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Low-voltage (80-kVp) abdominopelvic computed tomography allows 60% contrast dose reduction in patients at risk of contrast-induced nephropathy

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ABSTRACT

Purpose: The purpose of this study was to evaluate the quality of image in abdominopelvic late phase computed tomography (CT) with a low tube voltage plus low dose contrast medium (CM) protocol (80-kVp, 60% CM). A compared with the conventional protocol (120-kVp, 100% CM) B in the same patients.
Material and methods: This study included with 22 patients {36 to 77 kg (mean: 55.5 kg)} who had renal insufficiency and had experience of performance conventional CT without renal insufficiency during pre-18 months. The CT value of the portal vein, liver parenchyma, abdominal aorta, psoas muscle was measured. The estimated mean CNR (contrast-to-noise ratios), FOM (figure of merit), DLP (dose length product) and ED (effective dose) were compared between protocol A and B. Moreover, two radiologists assessed the visual quality of the CT images.
Results: The mean DLP and ED in the protocol B was about 50% lower than that in the protocol A ($p < 0.01$). The mean CT value of the portal vein and abdominal aorta in the protocol B were significantly higher than that in the protocol A ($p < 0.01$). All of the FOM in the protocol B was significantly higher than that in the protocol A ($p < 0.01$). However, there was no significant difference in the mean CNR and visual quality between protocol A and B.
Conclusion: Performance of abdominopelvic CT using a low tube voltage plus reduced CM dose (80-kVp, 60% CM) achieved reduction of the radiation dose without impairing image quality in relatively light weight group.
Clinical relevance/application: In abdominopelvic CT, protocol of low tube voltage (80-kVp) plus iodine dose reduction (60%) is able to provide the same quality of traditional protocols, also able to reducing radiation exposure (50%).

1. Introduction

Due to advances in equipment and image reconstruction techniques for computed tomography (CT), progress is being made in reducing the dose of contrast medium (CM) required for contrast-enhanced examinations compared with conventional protocols. If performing CT with CM is required in patients with renal dysfunction, it is particularly important to reduce the CM dose as much as possible [1–3]. It is also important for patients who need periodical follow-up scans in order to keep exposure as low as possible.

Reducing the CM dose used for imaging studies is known to be a useful preventive measure against contrast-induced nephropathy. Although contrast enhancement is attenuated when standard imaging is performed with a reduced dose of CM, it can be improved by using a low tube voltage because the X-ray energy becomes closer to the iodine k edge value of 33-keV [4–8].

On the other hand, the conventional filtered back projection (FBP) method of image reconstruction cannot effectively reduce noise in images obtained with a low tube voltage and a reduced dose of CM, which means that CT with a low voltage and low CM protocol had not been used much clinically [9, 10]. With the development of iterative reconstruction techniques, it became possible to reduce the noise in images obtained by using a low tube voltage and a low dose of CM, also resulting in decreased exposure to radiation [11–14].

Although there have been some reports about these techniques, no previous study has compared image quality in the same patient. Therefore, the present retrospective study was performed to compare image quality in same patients undergoing abdominopelvic CT by two protocols, which were a low tube voltage plus low dose CM protocol (80-kVp, 60% CM) and a conventional protocol (120-kVp, 100% CM) in late phase which the liver parenchyma got enough contrast enhancement.

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2. Materials and methods

This study received institutional review board approval and written informed consent to participation was obtained from all of the patients. Between March 2014 and December 2016, 22 consecutive patients were enrolled prospectively. The inclusion criteria were 1) renal insufficiency (estimated glomerular filtration rate (eGFR) < 45 mL/min/1.73 m^2) and 2) performance of conventional CT (120-kVp, 100% CM) without renal insufficiency during the 18-month period before registration in this study.

Exclusion criteria were as follows: 1) severe renal failure (eGFR < 30 mL/min/1.73 m^2), 2) previous adverse reaction to iodinated CM, and 3) possible or confirmed pregnancy.

All patients were examined with a 320-detector row CT scanner (Aquilion ONE™/ViSION FIRST Edition; Canon, Japan) using the following scan parameters: tube voltage of 80-kVp or 120-kVp; CT auto exposure control (AEC), standard deviation (SD) of 19 Hounsfield units (HU) at 5-mm slice collimation for 80-kVp imaging and 13 HU for 120-kVp imaging; variable tube current; detector configuration, 320 detectors with 0.5-mm slice thickness; beam collimation, 80 mm; rotation time, 0.5 s; pitch factor, 0.813; and reconstruction algorithm, adaptive iterative dose reduction 3D (AIDR 3D).

