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Performance of adaptive iterative dose reduction 3D integrated with automatic tube current modulation in radiation dose and image noise reduction compared with filtered-back projection for 80-kVp abdominal CT: Anthropomorphic phantom and patient study

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ABSTRACT

Objectives: Evaluate the performance of Adaptive Iterative Dose Reduction 3D (AIDR 3D) and compare with filtered-back projection (FBP) regarding radiation dosage and image quality for an 80-kVp abdominal CT.

Materials and methods: An abdominal phantom underwent four CT acquisitions and reconstruction algorithms (FBP; AIDR 3D mild, standard and strong). Sixty-three patients underwent unenhanced liver CT with FBP and standard level AIDR 3D. Further post-acquisition reconstruction with strong level AIDR 3D was made. Patients were divided into two groups (< and ≧29 cm) based on the abdominal effective diameter (D_{eff}) at T12 level. Quantitative (attenuation, noise, and signal-to-noise ratio) and qualitative (image quality, noise, sharpness, and artifact) analysis by two readers were assessed and the interobserver agreement was calculated.

Results: Strong level AIDR 3D reduced radiation dose by 72% in the phantom and 47.1% in the patient study compared with FBP. There was no difference in mean attenuations. Image noise was the lowest and signal-to-noise ratio the highest using strong level AIDR 3D in both patient groups. For $D_{eff} < 29$ cm, image sharpness of FBP was significantly different from those of AIDR 3D ($P < 0.05$). For $D_{eff} \geqq 29$ cm, image quality of AIDR 3D was significantly more favorable than FBP ($P < 0.05$). Interobserver agreement was substantial.

Conclusions: Integrated AIDR 3D allows for an automatic reduction in radiation dose and maintenance of image quality compared with FBP. Using AIDR 3D reconstruction, patients with larger abdomen circumference could be imaged at 80 kVp.

1. Introduction

Reducing the radiation dose from computed tomography (CT) exams is an area of active research because of concerns about the detrimental effects of radiation on patients [1]. Reducing the tube voltage and using automatic tube current modulation (ATCM) are established methods for minimizing CT radiation exposure [2]. Achievable dose reductions are in the order of 20%–50% for using ATCM [3,4] and 24%–48% for low tube voltage acquisitions [5].

However, until the introduction of iterative reconstruction (IR), low tube voltage resulted in increased image noise, thus limiting

Abbreviations: AIDR 3D, adaptive iterative dose reduction 3D; ATCM, automatic tube current modulation; $CTDI_{vol}$, CT volume dose index; D_{eff}, effective diameter; DLP, dose length product; FBP, filtered-back projection; IR, iterative reconstruction; ROI, region of interest; SNR, signal-to-noise ratio; SSDE, size-specific dose estimate.

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its use. As opposed to filtered-back projection (FBP), IR techniques incorporate a physical model of the CT system that more accurately reproduce the data acquisition process [6]. IR can be subclassified into two major categories: (1) hybrid reconstruction that involves blending of FBP with IR images and (2) pure or model-based reconstruction in the space domain [6]. A new generation of IR that works on both projection and image space data has shown greater ability in reducing noise [7,8]. One such hybrid reconstruction method is adaptive iterative dose reduction 3D (AIDR 3D, Toshiba Medical Systems, Otawara, Japan), which has been integrated into the imaging chain through ATCM (^{SURE}Exposure 3D) and affects both image noise and radiation exposure through tube current reduction [9,10]. AIDR 3D is available at three strength levels: strong, standard, and mild [11]. The performance of the different strengths has not been previously studied. Other hybrid and pure IR techniques introduced by CT vendors include adaptive statistical iterative reconstruction(ASIR)/model-based iterative reconstruction(MBIR) (GE Healthcare, Waukesha, USA), sinogram affirmative iterative reconstruction (SAFIRE)/adaptive model iterative reconstruction(ADMIRE) (Siemens Healthcare, Erlangen, Germany) and iDose^4/iterative model reconstruction(IMR) (Philips Healthcare, Best, the Netherlands).

