

CT Angiography of the Renal Arteries: Comparison of Lower-Tube-Voltage CTA With Moderate-Concentration Iodinated Contrast Material and Conventional CTA

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OBJECTIVE. The objective of our study was to investigate the feasibility of an 80-kVp protocol using a moderate-concentration contrast medium (CM) for CT angiography of the renal arteries by comparison with a conventional 120-kVp protocol using a high-concentration CM.

SUBJECTS AND METHODS. Attenuation values and signal-to-noise ratios (SNRs) were determined in a phantom for the 120-kVp protocol with a high-concentration CM and the 80-kVp protocol with a moderate-concentration CM. In addition, 50 patients were prospectively enrolled in the study: 25 were scanned with 120 kVp and 200 effective mAs (mAs_{eff}) after the administration of 110 mL of high-concentration CM (370 mg I/mL), and the other 25 were scanned with 80 kVp and 585 mAs_{eff} after the administration of 110 mL of moderate-concentration CM (300 mg I/mL). Images of the two groups were compared in terms of arterial attenuation, SNR, contrast-to-noise ratio (CNR), and subjective degree of arterial enhancement and image quality.

RESULTS. The mean attenuation of the main renal artery was significantly higher ($p < 0.001$) in the 80-kVp group who received moderate-concentration CM (mean \pm SD, 370.0 ± 65.0 HU) than in the 120-kVp group who received high-concentration CM (269.9 ± 27.8 HU) without significant differences in SNR and CNR values. The 80-kVp protocol had significantly higher quality scores for arterial enhancement, sharpness of the artery, and overall diagnostic quality compared with the 120-kVp protocol. The effective dose of the 80-kVp protocol (4.5 mSv) was 8.2% lower than that of the 120-kVp protocol (4.9 mSv).

CONCLUSION. The use of 80 kVp with moderate-concentration CM could improve arterial enhancement and provide superior image quality with a smaller amount of iodine and a lower radiation dose.

Keywords: angiography, contrast media, CT angiography, radiation, renal artery, renovascular hypertension

DOI:10.2214/AJR.11.7450

Received June 30, 2011; accepted after revision November 3, 2011.

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AJR 2012; 199:96–102

0361–803X/12/1991–96

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CT angiography (CTA) is one of the well-established minimally invasive diagnostic procedures for the assessment of suspected renovascular hypertension [1–4]. Among the different types of CT contrast medium (CM) with various iodine concentrations [5], a high-concentration CM (350–370 mg I/mL) is usually preferable to increase vascular attenuation in CTA [2, 6]. Although no significant differences in the incidence and severity of acute adverse reactions between a high-concentration CM (370 mg I/mL) and a moderate-concentration CM (300 mg I/mL) have been reported [5, 7], to our knowledge, a high-concentration CM has a higher risk of medullary hypoxic injury or direct toxicity to the renal tubular cells resulting in contrast-induced nephropathy (CIN) than a CM with a lower osmolality or lower viscosity [8–11].

Taking advantage of reducing the radiation dose and CM amount and increasing the attenuation values in the vasculature, the use of lower tube voltages for greater photoelectric effect and lesser Compton scattering for the iodine has recently been proposed for CTA of various organs [3, 12–14]. In the current study, we applied a volume of moderate-concentration CM that was equal to the volume of conventional high-concentration CM for CTA of the renal arteries and used a lower tube voltage setting to compensate for decreased vascular attenuation values. The purpose of our study was to investigate the feasibility, in terms of vessel attenuation, image quality, and radiation dose, of a lower-tube-voltage (80-kVp) protocol with a moderate-concentration CM as compared with a conventional higher-voltage (120-kVp) protocol with a high-concentration CM for CTA of the renal arteries.

Subjects and Methods

We performed a phantom study to compare the attenuation values and signal-to-noise ratios (SNRs) for two different iodine concentration CMs (high-concentration CM vs moderate-concentration CM) and two different tube voltages (80 vs 120 kVp). This comparison enabled us to quantify the increase in enhancement at different settings. Subsequently, two groups of patients who were scheduled to undergo CTA of the renal arteries were included in a clinical study to compare image quality at 80 and 120 kVp.

