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Image quality with iterative reconstruction techniques in CT of the lungs—A phantom study

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ABSTRACT

Background: Iterative reconstruction techniques for reducing radiation dose and improving image quality in CT have proved to work differently for different patient sizes, dose levels, and anatomical areas.
Purpose: This study aims to compare image quality in CT of the lungs between four high-end CT scanners using the recommended reconstruction techniques at different dose levels and patient sizes.
Material and methods: A lung phantom and an image quality phantom were scanned with four high-end scanners at fixed dose levels. Images were reconstructed with and without iterative reconstruction. Contrast-to-noise ratio, modulation transfer function, and peak frequency of the noise power spectrum were measured.
Results: IMR1 Sharp+ and VEO improved contrast-to-noise ratio to a larger extent than the other iterative techniques, while maintaining spatial resolution. IMR1 Sharp+ also maintained noise texture.
Conclusions: IMR1 Sharp+ was the only reconstruction technique in this study which increased CNR to a large extent, while maintaining all other image quality parameters measured in this study.

1. Introduction

For decades, filtered back-projection (FBP) has been used in reconstruction of CT images. The FBP reconstruction technique is based on several assumptions that simplify CT geometry as a compromise between reconstruction speed and image noise [1,2]. FBP is fast, but inherently also adds noise to the images. Increased computer processing power and −cost have made other more complex reconstruction methods clinically feasible, and hence, CT vendors developed new methods for image reconstruction a decade ago. These techniques are aimed at reducing image noise and/or radiation dose [2–9]. One group of these techniques are statistical iterative reconstruction techniques or hybrid techniques, which are more demanding compared to FBP with respect to reconstruction time, but strives to reconstruct CT images with less noise than with FBP, while preserving details and edges [2,3,5,6]. The hybrid reconstruction techniques work both in projection space and in image space with iterations between them, and blends iterative and FBP reconstruction. The four hybrid reconstruction techniques assessed in this study were ASIR, AIDR3D, iDose and SAFIRE. Some vendors have also introduced model based iterative techniques, where object, scanner geometry and optics are modelled in addition to noise and photon statistics. Model-based iterative reconstruction techniques reduce noise and artifacts more than hybrid techniques, but may also alter image texture more. The two model based iterative techniques assessed in this study were VEO and IMR [1,4,7]. Iterative reconstruction techniques have also proved to work differently for different patient sizes, dose levels and anatomical areas [10,11], and in addition to noise reduction, these techniques also can potentially alter spatial resolution and image texture [12,13]. CT of the lungs is commonly used in frequent follow-up of cancer patients, and can potentially also be used for screening-purposes. Therefore, reconstruction techniques enabling low-dose examinations of the lungs are of great importance for the patient. The aim of this study was to compare quantitative image quality parameters in CT of the lungs for high-end CT scanners from GE, Philips, Siemens and Toshiba using the recommended reconstruction techniques at different dose levels and patient sizes.

Abbreviations: MTF, modulation transfer function; CNR, contrast-to-noise ratio; CT, computed tomography; NPS, noise power spectrum; FBP, filtered back-projection

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2. Material and methods

2.1. Phantoms

The image quality phantom Catphan600® [14] and the Kyoto Kagaku Lungman® [15] lung phantom were scanned in this study. The lung phantom was a torso with soft tissue and bone, and inside the cavity, the phantom consisted of heart, trachea, pulmonary vessels and diaphragm/abdomen. The size of the phantom was 43 cm lateral diameter x 40 cm anteroposterior diameter, and 48 cm hight, with a circumference of 94 cm. The lung phantom was used both with and without additional padding, simulating a small and a large patient. With padding, 30 mm was added to the front and to the back of the phantom. The soft tissue and vessels of the lung phantom were made from polyurethane (gravity1.06), and the bone structures were made from epoxy resin and calcium carbonate. The lung phantom contained two spherical inserts of 12 mm in diameter simulating both high- and low-density lesions. The nominal densities of the lesions were approximately −800 and +100 HU. The Catphan600® is an image quality phantom for quantitative measurements. In this study, the module CTP528 for measurement of spatial resolution was used. The module consisted of two wolfram beads embedded in a homogenous material [14].

