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CT patterns of fungal pulmonary infections of the lung: Comparison of standard-dose and simulated low-dose CT

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ABSTRACT

Purpose: To assess the effect of radiation dose reduction on the appearance and visual quantification of specific CT patterns of fungal infection in immuno-compromised patients.
Materials and methods: Raw data of thoracic CT scans (64×0.75 mm, 120 kVp, 300 reference mAs) from 41 consecutive patients with clinical suspicion of pulmonary fungal infection were collected. In 32 patients fungal infection could be proven (median age of 55.5 years, range 35–83). A total of 267 cuboids showing CT patterns of fungal infection and 27 cubes having no disease were reconstructed at the original and 6 simulated tube currents of 100, 40, 30, 20, 10, and 5 reference mAs. Eight specific fungal CT patterns were analyzed by three radiologists: 76 ground glass opacities, 42 ground glass nodules, 51 mixed, part solid, part ground glass nodules, 36 solid nodules, 5 lobulated nodules, 6 spiculated nodules, 14 cavitary nodules, and 37 foci of air-space disease. The standard of reference was a consensus subjective interpretation by experts whom were not readers in the study.
Results: The mean sensitivity and standard deviation for detecting pathological cuboids/disease using standard dose CT was 0.91 ± 0.07. Decreasing dose did not affect sensitivity significantly until the lowest dose level of 5 mAs (0.87 ± 0.10, $p = 0.012$). Nodular pattern discrimination was impaired below the dose level of 30 reference mAs: specificity for fungal 'mixed nodules' decreased significantly at 20, 10 and 5 reference mAs ($p < 0.05$). At lower dose levels, classification drifted from 'solid' to 'mixed nodule', although no lesion was missed.
Conclusion: Our simulation data suggest that tube current levels can be reduced from 300 to 30 reference mAs without impairing the diagnostic information of specific CT patterns of pulmonary fungal infections.

1. Introduction

Opportunistic fungal infections of the lung are a common complication in immunocompromised patients and are related to a high morbidity and mortality [1]. The clinical diagnosis of fungal pulmonary infection is based on host factors (i.e. immune-status, neutropenic fever), microbiological evidence of infection, and on specific CT patterns [1–3]. CT plays an important role in the diagnosis and management of patients with pulmonary fungal infections due to its ability to depict disease at an early stage. CT is also the imaging modality of choice to monitor response to antifungal treatment. Serial follow-up CT scans, however, result in accumulation of radiation exposure, which is a particular concern in young patients such as patients treated with bone marrow transplantation who also have a substantial risk of recurrence of infection.

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Multiple studies have demonstrated the feasibility of lowering the radiation dose in thoracic CT without substantial loss of diagnostic information despite increased image noise [4–9]. Image quality of low-dose chest CT has been shown to be satisfactory for mediastinal and lung parenchyma in patients with cancer (140 kV, 60 mAs) [4], and in the evaluation of bronchiectasis in patients with cystic fibrosis, (120 kV, 70 mAs) [5]. Tack et al. [6] reported that a simulated reduction of tube current to as low as 10 mAs does not influence the accuracy of CT in the detection of pulmonary embolism and Bankier et al. reported that the tube current can be reduced to 20 mAs without impairing the visual quantification of air trapping at expiratory chest CT [7].

Ground glass opacities (GGO) – with or without associated other pulmonary abnormalities – are important imaging features for the diagnosis and monitoring of active fungal infections on chest CT. Due to the inherently low contrast of GGO these lesions are more difficult to detect in the presence of increased image noise, which may limit the application of dose reduction strategies in this setting. To our knowledge, the effect of dose reduction on the conspicuity of specific CT patterns associated with pulmonary fungal infections has not been described. The purpose of this study was to visually assess and quantify the effect of simulated radiation dose reduction on the appearance of CT patterns of fungal infections in immunocompromised patients.

2. Materials and methods

2.1. Patients

Raw data of thoracic CT scans from forty-one consecutive outpatients referred for the CT evaluation of suspected fungal infections of the lung were enrolled in this HIPPA compliant study between May 2008 and February 2009. The study protocol was approved by the local IRB and informed consent was waived due to the retrospective nature of data analysis.

Our study population consisted of 32 patients in whom fungal infection was proven by histological tissue sampling, positive cultivation or based on improvement of clinical and radiological symptoms within 2 weeks after antifungal therapy and 9 patients without subsequent evidence for fungal infection. All patients were immunocompromised, 26 post bone-marrow-transplant, 13 post organ transplant and 2 cancer patients under chemotherapy. There were 23 men and 18 women with a median age of 54 years (range 35–83) and a median body weight of 72 kg (range 42–120). The median scan length of the chest was 36.2 cm (range 28.5–39.9), while the median lung length was 25 cm (range 17.4–31.6).

