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CLINICAL IMAGING

Pediatric chest CT radiation dose reduction: protocol refinement based on noise injection for pulmonary nodule detection accuracy

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Abstract

To establish appropriate chest computed tomography (CT) acquisition protocols that balance radiation dose and diagnostic capability in pediatric bone marrow transplant patients by assessing the accuracy of pulmonary nodule detection at simulated lower-radiation acquisitions, chest CT images from bone marrow transplant patients were reviewed by four pediatric radiologists at artificially reduced CT dose levels (0%, 30%, and 60%). Average accuracy for nodule detection in 31 randomly selected cases was 0.87 at 0% dose reduction, 0.90 at 30% reduction, and 0.86 at 60% reduction. We observed no clinically relevant difference in acceptability of images or accuracy levels with tested dose reductions to 60%.

Keywords: Pediatric; CT; Pulmonary nodules; Bone marrow transplantation; Radiation dose

1. Introduction

Given the stochastic biologic effects of low levels of ionizing radiation in diagnostic imaging [1,2], it is widely expected that all imaging centers should strive to achieve as low as possible a radiation dose for medical diagnosis. The potential additional lifetime risk of cancer incidence and death from cancer related to computed tomography (CT) has received much attention in the last decade as the utilization of CT increased substantially in America and worldwide [2–5]. Very conservative estimates suggest that each independent diagnostic CT scan potentially carries a risk of 1 in 1000 of inducing cancer over a lifetime, and there is some controversial evidence that the effects of multiple diagnostic CT scans accumulate, leading to an increased cumulative risk of cancer [6–9].

Certain patient populations deserve particular attention in our efforts to reduce radiation exposure. Pediatric patients, for example, have more radiosensitive tissues than do adults, have a longer lifetime during which radiation-induced cancer may develop, and can receive a larger whole-body dose of radiation delivered, attributable to the small body size relative to the surface entrance dose [5,9,10]. Certain diseases such as cancer, interstitial pulmonary disease, and intracranial pathologies like hydrocephalus require repeat imaging by CT. Strategies to reduce CT radiation dose in these groups are important and may include modifying the technique to reduce dose, scanning a limited region to address a very specific diagnostic question, and eliminating unnecessary examinations.

In this study, we investigate the potential to reduce radiation dose in CT of the chest in pediatric bone marrow transplantation (BMT) patients, given the frequently arising clinical concern of pulmonary infection as a complication of BMT. Nodular pulmonary opacities in these patients may represent invasive fungal infection or malignancy, which

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may necessitate subsequent follow-up chest CT. When reducing the radiation dose to the patient by modifying chest CT procedures, it is imperative that the image quality not be so compromised that pulmonary nodules go undetected. Ongoing discussions about "intelligent imaging" caution radiology centers from reducing radiation dose so much that the benefit of the study is adversely reduced [11,12]. Other groups have evaluated the effects of increasing noise on pulmonary nodule detection [13,14] using artificially introduced nodular opacities and noise on a routine chest CT and have identified limits of a radiologist's ability to detect nodules as signal-to-noise changes. Here, we retrospectively review a group of chest CT studies acquired on BMT patients at three levels of noise introduction, 0%, 30%, and 60%, using software to artificially apply noise to clinically relevant images. We compared the detection of pulmonary nodules across noise levels by three individual pediatric radiologists.

2. Methods

Institutional review board approval was obtained for this retrospective study. A search was performed using our radiology information system to identify diagnostic chest CT studies performed on pediatric patients who had undergone BMT within our institution between August 2007 and March 2009. Thirty-one of these (performed on 24 unique patients) were randomly selected to be included in this study. The indications for the studies performed included persistent fever, fever and neutropenia, follow-up of nodular opacities, follow-up of bronchiolitis, new hypoxia, and follow-up of complex pleural effusion. We recorded patient age and weight at the time of imaging.

2.1. Simulated noise addition tool

Detection performance of radiologists was evaluated for initial full-dose studies and dose-reduced studies. The dose-reduced studies were simulated using noise addition software (VCT Noise Insertion Tool, version 3.0; GE Healthcare, Waukesha, WI, USA). Li et al. [15] have validated an earlier version of this software, and their recent work has used this tool [13]. This software converts individual image slices using DICOM format (Digital Imaging and Communication in Medicine) to simulated versions at a reduced dose level (simulating an acquisition with reduced tube current). For verification of the current software version, we performed CT scans (120 kVp, 0.5-s rotation, standard filter, pitch 1.375) of an anthropomorphic torso phantom (Radiology Support Devices, Long Beach, CA, USA) with different tube current time products (300, 150, 75, 25, 5 mAs). Transaxial slices from the 300-mAs acquisition were processed with the noise addition software to generate dose-reduced versions. The simulated versions were compared with the matching dose-reduced acquisitions in terms of standard deviation of voxel values and subjective visual perception.

2.2. Lung detection study

For each patient study, standard transaxial images with 5-mm slice thickness spanning the entire chest volume were anonymized prior to noise addition. Initial full-dose images were modified using the noise addition tool to simulate noise approximating dose reduction at 0%, 30%, and 60%, leading to a total of $31\times3=93$ image volumes. These image volumes were stored in and read from a Picture Archive and Communication System (PACS) matching routine clinical review protocols. Pediatric radiologists (with 3–9 years of experience reading pediatric chest CT) interpreted the studies. The first set of images provided for review was the noisiest (60% dose reduction), followed by the 30% dose reduction and, finally, the 0% images, in order to reduce recall bias. Within each noise level, the order of the reads was randomized. The radiologist was permitted to scroll through the images on PACS at his or her own pace, with the option to use any standard image modification tools on the GE PACS, including modifying window and level and magnification of images. Of note, all images were reconstructed with a standard soft tissue kernel as the noise injection software does not accommodate images reconstructed with a lung/bone kernel.

Radiologists were instructed to review no more than 10 studies at any one sitting to avoid fatigue, and they were asked four questions to answer on a summary sheet: (1) Is the study satisfactory in diagnostic quality (yes or no)? (2) Is there a pleural effusion (yes or no)? (3) What is the number of nodular opacities seen (emphasizing that a nodular opacity is a focal opacity that could signify real disease in the clinical context of a bone marrow transplant patient), from the given choices of 0, 1, 2–4, 5–10, or >10? And finally, (4) what is the size of the smallest nodular opacity detected? Results were tabulated, and statistical analysis was performed with Matlab (MathWorks, Natick, MA, USA) and Stata 9.2 (StataCorp, College Station, TX, USA). The reference standard for the presence of disease was based on a record review performed by a fourth pediatric radiologist (with 20-year experience).

3. Results

3.1. Verification of noise addition software

Coronal views through the acquisitions of the phantom (Radiology Support Devices, Long Beach, California) at different dose levels are shown in Fig. 1. The second row in this figure presents the simulated images based on adding noise to the original 300-mAs acquisition. Analysis of the standard deviation of the CT number (Hounsfield unit) in a fixed mediastinum and lung region revealed that the simulated dose versions have, on average, 15% more noise than their matched true acquisition. This reveals that the magnitude of noise will be slightly overestimated in the simulated versions, which is in keeping with prior validation studies of the noise addition tool [15].