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Comparison of applied dose and image quality in staging CT of neuroendocrine tumor patients using standard filtered back projection and adaptive statistical iterative reconstruction

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ABSTRACT

Objective: To investigate whether dose reduction via adaptive statistical iterative reconstruction (ASIR) affects image quality and diagnostic accuracy in neuroendocrine tumor (NET) staging.
Methods: A total of 28 NET patients were enrolled in the study. Inclusion criteria were histologically proven NET and visible tumor in abdominal computed tomography (CT). In an intraindividual study design, the patients underwent a baseline CT (filtered back projection, FBP) and follow-up CT (ASIR 40%) using matched scan parameters. Image quality was assessed subjectively using a 5-grade scoring system and objectively by determining signal-to-noise ratio (SNR) and contrast-to-noise ratios (CNRs). Applied volume computed tomography dose index ($CTDI_{vol}$) of each scan was taken from the dose report.
Results: ASIR 40% significantly reduced $CTDI_{vol}$ (10.17 ± 3.06 mGy [FBP], 6.34 ± 2.25 mGy [ASIR] ($p < 0.001$) by 37.6% and significantly increased CNRs (complete tumor-to-liver, 2.76 ± 1.87 [FBP], 3.2 ± 2.32 [ASIR]) ($p < 0.05$) (complete tumor-to-muscle, 2.74 ± 2.67 [FBP], 4.31 ± 4.61 [ASIR]) ($p < 0.05$) compared to FBP. Subjective scoring revealed no significant changes for diagnostic confidence (5.0 ± 0 [FBP], 5.0 ± 0 [ASIR]), visibility of suspicious lesion (4.8 ± 0.5 [FBP], 4.8 ± 0.5 [ASIR]) and artifacts (5.0 ± 0 [FBP], 5.0 ± 0 [ASIR]). ASIR 40% significantly decreased scores for noise (4.3 ± 0.6 [FBP], 4.0 ± 0.8 [ASIR]) ($p < 0.05$), contrast (4.4 ± 0.6 [FBP], 4.1 ± 0.8 [ASIR]) ($p < 0.001$) and visibility of small structures (4.5 ± 0.7 [FBP], 4.3 ± 0.8 [ASIR]) ($p < 0.001$).
Conclusion: In clinical practice ASIR can be used to reduce radiation dose without sacrificing image quality and diagnostic confidence in staging CT of NET patients. This may be beneficial for patients with frequent follow-up and significant cumulative radiation exposure.

1. Introduction

Neuroendocrine tumors (NETs) of the digestive system are a complex group of neoplasms [1]. The spectrum ranges from well- and moderately differentiated slowly growing tumors (NET G1/G2) to aggressive, poorly differentiated neuroendocrine carcinoma (NEC G3), which differ in terms of prognosis and treatment [1]. The symptoms of NETs vary with their functional status and location and can point to the diagnosis. In a significant proportion of patients, NETs are found incidentally on conventional imaging scans performed for other reasons. The most frequent sites of primary NETs are the small and large intestine including the appendix and the pancreas [1]. Radiologic imaging is an important tool in the diagnosis of NETs. Somatostatin receptor imaging – either as somatostatin receptor scintigraphy (SRS), ^{68}Ga positron emission tomography (PET) or single-photon emission computed tomography (SPECT) – is the standard procedure for the identification and staging of the primary tumor, next to conventional imaging modalities such as ultrasound (US), endoscopic ultrasound (EUS),

Abbreviations: ALARA, as low as reasonably achievable; ASIR, adaptive statistical iterative reconstruction; ATCM, automated tube current modulation; CNR, contrast-to-noise ratio; $CTDI_{vol}$, volume computed tomography dose index; CUP, cancer of unknown primary; EUS, endoscopic ultrasound; FBP, filtered back projection; HU, Hounsfield unit; IR, iterative reconstruction; MRI, magnetic resonance imaging; NET, neuroendocrine tumor; PET, positron emission tomography; SNR, signal-to-noise ratio; SPECT, single-photon emission computed tomography; SRS, somatostatin receptor scintigraphy; US, ultrasound.

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magnetic resonance imaging (MRI) and computed tomography (CT) [1].

Due to diagnostic suitability, availability, and cost-effectiveness, CT is often used in both primary diagnostic work-up and follow-up of NET patients. NET patients with a relatively good prognosis and long disease course may undergo a large number of whole-body CT examinations. This results in a high cumulative dose of ionizing radiation, which is known to increase carcinogenic risks for patients [2]. Therefore, it is desirable to identify measures that can help to reduce diagnostic X-ray exposure in this particular patient group.

Factors influencing the applied dose in CT scans are tube current, voltage, scan length, patient size, rotation time, pitch, collimation, slice thickness, noise index, and field of view. A practical dose reduction approach is the use of low-voltage protocols [3,4]. However, low-voltage protocols increase noise and can only be used for examinations with low density of penetrated tissue or in patients with small body diameters. Several techniques reduce the applied dose by lowering tube current. Different vendors provide automated tube current modulation (ATCM) [5]. Lower tube current is also associated with increasing image noise.