2.2. Image acquisition

All patients were scanned in the supine position from the lung apex to the base of the chest at withheld full inspiration. No intravenous contrast was applied. Image data were obtained with a 64 multi-detector row CT scanner (Somatom Sensation, Siemens, Erlangen, Germany) with a detector configuration of 32×0.6 mm, and flying focal spot technology, at a pitch of 2.0. Tube voltage was set to 120 kVp. Automated tube current modulation (Care Dose®, Siemens, Erlangen, Germany) with 300 reference mAs (ref. mAs) was used to individualize radiation exposure to patient size. Tube current adaptation was set to "average" for both decrease for slim and increase for obese patients/regions to minimize the influence of the variable weight on image quality. Routine 512×512 matrix clinical images were reconstructed with 1 mm section thickness at 0.8 mm intervals using a sharp (B46) kernel. Raw data of the CT scans were stored on the scanner and offline for subsequent generation of simulated low dose scans.

2.3. Reconstruction of simulated low dose scans

There is a mathematical correlation between tube current time and image noise. This can be exactly calculated [10]. The calculated noise is then superimposed on raw data before applying the back-projection and the filters/kernels. CT raw-data of the 41 scans was used to reconstruct 6 additional image datasets at simulated low radiation dose levels. Computer calculated noise was superimposed on the original raw data by using validated CT software (Somatom Noise+ V5.Obeta, 2006 Siemens, Erlangen, Germany) [10]. Tube currents of 100, 40, 30, 20, 10 and 5 ref. mAs were simulated. This resulted in 7 data sets per patient for subsequent image analysis.

2.4. Expert-derived standard of reference

Since pulmonary fungal infections commonly involve multiple lobes and since different CT patterns of fungal infections may coexist in one individual patient, images were analyzed on isolated CT findings rather than on a per patient evaluation. A consensus panel of two thoracic radiologists not involved in the observer study, with 9 and 12 years experience in the interpretation of chest CT, respectively, established the standard of reference by identifying individual CT findings suggesting pulmonary fungal infection on the original CT images (300 ref. mAs). All typical pathological CT findings of fungal infections in a patient were identified and cuboidal regions of interest ($3\ \text{cm} \times 3\ \text{cm} \times 1.5\ \text{cm}$ cuboidal volumes) containing only one specific CT pattern were selected by transferring its center coordinates to the lung nodule evaluation platform (LNEP, as described in detail below). Cubes were selected from regions without motion or beam hardening artifacts. A total of 267 cuboids showing CT patterns of fungal infections were selected for subsequent image analysis (mean 8 cuboids per patient; range 3–15). A total of 27 cuboids of the 9 patients having no disease were randomly selected and added for image analysis. The greatest dimension of each CT finding was measured with digital calipers.

2.5. Image analysis

Lung lesions were interpreted on a dedicated, non-commercially available lung nodule evaluation platform (LNEP) that featured automated display of transverse cross sections in a stacked cine mode of a cuboidal region of interested. LNEP was installed on a PC workstation (Dell E520, 2.1 GHz, Intel Core 2 Duo, 4 GB RAM) with a 20 in. LCD display (Dell Ultrasharp, 1600×1200 pixels). Ambient light conditions were similar to our clinical reading conditions, as well as the display window settings (window center −600 HU and width 1500 HU) were kept constant for all reading sessions and radiologists.

2.6. Interpretation of simulated low dose scans

Three board-certified radiologists with 5 years (reader 1), 6 years (reader 2) and 12 years (reader 3) of experience in the interpretation of thoracic CT examinations were instructed to identify and classify the following focal CT patterns within the cuboidal regions of interest using the LNEP: 1 – ground glass opacity (GGO, increase in lung attenuation without obscuring pulmonary vessels); 2 – ground glass nodule (GGN, nodule with ground glass density); 3 – mixed nodule (mixN, nodule with a solid center and a peripheral halo of GGO of at least 1 mm thickness); 4 – solid nodule (N, well demarcated dense nodules); 5 – lobulated nodule (lN, convex outpouchings); 6 – spiculated nodule (sN, linear radiations extending from the nodule); 7 – cavitary nodule (cN, presence of gas in the nodule); 8 – air-space disease (AS, dense consolidation with positive air bronchogram); 0 – normal lung parenchyma. The descriptions of borders (4–6) were only applied in the presence of