For standard imaging (Protocol A), the tube voltage was set at 120-kVp and the CM dose was 100% weight equivalent for each patient (eGFR range: 45.1 to 68.2; mean: 49.5; CM dose: 550–600 mgI/kg). For low voltage imaging (Protocol B), the tube voltage was set at 80-kVp and the CM dose was 60% weight equivalent for each patient (eGFR range: 35.2 to 42.4; mean: 44.2; CM dose: 330–360 mgI/kg).

With both protocols, contrast enhanced abdominopelvic CT was performed in the arterial phase (30 s after bolus tracking) and the late phase (180 s after bolus tracking). Scanning was always commenced at the top of the liver and proceeded in a cephalocaudal direction.

2.1. Estimation of the radiation dose

We obtained the dose length product (DLP) recorded for each patient by the CT scanner and we calculated the effective dose (ED) as DLP × 0.015 (tissue weighting factor by ICRP publication 102). The estimated mean DLP and ED were compared between protocols A and B.

2.2. Quantitative analysis

We measured the CT values of the portal vein, hepatic parenchyma, and abdominal aorta by setting circular regions of interest (ROIs) on a horizontal image at the portal vein level in the late phase. The size of each ROI was approximately 25 mm^2. The CT value of the hepatic parenchyma was measured in three liver ROIs (S2 or S3 and S4 of the left lobe and posterior segment of the right robe) not containing visible blood vessels, and the results were averaged. In addition, the CT value and the standard deviation (SD) were determined for the right and left psoas muscles at the pelvic inlet not including obvious fat, and the results were averaged. The contrast/noise ratio (CNR) was calculated as follows: CNR = {CT value (each part) − CT value (psoas muscle)}/SD (psoas muscle). In addition, the figure of merit (FOM) was calculated as follows: FOM = CNR^2/ED. Then the mean CT value, SD, CNR, and FOM were compared between protocols A and B. CT values were calculated by averaging the measurements obtained by two readers.

2.3. Qualitative analysis

The quality of images obtained with protocols A and B was assessed by two radiologists (R.Y. and K.A. with 14 and 11 years of experience, respectively), who assigned scores on a four-point scale for the following factors: image noise and beam hardening artifacts, image sharpness, contrast enhancement, and overall image quality.

Image noise and beam hardening artifacts were graded as follows: 1 = present and unacceptable, 2 = present and interfering with depiction of abdominal structures, 3 = present, but not interfering with depiction of abdominal structures, and 4 = minimal or absent. Sharpness was graded as follows: 1 = blurry, 2 = worse than average, 3 = better than average, and 4 = excellent. Contrast enhancement and overall image quality were graded as follows: 1 = unacceptable, 2 = acceptable, 3 = good, and 4 = excellent.

The average score of assessment by two radiologists was calculated in each protocols.

2.4. Statistical analysis

For comparisons between protocols A and B, normality of the data was first confirmed by the Kolmogorov-Smirnov test. Then the F test was performed to compare variances if normality was confirmed, after which *t*-tests were carried out. The Wilcoxon rank sum test was conducted when the data did not show normality. Differences of $p < 0.01$ were considered to indicate statistical significance. All analyses were performed with R statistical software (version 3.3.3; www.r-project.org/).

3. Results

3.1. Patient characteristics

The 22 patients included 13 men and 9 women aged from 52 to 88 years (mean age: 76.8 years) who weighed from 36 to 77 kg (mean: 55.5 kg). The average interval from the first CT study (protocol A) to the second CT study (protocol B) was about 12 months (range: 2–18 months). At the second CT study, all of the patients had renal dysfunction (absent at the first study) because of dehydration or chemotherapy.

3.2. Radiation exposure

Table 1 shows the estimated DLP and ED values for each protocol. Mean DLP and ED values were significantly lower with protocol B, i.e., low tube voltage CT at 80-kVp ($p < 0.01$). In particular, estimated ED was about 50% lower with protocol B than with protocol A (5.96 ± 1.84 mSv vs.11.91 ± 5.32 mSv, $p < 0.01$).

3.3. Quantitative image analysis

Table 2 displays the results of quantitative image analysis. The mean CT values of the portal vein and aorta were significantly higher with protocol B than with protocol A ($p < 0.01$), while mean CT values for the liver parenchyma and psoas muscle showed no significant differences between the 2 protocols. There was also no significant difference with regard to the mean standard deviation (SD) of the psoas muscle and all of the mean CNR values showed no significant differences. However, the FOM values were all significantly higher with protocol B than with protocol A ($p < 0.01$).

Table 1
Radiation exposure.

	Protocol A	Protocol B	p value*
DLP (mGy·cm)	794.33 ± 354.84	397.28 ± 123.29	< 0.01
ED (mSv)	11.91 ± 5.32	5.96 ± 1.84	< 0.01

Note: Data are the mean ± standard deviation.
DLP = dose length product, ED = effective dose.
* Paired *t*-test.