Iterative image reconstruction algorithms (IR) reduce noise and have been used in PET and SPECT for many years. Since 2009, it has been possible to also use these algorithms for the reconstruction of CT data [6]. When the same dose is applied, IR algorithms reduce CT image noise compared to traditional filtered back projection (FBP). IR is used to compensate increased image noise caused by lower tube current which can reduce the applied dose while maintaining adequate image quality compared to FBP [7,8,9].

Several studies have compared image quality and applied dose of FBP and IR in phantom models [4,10–12]. Furthermore, initial clinical experience with IR has been reported for patients with different indications [7–9,13–17]. To our knowledge, there has been no evaluation in a homogeneous group of patients with hypervascular abdominal tumors such as NETs. The purpose of our study was to compare image quality and applied dose of FBP and IR protocols in NET patients.

2. Materials and methods

2.1. Patient population and study design

This study was approved by the institutional ethics board. Written informed consent was obtained from all patients included in this study and patient data were stored anonymously. From September 2012 to January 2014, we screened 296 patients with histologically proven NETs who underwent CT examinations at our institution. Additional inclusion criteria were visible primary tumor and/or metastatic lesion of NETs in abdominal CT and matched FBP prescan on the same 64-multislice CT scanner (LightSpeed VCT; GE Healthcare, USA). Exclusion criteria were absence of visible tumor, tumor surgery between scans, non-matching FBP prescan, pregnancy and patient age less than 18 years. Finally, 28 patients were enrolled for intraindividual comparison of FBP standard and ASIR 40% follow-up scan (Fig. 1). Female-to-male ratio was 12 to 16, mean age was 70 ± 11 years and mean follow-up time 1 year ± 8 months.

2.2. CT technique

Contrast-enhanced multiphase scans were performed on a 64-multislice CT scanner. After a p.-a. scout and intravenous contrast medium injection, scans were acquired during arterial, hepatic venous and venous phases. Phases were defined using automated scan-triggering software (SmartPrep, GE Healthcare). Delay times after reaching the attenuation threshold (100 HU) in the upper aortic bow were set to 18 s (arterial), 35 s (hepatic venous) and 80 s (venous). Patients received 120 ml nonionic contrast medium (Xenetix 350®, Guerbet, France) at a flow rate of 4 ml/s using a mechanical injector (Medtron CT2, MEDTRON AG, Germany).

Table 1
The two protocols were performed with matched CT scan parameters, except for the reconstruction algorithm—FBP and ASIR 40%.

CT parameter	FBP	ASIR 40%
Recon algorithm	100% FBP	60% FBP; 40% ASIR
Voltage	120 kVp	
Pitch	1.375	
Collimation	64 × 0.625 mm	
Rotation time	0.5 s	
Noise index	15	
Min/max mA	100/675	
Smart mA	On	
Auto mA	On	
Recon mode	Slice (axial)	
Recon slice thickness	5 mm	
Recon section interval	5 mm	
Field of view	DFOV: depending on patient SFOV: 50 cm	

Depending on the mathematical model and vendor, IR techniques are known by different acronyms. Our study patients were examined on a GE scanner using GE's iterative protocol, which is called adaptive statistical iterative reconstruction (ASIR). This protocol includes tube current reduction (in the range of preset min. and max. mA) resulting in a lower applied dose. The relation between noise reduction and resulting possible lowering of tube current was investigated/preset by the vendor and can be chosen by the user up to 50%.

Images were reconstructed from raw data with a soft-tissue kernel using the standard FBP algorithm for the first examination and a hybrid algorithm (60% FBP and 40% ASIR) for follow-up scans. FBP and ASIR 40% scans were performed with matched scan parameters (kVp, pitch, collimation, rotation time, noise index, slice thickness, auto mA, smart mA, 3 contrast phases) (Table 1).

2.3. Quantitative image analysis

All analyses were performed at a commercially available workstation (Advantage Workstation, GE Healthcare) with preset window settings (width: 400 Hounsfield units (HU), center: 50 HU) (in portal-venous phase). Maximum abdominal diameters in sagittal and coronal orientation were measured. At one slice, circular regions of interest (ROIs) were manually placed in the aorta, liver, pancreas (head, body, tail), paraspinal muscle, fat of the anterior abdominal wall and preabdominal air. The image level showing the largest tumor extent in the portal-venous phase was used to place a polygonal ROI in the lesion and a circular ROI in adjacent normal liver parenchyma. The area of the lesion was measured. To calculate signal-to-noise ratio (SNR) and contrast-to-noise ratios (CNRs), standard deviation of HU in abdominal wall fat was defined as denominator. Numerators were defined as mean HU of all ROIs (SNR) or of specific ROIs (CNR) (CNR = mean HU of $ROI_{tissue\ 1}$ − mean HU of $ROI_{tissue\ 2}$/standard deviation of HU of ROI_{fat}). CNRs were calculated as $CNR_{tumor\text{-}liver}$, $CNR_{tumor\text{-}muscle}$ and $CNR_{liver\text{-}muscle}$.

2.4. Qualitative image analysis

Measurements were performed by two independent, experienced and blinded readers, who were allowed to change zoom and window settings. Subjective image quality was scored in six categories (image noise, contrast, visibility of small structures,

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