Phantom Study

We used a cylindrical water phantom with a diameter of 300 mm to simulate the abdomen of intermediate-weight patients (estimated body weight, 72–85 kg) [15, 16]. A 25-mm-diameter tube filled with diluted CM was inserted into the center of the phantom (Fig. 1). We prepared 12 different CM concentrations (0.0%, 0.2%, 0.4%, 0.6%, 0.8%, 1.0%, 2.0%, 3.0%, 4.0%, 5.0%, 7.0%, and 10.0%) by diluting CM with distilled water and got two sets of 13 different CM concentrations using a moderate-concentration CM (iopromide 300 mg I/mL [Ultravist 300, Schering Korea]) and a high-concentration CM (iopromide 370 mg I/mL [Ultravist 370, Schering Korea]). We used tube voltage settings of 80 and 120 kVp and chose the effective tube current settings so that the phantom volume CT dose index ($CTDI_{vol}$) was as close as possible to 11.8 mGy for the two protocols. This was achieved by using a pitch of 0.486, a rotation time of 0.75 second, an FOV of 200 mm, and 655 effective mAs (mAs_{eff}) with 80 kVp and 200 mAs_{eff} with 120 kVp.

Attenuation was measured using a region of interest (ROI) ($\approx 100 \text{ mm}^2$) in the middle of the tube. Image noise was defined as the average of the SD of the attenuation values measured at the 12-, 3-, 6-, and 9-o'clock positions and at the center of the phantom. Measurements were obtained at five equidistant levels along the z-axis to correct for variations in noise over the phantom. The SNR of the tube filled with diluted CM was calculated using the following formula: $SNR = \text{mean attenuation value of the tube} / SD$. The CT attenuation value of a contrast-enhanced structure actually corresponds to the contrast between that structure and water because CT attenuation values are normalized to water (0 HU). Therefore, the SNR in the phantom can also be interpreted as a contrast-to-noise ratio (CNR) in which contrast is defined as the difference in CT attenuation value between the contrast-enhanced structure and water. The mean attenuation and SNR of the tube in the phantom were plotted against CM concentration. Data were analyzed with linear regression analysis and by calculating Pearson correlation coefficients.



Fig. 1—Photograph shows 300-mm-diameter cylindrical water phantom used to mimic abdomen of intermediate-size patients. For imaging, 25-mm-diameter tube filled with diluted contrast material was inserted into center of phantom.

Patients

The institutional review board reviewed and approved the study protocol, and written informed consent was obtained from all patients. We prospectively enrolled 50 consecutive patients who were referred for CTA of the renal arteries for evaluation of renovascular hypertension. MR angiography of the renal arteries was not available at our institution. All patients were randomly assigned to undergo CT performed using either 120 kVp ($n = 25$) or 80 kVp ($n = 25$). All of the enrolled patients had normal renal function and were male because of the nature of the institution; the mean age of the patients was 21.4 ± 2.8 (SD) years (age range, 18–34 years).

Imaging Techniques

All patients were examined using a 64-MDCT scanner (Brilliance 64, Philips Healthcare). We used a 120-kVp tube voltage with the following scanning parameters from the standard protocol used in daily practice at our institution: collimation of 64×0.625 mm, pitch of 0.641, rotation time of 0.75 second, and exposure setting of 200 mAs_{eff} with dose modulation (D-Dom, Philips Healthcare). This standard protocol resulted in a $CTDI_{vol}$ of 11.8 mGy. The scanning volume extended from the diaphragm to the iliac crest, and the images were reconstructed using a section thickness of 1.0 mm without overlap. For the 80-kVp protocol, we used the same scanning and reconstruction parameters except for the effective tube current–time product. The tube current settings were intended to result in a CTDI that was as close as possible to that of the 120-kVp protocol. However, at a pitch of 0.641 and a rotation time of 0.75 second, the maximum tube current available on the scanner was only 585 mAs_{eff} and not 655

mAs_{eff} as would have theoretically been required. Therefore, the resultant $CTDI_{vol}$ was 10.5 mGy.

