# Automated Detection of Small Pulmonary Nodules in Whole Lung CT Scans[1]

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**Rationale and Objectives.** The objective of this work was to develop and evaluate a robust algorithm that automatically detects small solid pulmonary nodules in whole lung helical CT scans from a lung cancer screening study.

**Materials and Methods.** We developed a three-stage detection algorithm for both isolated and attached nodules. The algorithm consisted of nodule search space demarcation, nodule candidates' generation, and a sequential elimination of false positives. Isolated nodules are nodules that are surrounded by lung parenchyma, whereas attached nodules are connected to large, dense structures such as pleural and/or mediastinal surface. Two large well-documented whole lung CT scan databases (Databases A and B) were created to train and test the detection algorithm. Database A contains 250 sequentially selected scans with 2.5-mm slice thickness that were obtained at Weill Medical College of Cornell University. With equipment upgrade at this college, a second database, Database B, was created containing 250 scans with a 1.25-mm slice thickness. A total of 395 and 482 nodules were identified in Databases A and B, respectively. In both databases, the majority of the nodules were isolated, comprising 72.1% and 82.3% of nodules in Databases A and B, respectively.

**Results.** The detection algorithm was trained and tested on both Databases A and B. For isolated nodules with sizes 4 mm or larger, the algorithm achieved 94.0% sensitivity and 7.1 false positives per case (FPPC) for Database A (2.5 mm). Similarly, the algorithm achieved 91% sensitivity and 6.9 FPPC for Database B (1.25 mm). The algorithm achieved 92% sensitivity with 17.4 FPPC and 89% sensitivity with 5.5 FFPC for attached nodules with sizes 3 mm or larger in the Database A (2.5 mm) and Database B (1.25 mm), respectively.

**Conclusion.** The developed algorithm achieved practical performance for automated detection of both isolated and the more challenging attached nodules. The automated system will be a useful tool to assist radiologists in identifying nodules from whole lung CT scans in a clinical setting.

**Key words.** CT; pulmonary nodules; compute-aided detection (CAD); segmentation; classification; lung cancer screening.



Lung cancer is the leading cause of cancer-related death, accounting for 29% of all cancer deaths in the United States. (1) According to the American Cancer Society, (1) there will be approximately 162,460 lung cancer–related deaths in the United States in 2006. Despite improvements in lung cancer treatment over the last several decades, about 95% of the people diagnosed with lung cancer eventually died of it. (1) However, the Early Lung Cancer Action Project (ELCAP) (2,3) showed that lung cancer can be identified early in more than 80% of those diagnosed with it, and it is well known that treatment of early stage lung cancer results in a substantially higher overall cure rate. The ELCAP study also compared CT with chest radiography and found that 83% of those diagnosed with early-stage lung cancer were missed on the

**Acad Radiol 2007;** 14:579–593

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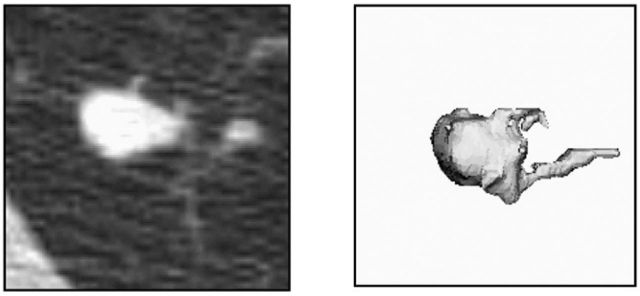
doi:10.1016/j.acra.2007.01.029



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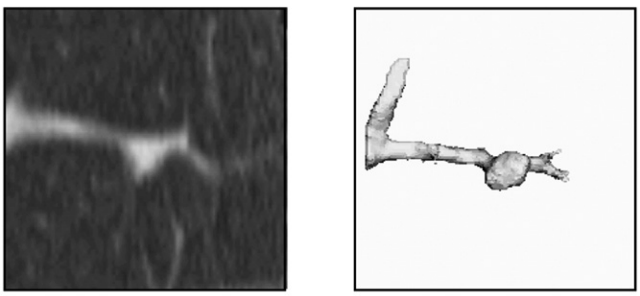

