ARTICLE IN PRESS

Radiography xxx (2017) 1–9

Contents lists available at ScienceDirect

Radiography

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

Impact of CT parameters on the physical quantities related to image quality for two MDCT scanners using the ACR accreditation phantom: A phantom study

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ARTICLE INFO

Article history:
Received 4 January 2017
Received in revised form
20 March 2017
Accepted 22 March 2017
Available online xxx

Keywords:
ACR phantom
CT number
Low contrast resolution
Uniformity
Spatial resolution
MTF

ABSTRACT

Introduction: To evaluate the image quality provided by MDCT scanners using an ACR phantom an to find out the relationship between CT parameters and physical quantities related to image quality.
Methods: A GE Lightspeed VCT and a GE Lightspeed Pro 16 are used. The ACR phantom consists of four modules for evaluating physical parameters. The image quality parameters, such as CT number, linearity, CNR, image uniformity, SNR and at least spatial resolution using MTF, by different sets of image acquisition protocols (IAPs) are characterized. The influences of the IAPs on the physical quantities are also discussed.
Results: The CT numbers behaved linearly relative to material density for all tube voltages. The impact of the tube current on the CT numbers is neglectable. However, the variation of the tube current reflects in the CT number uncertainties. The CNR are altered by changing the IAPs. 50% MTF decreases from 6.2 to 3.6 lp/cm and from 6.5 to 3.7 lp/cm using Lung and Soft kernel for the Lightspeed VCT and Lightspeed Pro 16 scanner, respectively.
Conclusion: The dependence of the image quality parameters on reconstruction kernels, tube peak voltages, tube currents and the slice thicknesses has been discussed. The tube peak voltage has the most influence on the CT numbers. The results indicate that the reconstruction kernel has the main impact on the spatial resolution. The spatial resolution dependence on the tube voltages, tube currents and slice thicknesses can be ignored.

Introduction

The improvement in diagnostic imaging by use of computed tomography (CT) led to the increasing number of CT examinations, with well over 100 million studies performed worldwide annually.[1–3] In addition to the technical development, such as the introduction of the helical CT in the early 90's and the multi-slice computed tomography at the end of 90's decade, the improvement of the image quality have accelerated new clinical uses of the CT. Consequently, a quality assurance (QA) program is required to ensure the maximum clinical information for high quality diagnostic images at acceptable radiation exposure to the patient. The QA program identifies the parameters if they are out of limits, which is reflected in decrease of the image quality and increase of the radiation exposure.[4,5] Access to the CT images in digital form has enabled to evaluate the image quality, which is an important characteristic of any imaging system. The image quality can be quantified by use of suitable phantoms and measurements of physical parameters, such as CT number, linearity, low contrast resolution, uniformity and spatial resolution.[6] In order to evaluate image quality of CT scanners, various testing phantom are commercially available, e.g. Catphan (The phantom laboratory, Salem NY, USA). In different studies the image quality with the Catphan phantoms has been analyzed.[7–10] In addition to the Catphan phantoms, the American College of Radiology (ACR) recommended to use the CT accreditation phantom (ACR phantom, model 464, Gammex-RMI, Middleton, W) to assess the imaging performance of CT scanners. Previous investigators have evaluated the image quality by different multidetector CT (MDCT) scanners using the ACR phantom. Hara et al.[11] analyzed the image noise, low contrast resolution and spatial resolution for a 64-MDCT scanner (CT750 HD, GE Healthcare). For the measurements the default ACR reference values for image acquisition protocols (IAPs) were utilized. Images have been reconstructed with filtered back projection (FBP) method and adaptive statistical iterative reconstruction (ASiR) technique. A comparison of the image quality parameters of helical and stepwise high-resolution CT images obtained with cone-beam reconstruction was discussed by Funama et al.[12] For

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http://dx.doi.org/10.1016/j.radi.2017.03.013

this study a fixed set of IAPs, e.g. X-ray tube peak voltage, X-ray tube current, detector collimation, in the stepwise and helical mode of a 64-MDCT scanner (Brilliance-64, Philips Healthcare) was used. A fan-beam algorithm with a lung reconstruction kernel just reconstructed the images. Cropp et al.[13] performed measurements on 36 scanners (25 GE, 10 Siemens and 1 Toshiba) to characterize the dependence of CT numbers on the tube voltage. For the evaluation of the measurements, one module of the ACR phantom was only utilized. To our knowledge, a systematical analysis using all modules of the ACR phantom and various sets of IAPs has never been studied. The primary goal of the current investigation was an image quality analysis of two MDCT scanners from the same vendor. For this purpose an evaluation of the physical quantities related with the image quality, such as the CT number, the low contrast resolution, the uniformity and the spatial resolution was presented in this work. The other purpose of this investigation was to find out the dependency of the image quality parameters on the CT parameters, among others, X-ray tube peak voltage, X-ray tube current, slice thicknesses and reconstruction kernels.

Materials and methods

CT scanners

Two clinical CT scanners used in this work were a 64-slice scanner (GE Lightspeed VCT, GE Healthcare, Waukesha, Wisconsin) and a 16-slice scanner (GE Lightspeed 16, GE Healthcare, Waukesha, Wisconsin). The scanners are in operation in the Institute of Diagnostic and Interventional Radiology at Hannover Medical School. The X-ray sources for both scanners are constructed with four tube voltages of 80, 100, 120 and 140 kVp.