A total volume of 110 mL of CM, which was warmed to body temperature (37°C), and a 50-mL saline chaser were administered with a dual-head power injector (Dual Shot, Nemoto Kyorindo) at 5.0 mL/s through an 18-gauge cannula placed in the antecubital vein of the right arm. For the 120-kVp protocol, high-concentration CM (Ultravist 370) was used and had an osmolality and viscosity of 0.77 Osm/kg H_2O and 10 $\text{mPa} \cdot \text{s}$ at 37°C , respectively. For the 80-kVp protocol, moderate-concentration CM (Ultravist 300) was used and had an osmolality and viscosity of 0.59 Osm/kg H_2O and 4.7 $\text{mPa} \cdot \text{s}$ at 37°C , respectively. An automatic bolus-tracking program (Bolus Pro Ultra, Philips Healthcare) was used for initiating arterial phase scanning after CM injection.

An ROI was placed in the abdominal aorta at the level of the diaphragm, and a threshold of 150 HU for peak enhancement in the abdominal aorta was selected for triggering arterial phase imaging. The 1.0-mm-thickness reconstruction images were sent to online workstations. One workstation (Extended Brilliance Workspace, Philips Healthcare) was used for quantitative image analysis and another workstation (Aquarius iNtuition, TeraRecon) was used for qualitative image analysis.

Data Analysis

For quantitative evaluation, attenuation was measured in both renal arteries, 1 cm from their origin. ROIs were drawn as large as the vessel lumen; wall calcifications that might cause artifacts were avoided (range of ROI sizes, 11.6–45.0 mm^2). A board-certified radiologist with 5 years of experience interpreting abdominal CT performed all of the measurements. The SD, which serves as a quantitative marker of the image noise, and the attenuation of the right psoas muscle were measured at the level of the lower pole of the right kidney using a 200- mm^2 ROI [17]. To minimize bias from the use of a single measurement, we obtained three measurements for each of the following: the attenuation of the renal artery, image noise, and the attenuation of the psoas muscle. The mean of these values was used for further calculations. The SNR and CNR of the renal arteries were calculated using the following formulas: $SNR = \text{mean attenuation value} / \text{image noise}$; and $CNR = (\text{mean attenuation value} - \text{psoas muscle attenuation value}) / \text{image noise}$ [17].

Qualitative image analysis was performed on a workstation for the volume-rendering image, three (axial, coronal, sagittal) orthogonal maximum intensity projections, and curved multiplanar reconstruction of the renal arteriography. Two radiologists, with 6 and 3 years of experience in visceral vascular imaging, independently assessed the over-

