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The evolution of radiation dose over time: Measurement of a patient cohort undergoing whole-body examinations on three computer tomography generations

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ABSTRACT

Objectives: To evaluate and compare the radiation dose and image quality of whole-body-CT (WBCT) performed on the 3rd-generation dual-source-CT (DSCT) with 2nd-generation DSCT and 64-slices-Single-Source-CT (SSCT) in a large patient cohort.

Material and methods: Using a monitoring and tracking software 1451, 747 and 1861 patients scanned with a one-spiral-thorax-abdomen-pelvis-CT-examination on a 3rd-, 2nd-generation DSCT and SSCT, respectively, were extracted from the PACS server. For the intra-individual analysis, 203 patients on the 3rd-generation DSCT were identified. Out of those 203 patients, 155 had the same examination on the 2nd-generation DSCT, 91 patients had the same examination on the SSCT and 43 patients had an examination on all three CT-generations. Automatic tube current modulation was active on all three CT-generations, whereas automatic tube voltage selection was only available on both DSCT-generations. Dose was recorded by the size-specific-dose-estimate-method (SSDE); signal-to-noise-ratio (SNR) and contrast-to-noise-ratio (CNR) were calculated placing a ROI on the ascending aorta/liver and the subcutaneous adipose tissue at comparable level. Image quality of axillary and mediastinal lymph nodes and adrenal glands was assessed by two experienced radiologists.

Results: Subjective image quality was excellent throughout all three CT-generations ($p = 0.38–0.98$). Quantitative image quality in both DSCT generations was superior to SSCT ($p < 0.001$). SNR and CNR in the liver parenchyma were superior in the 3rd-generation DSCT compared to the 2nd generation DSCT ($p < 0.001$), whereas there was no difference in the aorta. In the inter-individual analysis, $CTDI_{vol}$ was lower by 26.9% and 44.3% in the 3rd-generation DSCT, when compared to the 2nd-generation DSCT and SSCT, respectively; SSDE was lower by 31.5% and 51% in the 3rd-generation DSCT, when compared to the 2nd-generation DSCT and SSCT, respectively. In the intra-individual comparison $CTDI_{Vol}$ in the 3rd-generation DSCT was lower by 33% and 45%, when compared to the 2nd-gneration DSCT and the SSCT, respectively. Consequently, SSDE in the 3rd-generation DSCT was lower by 29% and by 43% when compared to the 2nd-generation DSCT and SSCT, respectively.

Conclusion: State-of-the-art CT-equipment substantially reduce radiation dose without affecting image quality.

1. Introduction

Computed tomography (CT) has been established as a safe and non-invasive modality with up to 65 million CT examinations performed in the USA per year, accounting for over half of the collective radiation dose [1]. This makes radiation safety pivotal, especially for pediatric and oncological patients, as the latter often undergo multiple CT-examinations in the course of disease surveillance. Many

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new technologies and approaches have been continuously implemented to reduce the radiation footprint and enhance the image quality since the introduction of CT in the early 1970's [2]. Important determinants in radiation dose and image quality are detector efficiency, tube potential, tube current, scanned area and usage of post processing denoising technique, such as iterative reconstruction. Decreasing the tube current at a constant tube potential lowers the radiation dose, but simultaneously increases the image noise thus impairing image quality and consequently diagnostic accuracy [3] On the other hand, while increasing the tube current leads to an increase in radiation dose, the associated noise-reduction may not necessarily reveal additional diagnostic information. As the human body is non-homogeneous in terms of tissue density and topologically inconsistent, the trade-off between radiation dose and image quality calls for a more nuanced approach, applying different dose-reducing techniques, such as automatic tube current modulation [4,5] or choosing a lower tube potential, if the patient's habitus permits [6]. The resulting increased signal-to-noise ratio can be improved by applying the method of iterative reconstruction (IR). Although the vendor specific algorithms are provided as "black boxes", the general principle is based on repetitions and comparisons of reconstruction steps, until a determined number of iterations have been reached or the image quality criterion is fulfilled [7].

Acquisitions with two activated tubes at two different voltage settings form the basis for material decomposition [8]. Optimal discrimination between two materials is achieved with a large spectral separation, which can be enhanced by using an additional filtration [9]. The use of tin filtration in the high-kV tube hardens the high-energy kV spectrum, resulting in an improved material separation, without affecting the image quality and dose [10].

A number of studies were performed comparing dose and image quality, especially in the field of cardiac CT (e.g. the PROTECTION-study) [11]. The evaluation of radiation dose and application of new dose-efficient techniques in whole-body-CT (WBCT) is however still scarce and has been predominantly focused on trauma patients [12]. Additionally, dose estimates do vary considerably throughout the different institutions [13]. In order to objectively observe and help standardize CT radiation dose, manufacturers have developed monitoring and tracking software in order to better evaluate the vast amount of data.

