CHEST

The Effect of Respiratory Motion on Pulmonary Nodule Location During Electromagnetic Navigation Bronchoscopy

Alexander Chen, MD; Nicholas Pastis, MD, FCCP; Brian Furukawa, MD; Gerard A. Silvestri, MD, FCCP

BACKGROUND: Electromagnetic navigation has improved the diagnostic yield of peripheral bronchoscopy for pulmonary nodules. For these procedures, a thin-slice chest CT scan is performed prior to bronchoscopy at full inspiration and is used to create virtual airway reconstructions that are used as a map during bronchoscopy. Movement of the lung occurs with respiratory variation during bronchoscopy, and the location of pulmonary nodules during procedures may differ significantly from their location on the initial planning full-inspiratory chest CT scan. This study was performed to quantify pulmonary nodule movement from full inspiration to end-exhalation during tidal volume breathing in patients undergoing electromagnetic navigation procedures.

METHODS: A retrospective review of electromagnetic navigation procedures was performed for which two preprocedure CT scans were performed prior to bronchoscopy. One CT scan was performed at full inspiration, and a second CT scan was performed at end-exhalation during tidal volume breathing. Pulmonary lesions were identified on both CT scans, and distances between positions were recorded.

RESULTS: Eighty-five pulmonary lesions were identified in 46 patients. Average motion of all pulmonary lesions was 17.6 mm. Pulmonary lesions located in the lower lobes moved significantly more than upper lobe nodules. Size and distance from the pleura did not significantly impact movement.

CONCLUSIONS: Significant movement of pulmonary lesions occurs between full inspiration and end-exhalation during tidal volume breathing. This movement from full inspiration on planning chest CT scan to tidal volume breathing during bronchoscopy may significantly affect the diagnostic yield of electromagnetic navigation bronchoscopy procedures.

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ABBREVIATIONS: 3-D = three-dimensional; ENB = electromagnetic navigation bronchoscopy; EXP = expiratory; INSP = inspiratory

AFFILIATIONS: From the Division of Pulmonary and Critical Care Medicine (Dr Chen), Washington University School of Medicine, St. Louis, MO; and the Division of Pulmonary and Critical Care Medicine (Drs Pastis, Furukawa, and Silvestri), Medical University of South Carolina, Charleston, SC.

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CORRESPONDENCE TO: Alexander Chen, MD, Division of Pulmonary and Critical Care Medicine, Washington University School of Medicine, 660 S Euclid Ave, Campus Box 8052, St. Louis, MO 63110; e-mail: achen@dom.wustl.edu

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With the increasing use of chest CT scans for a myriad of chest disorders, solitary pulmonary nodules have become a common finding. In addition, the national lung cancer screening trial demonstrated a significant reduction in lung cancer-related mortality among high-risk patients screened with low-dose chest CT scans.[1] With the potential widespread adoption of lung cancer screening, physicians can expect to see patients with increasing numbers of pulmonary nodules presenting to their practices, some of whom will require diagnostic procedures.

Technological advancements, such as electromagnetic navigation bronchoscopy (ENB), have improved the diagnostic yield of bronchoscopy over conventional bronchoscopic approaches.[2,3] Several studies, including a large meta-analysis, have demonstrated diagnostic yields of 67% using ENB.[4] This offers a significant improvement over conventional bronchoscopic techniques, which have traditionally had a diagnostic yield of $< 20\%$ for smaller, peripheral lung nodules.[5,6] In spite of growing experience with navigation technology, further improvements in diagnostic yield have not been observed.

Electromagnetic navigation makes use of a reference, thin-slice, chest CT scan to create a virtual airway reconstruction. An electromagnetic sensor advanced into the airways during bronchoscopy is then paired with the airway reconstruction using registration points, external fiducial markers, or both.[7] Prior to bronchoscopy, the reference CT scan is obtained by instructing patients to take a deep breath and hold at full inspiration, where the physical state of the lung approximates total lung capacity.

One observation is that bronchoscopy is a dynamic process performed in patients who are breathing either spontaneously or in a controlled fashion under the influence of procedural sedation. Accordingly, targeted lung nodules are subject to movement due to respiratory motion during bronchoscopy, where the physical state of the lung is likely closer to tidal volume than to total lung capacity.

Pulmonary nodule movement from full inspiration to end-exhalation during tidal volume breathing is unknown and has not been described. The purpose of this study is to quantify pulmonary lesion movement within the lung between full inspiration and end-exhalation with tidal volume breathing for electromagnetic navigation bronchoscopy procedures.

Materials and Methods

This was a retrospective review of deidentified patient datasets of electromagnetic navigation cases. Individual datasets consisted of full inspiratory chest CT scans and end-expiratory chest CT scans performed during tidal volume breathing prior to electromagnetic navigation procedures. This study was evaluated by the Institutional Review Board and was considered exempt from full review, as no patient identification was associated with the datasets.

CT Scan Protocol

CT scans were performed using a slice thickness ranging from 0.5 to 1.0 mm and a scan time of 10 to 15 s. Patients were instructed to breathe normally (at tidal volume) and then take a deep breath (at full inspiration) with arms raised above their head (inspiratory CT scan). Patients were then instructed to breathe normally, and a CT scan was taken while patients performed a breath hold at the end of expiration (expiratory CT scan) during normal tidal breathing with arms to their sides. These two scans were used as the inspiratory (INSP)-expiratory (EXP) CT scan pair. The same pulmonary lesion was identified on each INSP-EXP CT scan pair, and two independent investigators (A. C., B. F.) confirmed that the pulmonary lesion identified on each INSP-EXP CT scan pair represented the same lesion.

INSP-EXP CT Scan Pairing

INSP-EXP CT scan pairs were aligned using two methods to determine the respiratory motion between the INSP state and EXP state. The INSP-EXP CT scan pairs were first aligned using the main carina as a common point of translation between datasets, and the physical three-dimensional (3-D) motion was calculated (total movement). Motion in the X direction equated to medial and lateral movement, motion in the Y direction equated to anterior and posterior movement, and motion in the Z direction equated to cranial and caudal movement within each patient. Anterior and posterior points were defined based on their location relative to the main carina. Lumen registration was also implemented between the INSP and EXP scan using the airway trees in each of the scans to compensate for the shape change of the lung and associated airways. Airways were segmented from the INSP scan to provide a robust airway tree, and nonrigid deformable registration was applied to the dataset to define the segmented airway tree in the EXP scan using the SPiN Planning 2.0 workstation (Veran Medical Technologies). Lumen registration was then applied to align the INSP and EXP datasets and calculate the nonlinear 3-D motion of the lung.

Measurements

Pulmonary lesion size was recorded as the largest diameter on axial CT imaging, and movement was measured from the lesion center during full inspiration to the nodule center at end-exhalation during tidal volume breathing. Respiratory movement in the X, Y, and Z directions was calculated as a vector where movement $(m) = \sqrt{(x^2 + y^2 + z^2)}$; this was reported as the physical 3-D movement of the lung lesion. Lesion movement reported is based on the physical motion of lesions between full inspiration and end-exhalation during tidal volume breathing when the inspiratory scan is overlaid upon the end-exhalation scan using the main carina as the common point of translation.