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Research article

Image quality and radiation dose of low-tube-voltage CT with reduced contrast media for right adrenal vein imaging

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ABSTRACT

Objectives: To compare image quality and radiation dose of right adrenal vein (RAV) imaging computed tomography (CT) among conventional, low kV, and low kV with reduced contrast medium protocols.
Methods: One-hundred-and-twenty patients undergoing adrenal CT were randomly assigned to one of three protocols: contrast dose of 600 mgI/kg at 120-kV tube voltage setting (600-120 group), 600 mgI/kg at 80 kV (600-80 group), and 360 mgI/kg at 80 kV (360-80 group). Iterative reconstruction was used for 80-kV groups. Signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) of the RAV and size-specific dose estimates (SSDE) were measured. Three radiologists evaluated 4-point visualisation scores of RAV by consensus reading.
Results: The RAV detectability was 95%, 97.2%, and 97.3% for 600-120, 600-80, and 360-80 groups, respectively ($p = 1.000$). Visualisation scores were not significantly different among the groups ($p = 0.152$). There were no significant differences in CNR or SNR between the 600-120 and 360-80 groups. SSDE of the 360-80 group was significantly lower than that of the 600-120 group (5.86 mGy ± 1.44 vs. 7.27 mGy ± 1.81, $p < 0.001$).
Conclusions: 80-kV scans with 360 mgI/kg contrast media showed comparable detectability of RAV to conventional scans, while reducing 19% of SSDE.

1. Introduction

Adrenal vein sampling (AVS) is considered the gold standard for diagnosis of primary aldosteronism (PA) [1]. To discuss the treatment strategy for PA, it is important to distinguish unilateral hyperaldosteronism from bilateral hyperaldosteronism. Therefore, successful AVS is required. However, AVS is technically challenging, especially in the right side because the right adrenal vein (RAV) is small and there are anatomical variations [2].

Contrast-enhanced multidetector computed tomography (MDCT) is used for the identification of RAV prior to AVS, and multiphase dynamic computed tomography (CT) examinations provide excellent detectability of RAV [3–5]. However, contrast-enhanced CT holds risks of radiation exposure and iodine-contrast-induced adverse side effects [6–8]. Contrast-induced acute kidney injury (CI-AKI) is a serious complication of iodinated contrast media [9]. Although the incidence of CI-AKI is low, it has been reported that patients with renal impairment or diabetes have increased risk of CI-AKI [10]. As for percutaneous coronary intervention, contrast media dose is a risk factor of acute kidney injury [11,12]. However, several studies have reported that intravenous contrast media is not associated with acute kidney injury among patients with normal renal function [13,14]. In the guidelines of the European Society of Urogenital Radiology, estimated glomerular filtration rate (eGFR) less than 45 ml/min/1.73 m^2 is considered as a risk factor of CI-AKI and even limited doses of contrast media may cause CI-AKI in high-risk patients [15]. Previous studies have reported that PA

Abbreviations: AP + LAT, the sum of anteroposterior length and lateral width; AVS, adrenal vein sampling; CI-AKI, contrast-induced acute kidney injury; CNR, contrast-to-noise ratio; $CTDI_{vol}$, the volume CT dose index; DLP, dose-length product; FBP, filtered back projection; IR, iterative reconstruction; MDCT, multidetector computed tomography; RAG, right adrenal grand; RAV, right adrenal vein; ROI, region of interest; SNR, signal-to-noise ratio; SSDE, size-specific dose estimate

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was associated with glomerular hyperfiltration, which was unmasked after treatment of aldosterone excess along with normalised blood pressure [16,17]. PA patients with apparently normal kidney function have potential of declines in eGFR after treatment of PA [16]. Therefore, it would be reasonable to reduce the amount of iodine contrast media for evaluation of RAV prior to AVS even if eGFR exceeded 60 ml/min/1.73 m^2.

Recent clinical studies have suggested that low-tube-voltage imaging enables radiation dose reduction. Moreover, using low tube voltage results in higher iodine contrast enhancement and enables dose reduction of contrast media [18,19]. Although low-tube-voltage imaging raises noise and decreases image quality, iterative reconstruction (IR) technique yields higher signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) and provides better image quality than the standard filtered back projection (FBP) [20]. Low-tube-voltage CT imaging can be applied without deterioration of image quality to large vessels, medium-sized vessels, and parenchymal organs [21–27]. However, it has not been proven whether low-tube-voltage CT imaging is also applicable for imaging of small venous structures such as RAV.

The purpose of this study was to compare RAV detectability and radiation doses among conventional and low-tube-voltage CT imaging protocols.

2. Materials and methods

This prospective randomised study received institutional review board approval in our institution, and informed consent was obtained from all participating patients.

2.1. Patient population

Between February 2015 and August 2016, 120 patients with known or suspected PA were consecutively enrolled. They were referred for MDCT examinations for evaluation of adrenal lesions and mapping of adrenal veins prior to AVS. The exclusion criteria were any of the following: (1) estimated glomerular filtration rate of < 60 ml/min/1.73 m^2 and (2) a history of allergic reaction to iodine contrast media.

