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The advantage of digital tomosynthesis for pulmonary nodule detection concerning influence of nodule location and size: a phantom study

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AIM: To investigate the advantage of digital tomosynthesis (DTS) over chest radiography (CXR) and dual-energy subtraction radiography (DES) for pulmonary nodule detection according to the location and size of solid simulated pulmonary nodules (SPNs).

MATERIALS AND METHODS: Ninety-six SPNs of variable sizes were inserted into eight different regions of a lung phantom. These regions were further classified into two groups of danger and non-danger zones based on anatomical location influencing the detection of pulmonary nodules. The 96 cases with inserted SPNs and an additional nodule-free 96 control cases all underwent CXR, DES, and DTS examinations. Three observers independently reviewed all the images. The jackknife alternative free-response receiver operating characteristic was used to analyse diagnostic performance for each technique.

RESULTS: DTS was superior to CXR and DES for detection of smaller SPNs, except in the retrodiaphragmatic and apical regions. DTS outperformed CXR and DES for detection of larger SPNs in the paramediastinal region. For 5- and 8-mm SPNs, DTS was superior to CXR and DES in the apical, paramediastinal and lateral pulmonary regions. In the retrodiaphragmatic region, the three techniques showed similar diagnostic performance regardless of the SPN size. DES was similar to DTS for detection of 8-mm SPN in the apical region. For 10- and 12-mm SPNs, CXR and DES showed similar diagnostic performance to DTS in the apical and lateral pulmonary regions; however, DTS was superior to CXR and DES in the paramediastinal region.

CONCLUSIONS: DTS significantly improved the capability to detect synthetic pulmonary nodules compared with CXR and DES, for detection of smaller nodules in the apical, paramediastinal, and lateral pulmonary regions, and larger nodules located in the paramediastinal region in a thoracic phantom.

Introduction

Chest radiography (CXR) is a basic technique for the investigation of pulmonary disease and is frequently used because of its economical merit and accessibility. Several studies have reported that the accepted error rate for the

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detection of lung cancer ranged from 10 to 50%, and there has been insufficient improvement over the past decades.[1] Various obstacles influence the ability for detection of nodules in chest radiography. Above all, contrast difference between the nodule and surrounding area affects the rate of nodule detection: a poorly penetrated area of the lung (subpleural, retrodiaphragmatic, retrocardiac, and paramediastinal), superimposed structures, and complexity of the area could have a major impact on nodule detection.[2–5] As a result, nodule location and the anatomical background have been identified as major contributing factors for the detection of nodules.

Two representative technical developments in projection radiography for evaluating pulmonary nodules are digital tomosynthesis (DTS) and dual-energy subtraction (DES). The DES technique, which can remove overlying bone structures to create soft-tissue selective images, has emerged to enhance the visualisation of pulmonary nodules; however, reliable results have been confined only to nodules overlapping with rib or clavicle and it could not reduce the visual clutter from the overlying soft tissue.[6] DTS provides an arbitrary number of image planes throughout the entire chest by reconstruction of a set of projection radiographs at different angles during a limited range of X-ray tube movement. This technique enables improvement of nodule detection by eliminating the visual clutter of overlying anatomy and providing depth localisation.[7,8] Therefore, DTS could allow the observer to detect pulmonary nodules more accurately than CXR and DES by removing the effect of anatomical location; however, there are few studies evaluating the diagnostic performance of DTS to detect pulmonary nodules regarding location.[9–11]

The hypothesis of the present study was that DTS outperforms CXR and DES to detect pulmonary nodules located in danger zones than in non-danger zones. Therefore, the purpose of the present study was to investigate the advantages of DTS compared to CXR and DES for the detection of solid simulated pulmonary nodules (SPNs) especially focusing on the influence of nodule location and size.

Materials and methods

A total of 192 sets of examinations (each set comprised of three examination techniques; CXR, DES, and DTS) were prepared. Half (96/192) of the examinations contained SPNs (from 1 to 4) and the other half of the examinations were nodule-free.

CXR, DES, and DTS

All examinations were performed using commercially available digital radiographic systems with CsI/a-Si flat-panel detector system (Discovery XR 650, GE Healthcare, Chalfont St Giles, UK). A routine chest posteroanterior view was obtained at a tube voltage of 120 kVp, 500 mA with automatic exposure control (AEC) speed 125, source to image distance of 180 cm. The detector had an image size of 41×41 cm field of view. DES imaging was obtained in a dual-exposure technique between the 120 and 60 kVp energy exposures. DES chest images were composed with the "trio" format that included standard posteroanterior radiography, a soft-tissue selective image, and a bone-selective image. Each image was acquired at 250 mA and a 20–25 ms exposure time for low voltage X-rays and at 200 mA and ≤25 ms exposure time for high-voltage X-rays. Chest DTS examination was performed with VolumeRAD (GE Healthcare) with a setting of 100 kVp, 320 mA with AEC speed 400, 0.3 mm copper filer, 1:5 dose ratio, and source to image distance of 180 cm. The X-ray tube moved continuously in a vertical and linear direction with a tube angle range of ±17.5°, around the standard orthogonal posteroanterior projection for approximately 11.4 seconds. A total of 60 low-dose projection images were acquired with a tube angle between −15° and 15°, and 53 coronal reconstruction images were obtained with 5 mm thickness without overlap.[12]

Thoracic phantom and SPNs

The anthropomorphic chest phantom (Lungman, Kyoto Kagaku, Kyoto, Japan) composed of life-size main body with inner component including mediastinum, pulmonary vasculature and abdomen block was used. Soft-tissue materials and synthetic bones were made of polyurethane and epoxy resin, respectively. Synthetic nodules simulated by polyurethane and hydroxyapatite spheres were solid types (approximately 100 HU at 120 kVp). Synthetic nodules consisted of four different sizes (5, 8, 10, and 12 mm).

Lung fields were divided on chest radiography into eight regions based on anatomy as follows; regions 1 and 2 (apical), above the lower margin of the third rib posterior arch; regions 3 and 4 (paramediastinal), between the apical and retrodiaphragmatic regions, medial aspect of 3 cm lateral to the paraverbral line; regions 5 and 6 (lateral pulmonary), mid to outer region of lung field; regions 7 and 8 (retrodiaphragmatic), inferior to 1 cm above the diaphragmatic line. Furthermore, these regions were classified into two groups of danger zone and non-danger zone based on anatomical location influencing the detection of pulmonary nodules. Regions 1, 2, 3, 4, 7, and 8 were defined as danger zones, and regions 5 and 6 were classified as non-danger zones (Fig 1).[4,13,14] Ninety-six cases with SPNs (from 1 to 4) were prepared and the number, size, and location of the SPNs were randomly arranged. Placement of the SPNs was done by randomisation using an online Research Randomizer program (http://www.randomizer.org). Therefore, from 1 to 4 SPNs (combination of four different diameters) were placed at randomly assigned regions in the chest phantom by attaching them to pulmonary vessels using double-sided tape. Finally, a total of 240 nodules (61 nodules of 5 mm diameter, 64 nodules of 8 mm diameter, 59 nodules of 10 mm diameter, and 56 nodules of 12 mm diameter) were defined as true-positive lesions. With regard to nodule location, 175 nodules were placed in the danger zones (64 nodules in the apical, 58 nodules in the paramediastinal, and 53 nodules in the retrodiaphragmatic regions) and 65 nodules were located in non-danger zones (the lateral pulmonary region). The mean number of nodules per case was 2.5 in 96 cases having nodules. In order to provide 96

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