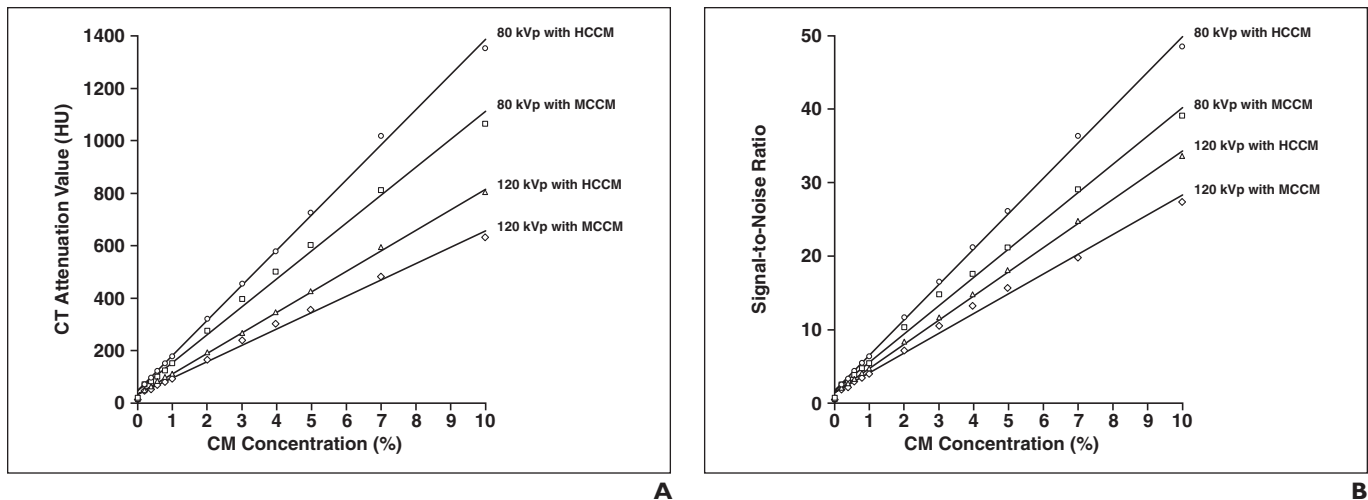


Fig. 2—Graphs show results of phantom study. **A**, Graph shows relationship between CT attenuation value and contrast material (CM) concentration. Relationship between CT attenuation value and CM concentration was as follows: for 80 kVp with high-concentration CM (HCCM), $y = 134.5x + 42.5$ ($r = 0.998$); for 80 kVp with moderate concentration CM (MCCM), $y = 106.1x + 49.2$ ($r = 0.995$); for 120 kVp with high-concentration CM, $y = 78.3x + 30.2$ ($r = 0.999$); and for 120 kVp with moderate-concentration CM, $y = 62.5x + 32.4$ ($r = 0.996$). **B**, Graph shows relationship between signal-to-noise ratio (SNR) and contrast medium (CM) concentration. Relationship between SNR and CM concentration was as follows: for 80 kVp with high-concentration CM (HCCM), $y = 4.8x + 1.7$ ($r = 0.998$); for 80 kVp with moderate-concentration CM (MCCM), $y = 3.8x + 1.9$ ($r = 0.996$); for 120 kVp with high-concentration CM, $y = 3.3x + 1.4$ ($r = 0.999$); and for 120 kVp with moderate-concentration CM, $y = 2.7x + 1.5$ ($r = 0.993$).

all diagnostic image quality for the renal arteries using the following 5-point scale: 1, nondiagnostic image quality; 2, substandard image quality; 3, standard image quality; 4, better-than-standard image quality; or 5, excellent image quality. Arterial enhancement and the sharpness of the artery boundary were recorded using the following 5-point scale: 1, bad; 2, poor; 3, moderate; 4, good; or 5, excellent. Readers also rated image noise as follows: 1, major, no diagnosis possible; 2, substantial; 3, moderate, acceptable; 4, minor; or 5, no graininess. The CT datasets were randomized, and the readers were blinded to the technical scanning parameters. Before beginning their assessments, the readers were instructed on the criteria for image grading, and as a group they assessed five test cases that were not included in the study to reduce interobserver variability. When the readers assessed arterial enhance-

ment and image noise subjectively, window level and width settings were fixed to 200 and 600 HU, respectively, to compare the two protocols.

The $CTDI_{vol}$ and dose-length product, which were provided by the scanner system after scanning, were recorded, and an approximation of the effective dose was calculated for every patient by multiplying the dose-length product by 0.015 mSv/(mGy × cm) [18–20].

Statistical Analysis

All statistical analyses were performed using statistics software (SPSS, version 13.0, SPSS) for Microsoft Windows. The characteristics of the two patient groups (age, height, weight, and body mass index) were compared using the Student *t* test for unpaired samples. The Mann-Whitney *U* test was used to analyze the differences in attenuation of the

renal artery, attenuation of the psoas muscle, image noise, SNR, CNR, $CTDI_{vol}$, and effective dose and in the subjective scores of the 80- and the 120-kVp protocols. The linear weighted kappa statistic was used to assess interreader agreement with respect to scoring and was interpreted using the guidelines of Landis and Koch [21]. Differences were considered significant when the *p* value was < 0.05.

Results

We found a linear relationship between CM concentration and CT attenuation value and between CM concentration and SNR for 120 and 80 kVp (Fig. 2). CT attenuation values and SNRs at 80 kVp with moderate-concentration CM were 38.3% and 18.2% higher than those at 120 kVp with high-concentration CM, respectively (Fig. 3).