2.2. MDCT protocol

All patients underwent CT using a dual-source MDCT scanner (SOMATOM Definition Flash, Siemens Healthcare, Forchheim, Germany) with a single-source acquisition mode. Patients were randomly assigned to one of three protocols: contrast dose of 600 mg iodine/kg body weight at conventional 120-kV tube voltage setting (600-120 group), 600 mg at 80 kV (600-80 group), and 360 mg at 80 kV (360-80 group). We generated a random number table using the RAND function in Excel 2013 (Microsoft, Seattle, WA) for patient randomisation. Referring to a previous study demonstrating RAV detectability of 93% [3], we performed power analysis assuming that the detectability of RAV by both the conventional and low-kVp protocols were 93% and we established the limit of the non-inferiority test to 15%. The required number of cases calculated with detection power of 80% and significance level of 5% was 36 cases per group. Considering inappropriate cases, we assigned 40 cases to each group. All images were reconstructed with filtered back projection (FBP). In the 80-kV setting, images were also reconstructed with IR (SAFIRE Strength 3, Siemens). We applied SAFIRE strength 3 which was routinely used for cardiovascular and body CT imaging at low kVp protocols. Quality reference mAs was set at 90 mAs in the 120-kV setting. In the 80-kV setting, it was automatically regulated to obtain almost the same image quality obtained from the 120-kV setting by using CARE kV technique. CARE kV technique can automatically suggest kV and effective mAs to optimise the contrast-to-noise ratio (CNR). Effective mAs was automatically regulated with Auto Exposure Control. The detailed scanning parameters are shown in Table 1.

Table 1
CT scan parameter.

	600-120	600-80	360-80
Rotation time (s)	0.5	0.5	0.5
Reconstruction kernel	B35f	B35f, I30f(3)	B35f, I30f(3)
Reconstructed slice thickness/interval (mm)	1/1	1/1	1/1
Collimation (slice count × mm)	128 × 0.6	128 × 0.6	128 × 0.6
Pitch	1.0	1.0	1.0
tube voltage (kV)	120	80	80
CARE kV setting	semi 80	semi 80	semi 80
maximum Effective mAs	48–202	135–322	89–322
minimum Effective mAs	38–144	76–321	43–321
contrast media injection (mgI/kg)	600*	600*	360
reference mAs	90	#1	#1

Effective mAs are the range.

* Some patients with large body (> 75 kg) were not able to be administered full dose of 600 mgI/kg due to the limitation dose of 45 g iodine per syringe.

1 Automatically regulated to obtain almost same level of image noise as 120 kV setting.

Four-phase dynamic imaging was performed. The amount of non-ionic contrast material administered via bolus injection was 600 or 360 mg iodine/kg body weight. One of the following contrast media was selected and injected at a speed of 3–5 ml/s: iohexol (240 mg iodine/ml in 100-ml syringe [Omnipaque 240, Daiichi-Sankyo, Tokyo, Japan], 300 mg iodine/ml in 100-ml and 150-ml syringes [Omnipaque 300, Daiichi-Sankyo], and 350 mg iodine/ml in 100-ml syringe [Omnipaque 350, Daiichi-Sankyo], 300 mg iodine/ml in 100-ml syringe [Iopaque 300, Fujipharma, Toyama, Japan]), iomeprol (300 mg iodine/ml in 100 ml syringe [Iomeron 300, Eisai, Tokyo, Japan]), or iopamidol (370 mg iodine/ml in 100-ml syringe [Iopamiron 370, Bayer Yakuhin, Osaka, Japan] and 300 mg iodine/ml in 100-ml syringe [Oypalomin 300, FujiPharma, Toyama, Japan]). However, injection speeds of < 3 ml at 240 mgI/ml for lean patients (< 50 kg) in the 360 mgI/kg group and that of > 5 ml/s at 300 mg/ml for obese patients (> 63 kg) in the 600 mgI/kg group were tolerated. In our clinical settings, only one syringe of contrast medium was administered per examination. The maximum dose was 45 g of iodine.

The injection time was fixed to 25 s and the injection speed was changed accordingly. The scan delay was set using an automatic triggering system. Early-arterial phase (1 st phase) scanning automatically started when the attenuation value at the abdominal aorta reached a preset threshold (CT value on native CT plus 50 Hounsfield Units). Late-arterial phase (2nd phase) scanning started 13 s after the 1 st phase completion. Venous phase (3rd phase) and delayed phase (4th phase) scanning began at 70 s and 3 min after contrast injection initiation, respectively.

2.3. Radiation dose

The volume CT dose index ($CTDI_{vol}$) and dose-length product (DLP) values provided by the CT scanner were recorded for each examination. We calculated size-specific dose estimates (SSDE) values according to the AAPM (American Association of Physicists in Medicine) Report 204 [28]. The sum of the lengths of the body in the anteroposterior and lateral directions at the level of adrenal glands (AP + LAT) was measured and conversion factors were obtained from the table in that report. Maximum and minimum effective mAs of scans were also recorded.

2.4. CT image interpretation

Three radiologists with experience of body radiology for 15 years (board-certificated), 5 years, and 5 years, respectively, performed image analysis. Scan protocols and patient's information were blinded.