In order to investigate the impact of the CT parameters, such as X-ray tube peak voltage (tube voltage), X-ray tube current (tube current), collimation and convolution kernel, on the image quality parameters, the IAPs were selected which are listed in Table 1. The variation of a CT parameter while all other parameters remained unchanged enables to analyze the impact of that CT parameter of the image quality. For instance, the influence of the convolution kernel was analyzed by remaining retaining the same tube voltage, tube current and slice thickness and variation only varying the convolution kernel (STD, BONE, LUNG, SOFT).

Furthermore, the measurements using both scanners were performed with a rotation time of 1 s, small bow-tie filters and in the step-and-shoot mode.

Table 1
IAPs of the GE scanners.

Nr.	X-ray tube peak voltage (kVp)	X-ray tube current (mA)	Slice thickness (Collimation) (mm)	Reconstruction kernel	† $CTDI_{vol}$ (mGy)
(a) GE Lightspeed VCT					
1	120	400	1.25 (1.25)	STD	40.67
2	120	400	5 (10)	STD	93.19
3	120	400	5 (40)	STD	71.69
4	120	100	5 (10)	STD	21.51
5	80	400	5 (40)	STD	26.08
6	100	400	5 (40)	STD	46.87
7	140	400	5 (40)	STD	99.59
8	120	400	5 (40)	BONE	71.69
9	120	400	5 (40)	LUNG	71.69
10	120	400	5 (40)	SOFT	71.69
(b) GE Lightspeed Pro 16					
1	120	400	1.25 (20)	STD	73.57
2	120	400	2.5 (20)	STD	73.57
3	120	400	5 (20)	STD	73.57
4	120	400	10 (20)	STD	73.57
5	120	100	10 (20)	STD	18.58
6	120	200	10 (20)	STD	37.15
7	80	400	10 (20)	STD	26.51
8	100	400	10 (20)	STD	47.34
9	140	380	10 (20)	STD	95.27
10	120	400	10 (20)	BONE	73.57
11	120	400	10 (20)	LUNG	73.57
12	120	400	10 (20)	SOFT	73.57

(† $CTDI_{vol}$: Volume Computed Tomography Dose Index).

ACR phantom

The ACR phantom consists of a water-equivalent material and contains four modules. Each module has a diameter of 20 cm with a length of 4 cm. A sketch of the ACR phantom is pictured in Fig. 1.

The modules are designed to determine image quality parameters, such as CT number, linearity, low contrast and spatial resolution. Images of the ACR phantom were exported via DICOM and analyzed using plug-ins and macros for the software program *ImageJ*.[17] The modules of the ACR phantom and the characterization of the image quality parameters are described as follows:

1. The CT number accuracy can be examined by means of the module 1 which contains five cylinders of materials with different densities. The materials and their densities are given in Table 2.

Except for the water-equivalent cylinder with a diameter of 50 mm, each cylinder has a diameter of 25 mm and a length of 4 cm. The CT numbers and their uncertainties within a circle shape ROI with an area of about 250 mm^2 for each cylinder were determined. Fig. 2(a) illustrates an image of the module 1. In order to justify the imaging system linearity, the CT numbers were fitted using a linear fitting function $f(x) = m \cdot x + b$.

2. Module 2 is constructed to evaluate the low contrast resolution. This module has a series of four cylinders of different diameters with CT numbers close to that of the background ($\Delta CT\# \approx \pm 6$ HU). The series of cylinders have diameters of 2, 3, 4, 5 and 6 mm. A 25-mm cylinder is included to determine the contrast-to-noise ratio (CNR). In order to calculate CNR, the definition introduced by[10,18] was used, i.e.

$$CNR = 2 \cdot \frac{\left(\overline{CT}\#_{obj} - \overline{CT}\#_{bg}\right)^2}{\sigma_{obj}^2 + \sigma_{bg}^2}, \quad (1)$$

where $\overline{CT}\#_{obj}$ and $\overline{CT}\#_{bg}$ are the mean CT number inside the 25-mm rod and the mean CT number of the background, respectively. The corresponding standard derivations of the CT numbers are denoted by σ_{obj} and σ_{bg}. For the CNR determination a ROI with an area of about 100 mm^2 in the 25-mm cylinder and a ROI of the same area between the 25-mm cylinder and the 6-mm cylinders were placed. An image of the module 2 with the ROIs for CNR assignment is shown in Fig. 2(b).

CNR depend on the reconstruction kernels, the tube voltages, the tube currents and also on the slice widths. In order to prove this assertion, one parameter of the IAPs was changed by retaining the other parameters. To evaluate the impact of the reconstruction kernel on CNR, the measurements were performed by a tube voltage of 120 kVp and a tube current of 400 mA. The collimation were set to 40 mm and 20 mm (slice thicknesses of 5 mm and 10 mm) for the GE Lightspeed VCT and the GE Lightspeed Pro 16 scanner, respectively. The dependency of the tube voltage on CNR was analyzed, while a tube current of 400 mA and the “standard” reconstruction kernel were chosen for both scanners. The collimation were also set to 40 mm and 20 mm (slice thicknesses of 5 mm and 10 mm) for the GE Lightspeed VCT and the GE Lightspeed Pro 16 scanners, respectively. The effect of the tube current was

Please cite this article in press as: Alikhani B, et al., Impact of CT parameters on the physical quantities related to image quality for two MDCT scanners using the ACR accreditation phantom: A phantom study, Radiography (2017), http://dx.doi.org/10.1016/j.radi.2017.03.013