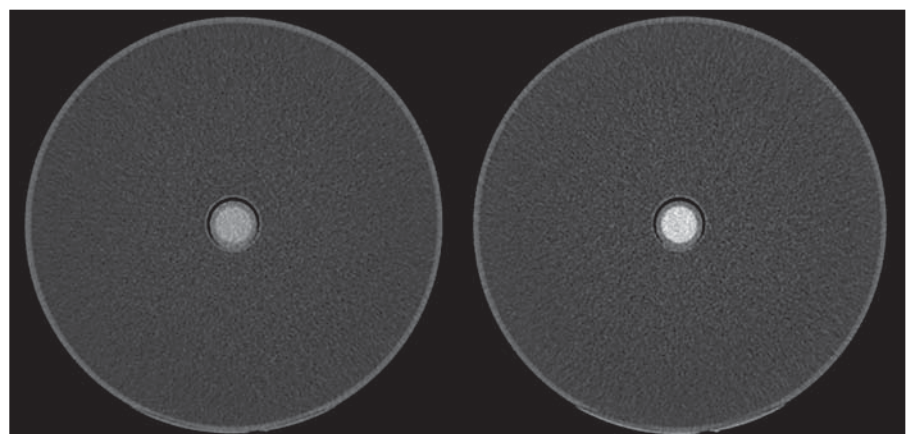


Fig. 3—Transverse 1-mm-thick CT scans of phantom obtained using 120-kVp protocol (left) with 3% high-concentration contrast material (CM) and 80-kVp protocol (right) with 3% moderate-concentration CM; 3% concentration of CM in tube had mean CT attenuation value most similar to that of renal arteries in clinical study (120 kVp with high-concentration CM, 269.9 HU; 80 kVp with moderate-concentration CM, 370.0 HU). CT attenuation value and signal-to-noise (SNR) at 120 kVp with 3% high-concentration CM were 269.0 HU and 11.6, respectively. CT attenuation value and SNR at 80 kVp with 3% moderate-concentration CM were 396.0 HU and 14.8, respectively.

CTA of the Renal Arteries

TABLE 1: Characteristics of Patients in Two Protocols

Patient Characteristics	120-kVp Protocol	80-kVp Protocol	<i>p</i> ^a
Age (y)	21.4±2.6	21.3±3.0	0.921
Height (cm)	174.2±5.9	177.2±3.4	0.104
Weight (kg)	72.7±5.2	79.2±10.3	0.053
Body mass index (kg/m ²)	24.0±2.0	25.2±3.1	0.242

Note—Data are presented as mean ± SD.

^aDifference is significant when *p* value is < 0.05.

There was no statistically significant difference with respect to patient age, height, weight, and body mass index between the patients in the 120-kVp group who received high-concentration CM and those in the 80-kVp group who received moderate-concentration CM (Table 1). Thus, further analysis and comparison of attenuation measurements and radiation exposure were considered to be feasible and valid. Only one patient had renal artery stenosis caused by fibromuscular dysplasia.

The mean attenuations at the renal artery were 370.0 ± 65.0 HU (range, 259.1–481.7 HU) for the 80-kVp protocol (Fig. 4) and 269.9 ± 27.8 HU (range, 215.3–321.3 HU) for the 120-kVp protocol (Fig. 5), yielding a mean difference of 100.1 HU (*p* < 0.001).

These data indicated a 37.1% increase in arterial attenuation at 80 kVp compared with arterial attenuation at 120 kVp. The mean attenuation of the psoas muscle and image noise (SD of the attenuation of the psoas muscle) using the 80-kVp protocol was a mean of 5.9 and 8.4 HU higher than those of the 120-kVp protocol, respectively. Although the noise level was significantly higher, the SNR and CNR at 80 kVp were not significantly different from those of the 120-kVp protocol (Table 2).

The linear weighted kappa value for the scoring of both protocols by the two readers was 0.748. There was substantial agreement between the two readers in subjective ratings about image quality. In qualitative image analysis, we found that images acquired

using 80 kVp were rated significantly better than those from the 120-kVp group with regard to arterial enhancement, sharpness of the artery boundary, and overall diagnostic image quality (Table 3). The subjective score for image noise in the 120-kVp protocol was higher than that in the 80-kVp protocol, but there was no statistically significant difference in qualitative image analysis (Table 3).

