European Journal of Radiology 82 (2013) 356–360

Contents lists available at SciVerse ScienceDirect

European Journal of Radiology

journal homepage: www.elsevier.com/locate/ejrad

Comparison of pure and hybrid iterative reconstruction techniques with conventional filtered back projection: Image quality assessment in the cervicothoracic region

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ARTICLE INFO

Article history:
Received 14 August 2012
Received in revised form 25 October 2012
Accepted 2 November 2012

Keywords:
Model-based iterative reconstruction
Adaptive statistical iterative reconstruction
Filtered back projection
Streak artifact
Image noise
Cervicothoracic region

ABSTRACT

Objectives: To evaluate the impact on image quality of three different image reconstruction techniques in the cervicothoracic region: model-based iterative reconstruction (MBIR), adaptive statistical iterative reconstruction (ASIR), and filtered back projection (FBP).

Methods: Forty-four patients underwent unenhanced standard-of-care clinical computed tomography (CT) examinations which included the cervicothoracic region with a 64-row multidetector CT scanner. Images were reconstructed with FBP, 50% ASIR-FBP blending (ASIR50), and MBIR. Two radiologists assessed the cervicothoracic region in a blinded manner for streak artifacts, pixilated blotchy appearances, critical reproduction of visually sharp anatomical structures (thyroid gland, common carotid artery, and esophagus), and overall diagnostic acceptability. Objective image noise was measured in the internal jugular vein. Data were analyzed using the sign test and pair-wise Student's *t*-test.

Results: MBIR images had significant lower quantitative image noise (8.88 ± 1.32) compared to ASIR images (18.63 ± 4.19, $P < 0.01$) and FBP images (26.52 ± 5.8, $P < 0.01$). Significant improvements in streak artifacts of the cervicothoracic region were observed with the use of MBIR ($P < 0.001$ each for MBIR vs. the other two image data sets for both readers), while no significant difference was observed between ASIR and FBP ($P > 0.9$ for ASIR vs. FBP for both readers). MBIR images were all diagnostically acceptable. Unique features of MBIR images included pixilated blotchy appearances, which did not adversely affect diagnostic acceptability.

Conclusions: MBIR significantly improves image noise and streak artifacts of the cervicothoracic region over ASIR and FBP. MBIR is expected to enhance the value of CT examinations for areas where image noise and streak artifacts are problematic.

1. Introduction

Image reconstruction in computed tomography (CT) is a mathematical process that generates images from the acquired X-ray projection data. Image reconstruction has a fundamental impact on image quality. For a given radiation dose, it is desirable to reconstruct images with the lowest possible noise without sacrificing image accuracy and spatial resolution. Two major categories of methods exist, analytical reconstruction and iterative reconstruction (IR). Methods based on filtered back projection (FBP) are one type of analytical reconstruction that is currently used on most clinical CT systems. In FBP, the reconstruction kernel, also referred to as "filter" or "algorithm" by some CT vendors, is one of the most important parameters that affect image quality. Generally, there is a trade off between image noise and spatial resolution. In the cervicothoracic region, image noise and streak artifact from the shoulders are problematic and interfere with adequate visualization of anatomical structures and lesions. In such areas, low-pass filter algorithms that decrease noise are usually used for image reconstruction, but these algorithms also degrade spatial resolution. High-pass filter algorithms preserve spatial resolution, however, there is usually too much image noise.

IR has recently received much attention in CT because it has many advantages compared with conventional FBP techniques. IR generates a set of synthesized projections by accurately modeling the data collection process in CT. The model incorporates statistical information of the CT system (including photon statistics and electronic acquisition noise), and details of the system optics (including the size of each detector cell, dimensions of the focal spot, and the shape and size of each image voxel), yielding lower image noise and higher spatial resolution compared with FBP.

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http://dx.doi.org/10.1016/j.ejrad.2012.11.004

Table 1
Patient characteristics and CT parameters.

Men/women	26/18
Age (years)	65.5 ± 15.5
Acquisition mode	Helical
Noise index	39.6 (at 0.625 mm)
Tube voltage (kVp)	120
Field of view (mm)	350[a]
Gantry rotation time (s)	0.5
Table speed (mm per gantry rotation)	39.37
Detector configuration (mm)	64 × 0.625
Pitch	0.984:1

Data are mean ± standard deviation for each value unless indicated otherwise.
[a] A field of view of 350 mm was typically set; however, it was adjusted according to patient size.

One of the first IR algorithms released for clinical use was the adaptive statistical iterative reconstruction (ASIR) algorithm (GE Healthcare, Waukesha, WI, USA). ASIR is a hybrid IR that involves blending with FBP images, and it models just the photons and electronic noise statistics that primarily affect image noise. Prior phantom and clinical studies have already shown that ASIR provides diagnostically acceptable images with a reduction in image noise compared to the FBP algorithm [1–10].