With the advent of IR, imaging of patients at reduced tube voltages has become practical even in larger size patients due to its significant image noise reducing capability [12]. Several studies on IR have reported *potential* radiation dose reductions when extrapolating reductions in image noise with IR during post-processing [13,14]. As comparing with reference standard FBP algorithm, other studies have achieved reductions in image noise and radiation dose through estimated or calculated manual adjustment of the image quality indicator (i.e., the noise index) for IR [10,15–17]. However, a recent liver phantom study showed that despite the increased contrast-to-noise ratio of AIDR 3D images, there was a lower sensitivity for low-contrast lesion detection when the radiation dose was reduced to 20% of the reference [18]. Similarly, another study showed that for middle-contrast objects, the modulation transfer function of AIDR 3D decreased with decreasing radiation dose and increasing strength of AIDR 3D [19]. For overcoming this, we hypothesized that using the same noise index setting as FBP for AIDR 3D would result in immediate radiation dose reduction and image quality comparable with those of reduced voltage abdominal CT.

Through validation with anthropomorphic phantom and clinical patients, this study evaluated the performance of AIDR 3D when integrated into ATCM compared with FBP reconstruction by evaluating the radiation dose, image quality, and image noise for 80-kVp abdominal CT.

2. Materials and methods

2.1. Study design

This prospective study was approved by the Institutional Review Board. Prior to the patient study, we conducted a phantom study to validate the effects of AIDR 3D integration into ATCM. In the patient study, we enrolled patients for follow-up CT after colon cancer treatment. Intraindividual comparisons were made to evaluate diagnostic image quality and radiation dose from FBP versus AIDR 3D.

2.2. Phantom study

We used a commercial abdominal phantom (Model 057 Triple Modality 3D Abdominal Phantom, CIRS, VA, USA) with simplified anthropomorphic geometry (width: length: height, 26 cm × 12.5 cm × 19 cm) to simulate the abdominal region from the T9/T10 to L2/L3 vertebra. The internal structure of the phantom includes the liver, kidneys, lung, abdominal aorta, spine, muscle, and outside fat layer.

2.3. Patient study

The Radiology Information System was used to identify patients scheduled for a CT examination. Inclusion criteria were the following: age ≧ 18 years, weight <90 kg, the ability to provide written informed consent, and the ability to hold one's breath while remaining still for at least 10 s. Between February 1, 2013 and May 31, 2013, 63 consecutive patients were identified; all of them participated in the study. The age, sex, weight, and height of each patient was recorded. The body-mass index (BMI) was calculated as the weight divided by the square of the height.

2.4. CT acquisition

CT acquisition was performed on a 320-row multidetector CT (Aquilion ONE, Toshiba Medical Systems; software Version 4.74ER004). To assess the performance of the ATCM and reconstruction algorithms, the entire length of the phantom was acquired four times with four reconstruction algorithms (FBP; AIDR 3D mild, standard, and strong). For the patient study, to minimize additional radiation exposure, we focused on the unenhanced liver CT. Two unenhanced CT acquisitions of equal length covering the whole liver were performed while the patient held one breath. The first acquisition involved using FBP and the second an AIDR3D standard algorithm (based on the findings of the phantom study). The other imaging parameters are as follows: the acquisition mode, helical; detector collimator dimensions, 80 × 0.5 mm; tube potential, 80 kVp; gantry rotation time, 0.75 s; table pitch, 0.638; *x*,*y*,*z*-axis tube current modulation (^{SURE}Exposure 3D); standard deviation of noise, 9; tube current, 10–580 mA; reconstruction kernel, FC18; and slice thickness and interval, 5 mm.

2.5. Image reconstruction

Four image sets were reconstructed (FBP and varying strengths of AIDR 3D) for the phantom study. For the patient study, a second set of images was reconstructed using the AIDR 3D strong algorithm from raw data obtained in the AIDR 3D acquisition. The subjective diagnostic acceptability of the two types of IR was evaluated and the objective image noise differences were determined. In total, three sets of images (FBP, AIDR 3D standard, and AIDR 3D strong) were analyzed.

2.6. Quantitative image analysis

Circular regions of interest (ROI) were made for each image set at the right and left lobe of the liver, the aorta at the level of the portal vein, and the psoas muscle in both the phantom and the patient. For the liver, ROIs were made as large as possible over a homogenous region and care was taken to avoid vessels and calcifications. In the psoas muscle, the surrounding bone and fat were carefully avoided. The mean attenuation value (in Hounsfield Unit, HU) and standard deviation (representing the noise) of each ROI were recorded. To ensure consistency in the phantom, the ROIs were copied and pasted to subsequent acquisitions. To minimize bias from a single measurement, we calculated the average of all ROI measurements at three consecutive slices. For each specific ROI, the signal-to-noise ratio (SNR) was calculated by dividing the mean attenuation value by the standard deviation. Patients were subdivided into two subgroups (<29 cm and ≧29 cm) based on their calculated effective diameter (D_{eff}) to facilitate image analysis. A