The mean CTDI_{vol} and estimated effective dose were significantly lower in the 80-kVp group than in the 120-kVp group (Table 2). Thus, the average reduction in the mean CTDI_{vol} and estimated effective dose from 120 to 80 kVp were 13.6% and 8.2%, respectively.

Discussion

The x-ray absorption of iodine increases with the use of a lower tube voltage as long as the mean effective energy of the polychromatic x-ray is closer to the k-edge of iodine (33.2 keV). Therefore, reducing the tube voltage increases the photoelectric effect and decreases Compton scattering, which lead to a higher mean attenuation value of iodine [22]. The mean photon energy in the x-ray spectrum was reported to be 56.8 keV when 120 kVp was used and 43.7 keV when 80 kVp was used [23]. Like our

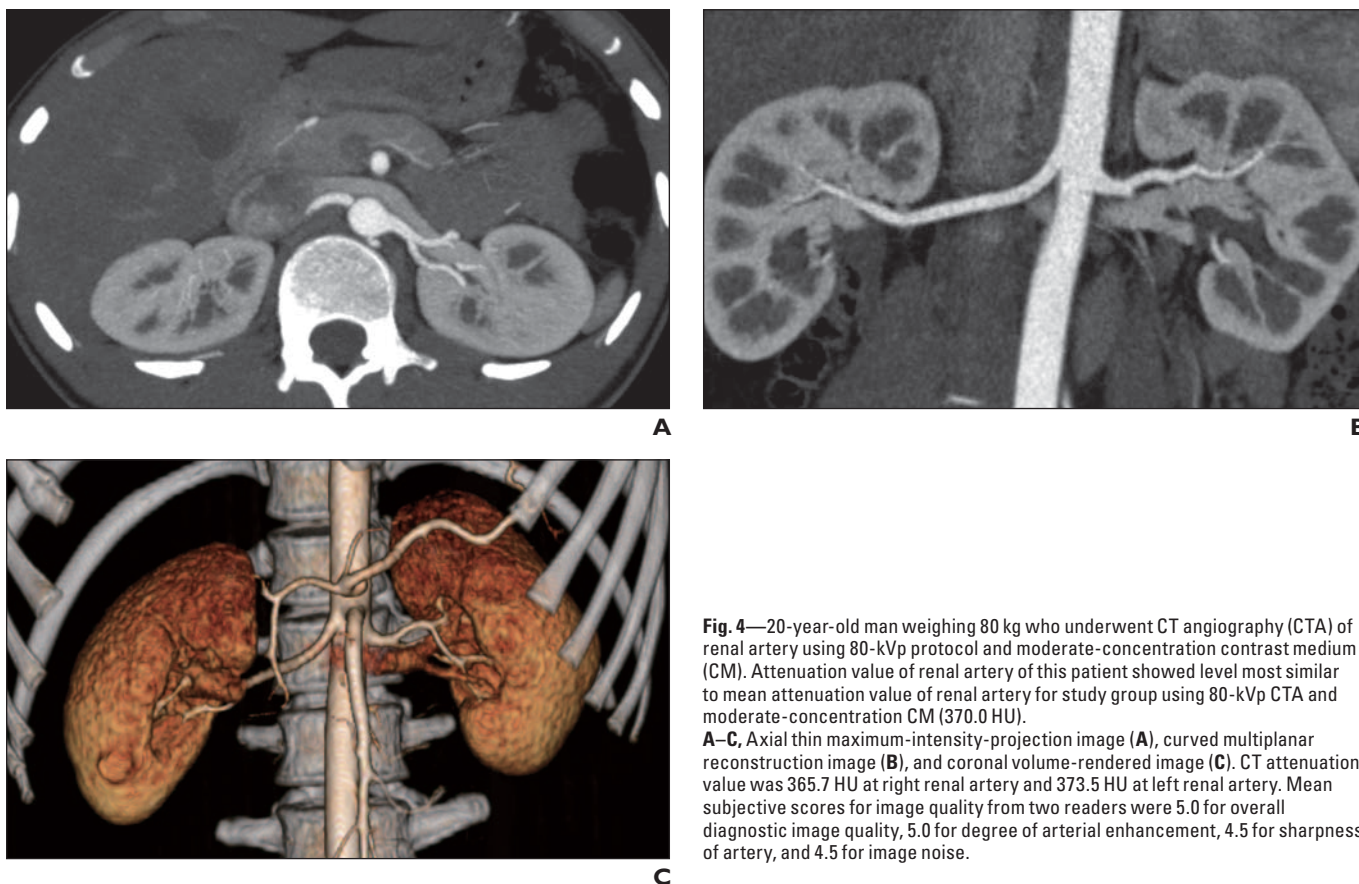


Fig. 4—20-year-old man weighing 80 kg who underwent CT angiography (CTA) of renal artery using 80-kVp protocol and moderate-concentration contrast medium (CM). Attenuation value of renal artery of this patient showed level most similar to mean attenuation value of renal artery for study group using 80-kVp CTA and moderate-concentration CM (370.0 HU).

A–C, Axial thin maximum-intensity-projection image (**A**), curved multiplanar reconstruction image (**B**), and coronal volume-rendered image (**C**). CT attenuation value was 365.7 HU at right renal artery and 373.5 HU at left renal artery. Mean subjective scores for image quality from two readers were 5.0 for overall diagnostic image quality, 5.0 for degree of arterial enhancement, 4.5 for sharpness of artery, and 4.5 for image noise.