The recently developed model-based iterative reconstruction (MBIR) technique is a pure IR technique that does not involve blending with FBP images (i.e. no reconstruction kernel), and is mathematically more complex and accurate than ASIR. MBIR not only incorporates modeling of photon and noise statistics like ASIR, it also involves modeling of system optics. Phantom experiments have shown that MBIR provides a significant reduction in image noise and streak artifacts, and a significant improvement in spatial resolution [11–13]. However, clinical studies that have directly compared MBIR with ASIR or FBP are limited [14,15]. The purpose of this study was to evaluate the impact on image quality of three different image reconstruction techniques (MBIR, ASIR and FBP) in one of the most common areas that image noise and streak artifacts are problematic: the cervicothoracic region.

2. Methods

This retrospective study was compliant with Health Insurance Portability and Accountability Act guidelines and was approved by the Human Research Committee of our Institutional Review Board. The requirement for informed patient consent was waived.

2.1. Patients

Between March 21, 2011, and March 25, 2011, 47 consecutive patients underwent unenhanced standard-of-care clinical CT examinations which included the cervicothoracic region at a single tertiary care center. Three patients were selected from the 47 patients using a random number table, and to understand the evaluation system, two thoracic radiologists (M.I. and J.S., with 4 and 13 years of experience, respectively) were trained in the subjective grading of image quality. Images of these three patients were subsequently eliminated from the rest of the analysis. Therefore, 44 patients were included in the final analysis.

Details of patient demographic information are summarized in Table 1. All patients were age ≥18 years, were able to undergo CT in the supine position with both arms elevated, and were able to remain still for the duration of CT acquisition. Patients underwent CT without intravenous contrast, as instructed by their attending physicians for any reason (e.g. no clinical indication for using contrast, history of a previous adverse reaction to iodine contrast media, or impairment in renal function). Scan range of CT examinations were as follows: from lower neck (the level of thyroid cartilage) to chest ($n = 19$), from lower neck to abdomen ($n = 12$), and from lower neck to pelvis ($n = 13$). The main clinical indications for CT were as follows: staging or restaging of known or suspected malignancy ($n = 22$), follow-up for a pulmonary nodule ($n = 9$), pneumonia ($n = 7$), interstitial lung disease ($n = 3$), and non-tuberculous mycobacterial disease ($n = 3$).

Table 2
Radiation dose descriptors.

	Lower neck to chest ($n = 21$)	Lower neck to abdomen ($n = 12$)	Lower neck to pelvis ($n = 14$)
CTDIvol (mGy)	6.59 ± 5.59	5.76 ± 2.23	6.75 ± 2.87
DLP (mGy-cm)	239.6 ± 200.3	282.5 ± 125.5	471.6 ± 221.5

Data are mean ± standard deviation of each value. CTDIvol = CT dose index volume; DLP = dose–length products.

2.2. CT data acquisition

CT data were acquired with a 64-row multidetector CT system (Discovery CT750 HD; GE Healthcare). Imaging parameters are summarized in Table 1. CT acquisition involved the use of automatic tube current modulation (ATCM; Auto mA 3D; GE Healthcare) with a fixed noise index (NI) of 35.6 at 0.625 mm, according to our institutional protocol. The operator-selected NI level modulates the tube current during gantry rotation to achieve a predicted average statistical noise level. All images were reconstructed with 0.625 mm thick axial slices, and then images with increased slice thickness of 2.5 mm were created and used for image analysis. Coronal/sagittal reformats were not used for evaluation in this study (discussed later) and only axial slices were used in the present study.

The estimated CT dose index volume (CTDIvol) and dose–length product (DLP) were recorded for each image data set following completion of the CT examination, according to the dose report. Radiation dose descriptors are summarized in Table 2.

2.3. Image reconstruction

For each patient, images were reconstructed with MBIR, blending of 50% filtered back projection (FBP) and 50% ASIR image data (ASIR50), and FBP, at the same workstation. The blending factor of 50% for ASIR was chosen based on previous literature [8,9] and vendor recommendations. Blending with FBP does not apply to MBIR, as it is a pure IR technique. Thus, three image datasets (MBIR, ASIR50 and FBP) were generated for each patient (Fig. 1). Each image dataset was coded, patient information was removed, and the datasets were randomized before blinded evaluation. For reconstructing FBP (and subsequently ASIR) images, we used the STANDARD kernel (a proprietary kernel of GE Healthcare), according to our institutional protocol for evaluating soft tissue structures in the neck and mediastinum. Reconstruction kernel does not apply to MBIR, since it is a pure IR technique.

2.4. Objective image quality

Objective measurements were performed for the three image datasets of the 44 patients (for a total of 132 image sets) on a diagnostic workstation (Centricity RA1000; GE Yokogawa Medical Systems) by a radiologist (MK) with 4 years of imaging experience. Circular regions of interest (ROI) approximately 10 mm in diameter were drawn in the homogenous part of the right internal jugular vein and the posterior paravertebral neck muscle at the level of cricoid cartilage. Calcifications and areas with prominent streak artifacts were carefully avoided, and the standard deviation (i.e.