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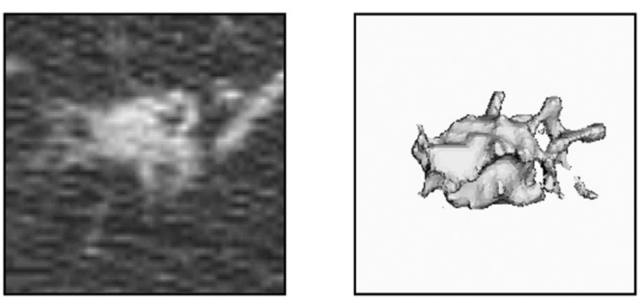
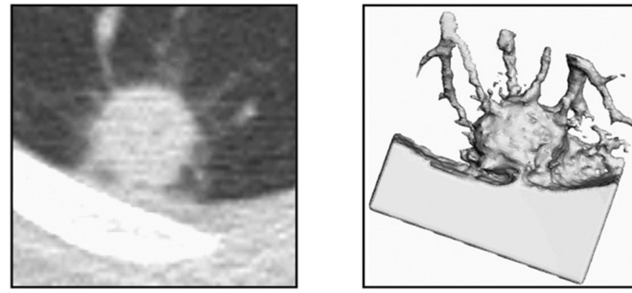


c.

**Figure 1.** Isolated pulmonary nodule examples showing 2D slice and 3D rendered images. (**A**) Nodule mainly surrounded by lung parenchyma. (**B**) Nodule attached to a blood vessel. (**C**) Large nodule with several vessel connections in streaking artifact-affected region.



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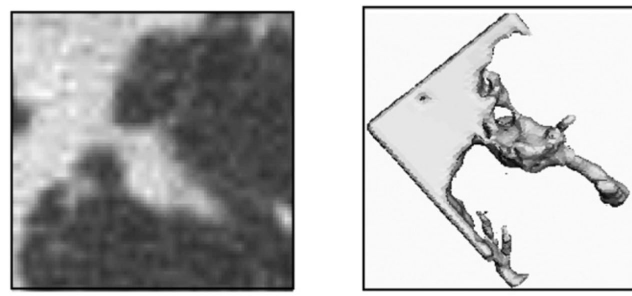

b.

**Figure 2.** Attached pulmonary nodule examples showing 2D slice and 3D rendered images. (**A**) Nodule attached to the pleural surface. (**B**) Nodule attached to the mediastinal surface.

chest radiographs. In the lung cancer screening process, radiologists analyze whole lung CT images of asymptomatic patients, searching for nodules. CT scanners produce many thin-slice axial images per patient. Hence, radiologists are confronted with the overwhelming task of interpreting a massive quantity of images. This has necessitated the development of a computer-aided diagnosis (CAD) system.

The majority of pulmonary nodules are of isolated type. Isolated nodules have no attachments to a large solid structure and are mainly surrounded by lung parenchyma. Figure 1A shows a large nodule surrounded by the lung parenchyma. Isolated nodules have, in general, a spherical shape. However, the spherical shape may be distorted by other small lung structures such as vessels, bronchi, scars, and regions of morbidity. For example, the shape of the isolated nodule in Figure 1B is distorted by a blood vessel attached to it. Moreover, the intensity distribution of isolated nodules may be perturbed by the occurrence of artifacts in the CT image. An example of a large nodule in a region with a high streaking artifact is shown in Figure 1C.

Nodules that are attached to other structures present a more challenging problem than isolated nodules. These types of nodules are attached to dense structures that are large compared with the pleural or mediastinal surface. Nodules attached to the pleural surface are the most prevalent of this group; Figure 2A shows an example of such a nodule. This particular nodule has significant vessel connections in addition to the pleural surface attachment. Our database includes nodules attached to the complex irregularly shaped mediastinal surface. This type of nodule is the most challenging case for automated detection. The surface irregularity, mainly caused by pulmonary vessels entering the lung parenchyma, forms nodule-like indentations. These indentations make designing a detection algorithm for nodules attached to the mediastinal surface challenging. A sample case is shown in Figure 2B.

Armato et al. (4) implemented a computerized scheme that uses two-dimensional (2D) and three-dimensional