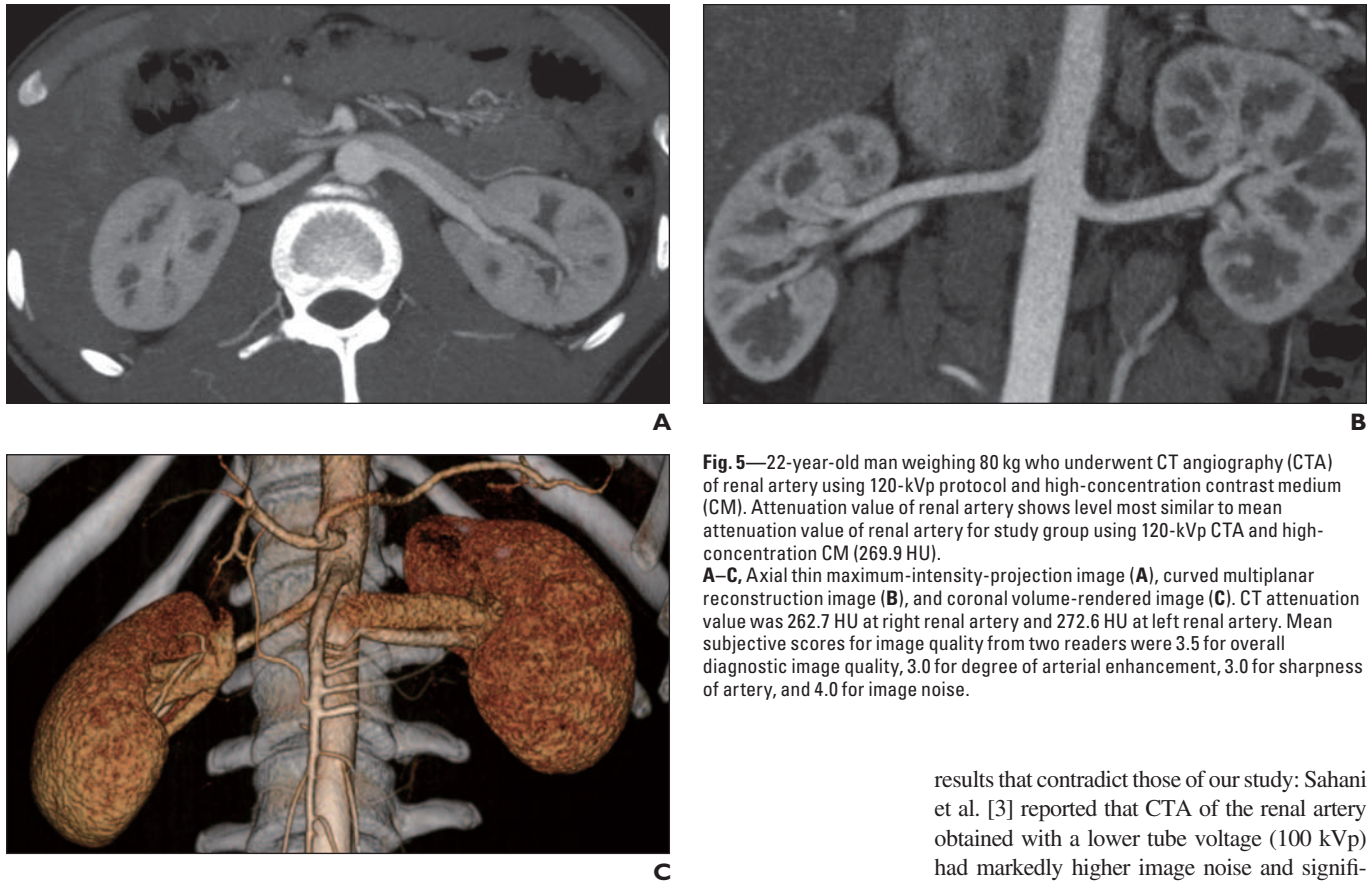


Fig. 5—22-year-old man weighing 80 kg who underwent CT angiography (CTA) of renal artery using 120-kVp protocol and high-concentration contrast medium (CM). Attenuation value of renal artery shows level most similar to mean attenuation value of renal artery for study group using 120-kVp CTA and high-concentration CM (269.9 HU). **A–C**, Axial thin maximum-intensity-projection image (**A**), curved multiplanar reconstruction image (**B**), and coronal volume-rendered image (**C**). CT attenuation value was 262.7 HU at right renal artery and 272.6 HU at left renal artery. Mean subjective scores for image quality from two readers were 3.5 for overall diagnostic image quality, 3.0 for degree of arterial enhancement, 3.0 for sharpness of artery, and 4.0 for image noise.

baseline assumption before this study, previous reports suggest that the use of 80 kVp instead of 120 kVp in CT could shift the mean photon energy closer to the k-edge of iodine and improve vascular enhancement [24]. The results of this study confirmed that vascular enhancement was higher on CTA acquired with 80 kVp and moderate-concentration CM and that subjective image quality of CTA acquired with 80 kVp and moderate-concentration CM was bet-

ter than that acquired with 120 kVp and high-concentration CM even though the mean CT-DI_{vol} and estimated effective dose were 13.6% and 8.2% lower using the 80-kVp protocol. Subjective scores for vascular enhancement and sharpness of vessel boundary showed improvement when using 80 kVp with moderate-concentration CM.

