central South University, Changsha, China, on 20 January 2015. The study was registered at www.ClinicalTrials.gov with Identification No. NCT02355405. Written informed consent was obtained from each patient before surgery.

Patients

Adult patients admitted to the Department of Neurosurgery who were scheduled for elective craniotomy or trans-sphenoidal surgery for intra-cranial tumors were consecutively included in this prospective observational study if they fulfilled the inclusion criteria. All included patients were within American Society of Anesthesiologists' (ASA) physical status classes I–III, and the surgical procedure was expected to take 2 h or longer. Patients were ineligible if they were pregnant; had a body mass index greater than 30 kg/m^2; had received general anesthesia and mechanical ventilation within 2 wk before surgery; had pulmonary comorbidities with abnormal thoracic radiography (presented as pulmonary parenchyma or/and inter-stitial lesions); had previously undergone thoracic procedures (thoracic drain, thoracotomy or thoracoscopy); or had recently developed pneumothorax or subcutaneous emphysema during the peri-operative period. Patients who declined post-operative CT scans were excluded from the study.

Anesthesia and mechanical ventilation

All included patients were pre-oxygenated with 100% oxygen for 5 min before the induction of anesthesia. Anesthesia was induced by intra-venous administration of midazolam 0.04–0.05 mg/kg, sufentanil 0.4–0.5 μg/kg and etomidate 0.1–0.3 mg/kg. Vecuronium 0.08–0.12 mg/kg was given to facilitate endotracheal intubation. After the induction of anesthesia, patients were kept in a supine position or turned to a contralateral prone position according to the surgical procedure. Anesthesia was maintained with a continuous intra-venous infusion of propofol, remifentanil and atracurium combined with inhaled sevoflurane. For patients who required intra-operative neurophysiologic monitoring, neuromuscular blocking drugs were administered only for the induction of anesthesia.

Intra-operative ventilation was set in a volume-control ventilation mode with a tidal volume (V_t) of 6–8 mL/kg of predicted body weight (PBW), a fraction of inspired oxygen of 0.6 to 1.0, a respiratory frequency of 12–15 breaths/min to maintain a P_aCO_2 of 30–35 mm Hg according to blood gas analysis, and 0 cm H_2O of positive end-expiratory pressure without recruitment maneuvers (RMs) or 5 cm H_2O of PEEP plus RMs. After surgery and the return of spontaneous breathing, patients were transferred to the post-anesthesia care unit (PACU) for further anesthesia recovery and extubation. In the PACU, the patient inhaled oxygen through a nasal cannula at 2–4 L/min; mechanical ventilation was ready for patients with an S_pO_2 <90%; and the settings were synchronized for intermittent mandatory ventilation (SIMV) mode with a fraction of inspired oxygen of 0.3, pressure support of 8 cm H_2O and the same levels of V_t and PEEP as in the intra-operative setting. Extubation was carried out after a successful spontaneous breathing test.

If needed, other peri-operative interventions, including analgesia and fluid management, were prescribed by the anesthetist and the surgeon in charge of the patient.

LUS investigations and scores

Patients underwent LUS investigations in two specific periods: 5 to 10 min before the induction of anesthesia and during the period after the surgical procedure was completed and the patient returned to spontaneous breathing in the operating room. LUS was performed using an M-Turbo and S-Series portable device (Sonosite, Seattle, WA, USA) with a 5- to 1-MHz convex probe. The detailed imaging settings on the machine were as follows: "AUTO GAIN," "GENeneral" penetrability with "Harmonics" and "MultiBeam" both off. Anterior and lateral parts of the lung were examined with the patient in the supine position, whereas posterior parts and the posterolateral alveolar and/or pleural syndrome (PLAPS) area were examined with the patient slightly rotated into the lateral position (Fig. 1). All investigations were performed in a systematic protocol by the same anesthetist, who was trained in LUS operation; all clips were exported to a portable hard drive for analysis.

According to the systematic protocol for LUS examination (Bouhemad et al. 2015), each hemithorax was divided into anterior, lateral and posterior regions using anterior and posterior axillary lines as anatomic landmarks, and each region was further divided into two parts: superior and inferior. Considering that the posterosuperior parts of the lung are located mostly behind the scapula, these two parts were omitted from our examinations. As reported in our pilot study and in other studies, peri-operative atelectasis affects predominantly the dependent and dorsal parts of the lung directly above the diaphragm (Cai et al. 2007; Volpicelli et al. 2012); therefore, we added a lateral subposterior investigation of the PLAPS area to comprehensively detect