2.2. Image acquisition

The scanner models used were the Siemens Definition Flash®, Toshiba Aquilion ONE®, GE Discovery 750HD® and Philips Ingenuity®. Scan techniques and reconstruction techniques are given in detail in Tables 1 and 2. All scans were done with the clinical scan protocol for CT of the lungs for each scanner. Catphan600® was scanned with a fixed dose level of 10 mGy CTDIvol. For the lung phantom, fixed dose levels of 2.5 mGy, 5 mGy and 10 mGy CTDIvol were used. All images were reconstructed to the same thickness of 2 mm, in order for measurements to be comparable. Images were reconstructed using the filtered back-projection (FBP) techniques for CT of the lungs, and also with a selection of the iterative options available on the scanners. The reconstruction kernels and levels of iterative reconstruction used were chosen according to recommendations from the vendors. The hybrid iterative techniques are a blend between FBP and iterative reconstruction. All these are based on the kernel used for the FBP reconstruction. With respect to Philips' Iterative Model Reconstruction (IMR) and GE's Model-based iterative reconstruction (VEO), these are not kernel based, but stand-alone reconstruction algorithms.

Table 1
Scan technique for all scanners and both phantoms.

	GE	Siemens	Philips	Toshiba
Detector width [mm]	40	38,4	40	40
Detector Collimation	64 × 0.625	64 × 0.6	64 × 0.625	80 × 0.5
rotation time [s/rotation]	0.5	0.5	0.5	0.5
pitch	0.984	1.2	1.015	1.1
mA	65/125/255	89/178/360	77/154/315	70/130/260
CTDIvol [mGy]	2.6/4.9/10	2.5/5/10.1	2.5/5/10.1	2.7/5/9.9
kVp	120	120	120	120
Reconstructed slice thickness [mm]	2	2	2	2
Displayed field-of-view [cm] for lung phantom	32	32	32	32
Displayed field-of-view [cm] for Catphan (MTF)	21	21	21	21

Table 2
Reconstruction techniques for all image series.

Scanner	Reconstruction	
GE	VEO	VEO
	Lung	ASIR20
		FBP
Siemens	70f	SAFIRE3
		FBP
Philips	IMR1	Routine
		Sharp+
	YB	iDose2
		FBP
Toshiba	FC56	AIDR3DSTD
		FBP(QDS)

2.3. Image quality analyses

Contrast-to-noise ratio (CNR) in all 66 series of the lung phantom was calculated from two simulated lesions of size 12 mm in diameter, with nominal densities of approximately −800 and +100 HU. CNR between the lesions was calculated using the following formula [16]:

$$CNR = \frac{2(HU_1 - HU_2)^2}{SD_1{}^2 + SD_2{}^2}$$

Where HU_1 and HU_2 are the Hounsfield numbers measured in the two nodules, and SD_1 and SD_2 are the corresponding standard deviations (Figs. 1 and 2). CNR is one of the most commonly used image quality descriptors in CT, and gives valuable input to the visibility of lung nodules [17].

Noise texture refers to correlations between adjacent pixel values that are manifest by the grainy appearance of CT images. These correlations are largely affected by the reconstruction technique used, and may influence the detectability of pathology [12]. Images with equal noise magnitude but different noise texture may not have the same image quality [13]. Noise texture and magnitude may be characterized in terms of the noise power spectrum (NPS). NPS was measured in the liver area of the lung phantom for all scan series of the lung phantom (Fig. 3).

NPS was calculated with a square ROI with a size of 80 mm x 80 mm, subdivided into 4 squares, and repeated in the three central slices in order to minimize noise in the measurement with ensemble

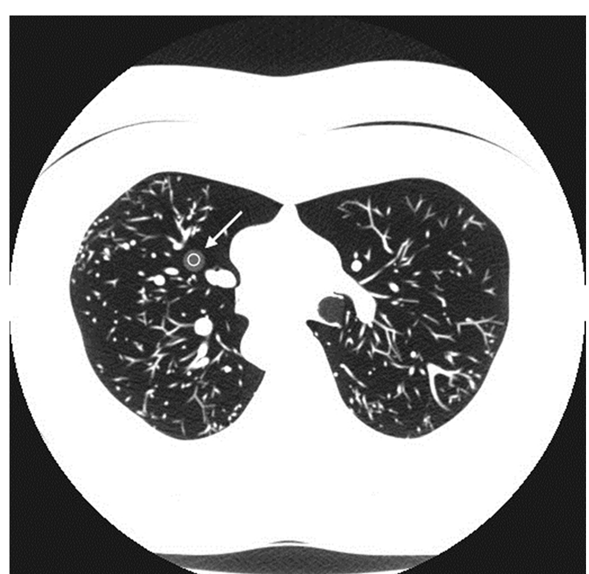

Fig. 1. Measurement of CNR in low-density insert simulating nodule.

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