Consequently, the purpose of this study is to evaluate and compare the radiation dose and image quality of WBCT performed on the 3rd-generation dual-source-CT (DSCT) with 2nd-generation DSCT and 64-slices Single-Source-CT (SSCT).

2. Methods and materials

2.1. Patients

This retrospective study was approved by the institutional review board. Patients clinically referred for a one-spiral-WBCT examination on the 3rd-generation DSCT at the Department of Radiology of the University Hospital of Tuebingen, between October 2014 and August 2015, were identified using a dicom header based tracking and monitoring software (Radimetrics, Bayer Healthcare, Whippany, NJ). Its functionality is described elsewhere in greater detail [13]. Subsequently we searched for prior examinations performed on either the 2nd-generation DSCT, the SSCT, or both. Exclusion criteria for this study were an additional spiral during the same CT-examination, pediatric (<18 years of age) and intensive-care patients. The latter patient group was excluded due to the extended intra- and extra-corporal material, such as tracheal tube and ventilation lines. Patients with clinical deterioration comprising weight loss were excluded as well, in order to enable the comparison between similar body sizes.

2.2. CT-Technique

CT-examinations on the 3rd-generation 192 slices DSCT (SOMATOM Force, Siemens Healthcare, Forchheim, Germany) were performed in Dual-Energy mode, with tin filtration, automated tube voltage selection (carekV, Siemens Healthcare, Forchheim, Germany), automated tube current modulation (careDose 4D, Siemens Healthcare, Forchheim, Germany), rotation time of 0.5 s, collimation of 128 × 0.6 mm by z-flying focal spot and a pitch of 0.6. The amount of iodinated contrast-media (Ultravist 370, Bayer Healthcare, Berlin, Germany) was weight-adapted according to a reference volume of 80 ml for a standard patient and injected into a 20-gauge cubital vein catheter at a rate of 2.2 ml/s, followed by a 30 ml saline-chaser. Acquisition was performed in the cranio-caudal direction from the apical maxillary sinus to the pelvic floor, with a delay of 90 s after infusion in order to obtain a portal venous phase. Data were reconstructed with 3 mm section thickness using the Bf40 kernel and a strength parameter of 2 for the advanced modeled iterative reconstruction algorithm (ADMIRE) [14].

Examinations on the 2nd-generation 256-slices DSCT (SOMATOM Flash, Siemens Healthcare, Forchheim, Germany) were also performed in Dual-Energy mode with automated tube voltage selection and tube current modulation. Although the pitch was set at 0.8, collimation setting and acquisition protocol were identical to the 3rd-generation DSCT. Data were reconstructed with 3 mm section thickness using the I31f kernel and a strength parameter of 2 for the sonogram affirmed iterative reconstruction (SAFIRE).

Examinations on the 64-slices SSCT (SOMATOM Sensation 64; Siemens Healthcare, Forchheim, Germany) were performed with activated tube current modulation and manual selection of the tube voltage according to the patient size. Rotation time was set at 0.5 s with a collimation of 64 × 0.6 mm by z-flying focal spot and a pitch of 0.9. Contrast-media application and acquisition protocols were identical to the previously mentioned. Data were reconstructed with 3 mm section thickness and using the FBP-based B40 kernel.

3. Image quality

3.1. Objective image quality

Signal-to-noise ratio (SNR) and the contrast-to-noise ratio (CNR) were assessed by placing an area of interest (ROI) of ~1 cm² in the subcapsular liver parenchyma (liver segment IV or VI) and the ascending aorta at three different z-levels and measuring the mean density and the standard deviation in Hounsfield unit (HU). Reference ROI's were placed in the subcutaneous adipose tissue at the same level. CNR and SNR were calculated according to [15]:

$$\mathrm{CNR} = (\mathrm{HU}_{\mathrm{Liver\ or\ Aorta}} - \mathrm{HU}_{\mathrm{adipose\ tissue}})/\mathrm{HU} - \mathrm{standard\ deviation}_{\mathrm{Liver\ or\ Aorta}}$$

$$\mathrm{SNR} = \mathrm{HU}_{\mathrm{Liver\ or\ Aorta}}/\mathrm{HU} - \mathrm{standard\ deviation}_{\mathrm{Liver\ or\ Aorta}}$$

3.2. Subjective image quality

Solid organs such as adrenal glands and lymph nodes are important markers for CT-surveillance studies. Those structures have been chosen for subjective image quality evaluation. Lymph nodes were evaluated at the level of the mediastinum, axilla, and lung hilum. Evaluation was completed by two radiologists