One study that used a lower tube voltage for CTA of the renal artery in a clinical setting had

results that contradict those of our study: Sahani et al. [3] reported that CTA of the renal artery obtained with a lower tube voltage (100 kVp) had markedly higher image noise and significantly lower subjective image quality when compared with images obtained with a higher tube voltage (120 or 140 kVp). The principal difference between our study and that of Sahani et al. was that Sahani and coworkers did not sufficiently increase the effective tube current-time product at the lower tube voltage setting, although they used automatic current tube modulation. This difference in protocol resulted in an approximate 30% reduction in the radiation dose at the 100-kVp setting compared

TABLE 2: Comparison of Two CT Angiography Protocols for Imaging the Renal Artery

Value	120-kVp Protocol With High-Concentration ^a CM	80-kVp Protocol With Moderate-Concentration ^b CM	<i>p</i> ^c
Effective mAs	200	585	
Renal artery attenuation (HU)	269.9 ± 27.8	370.0 ± 65.0	< 0.001
Psoas muscle attenuation (HU)	49.1 ± 5.4	55.0 ± 6.4	< 0.001
Image noise (HU)	20.4 ± 3.6	28.8 ± 4.8	< 0.001
Signal-to-noise ratio	13.6 ± 2.7	13.2 ± 3.1	0.279
Contrast-to-noise ratio	11.1 ± 2.3	11.2 ± 2.9	0.836
CTDI _{vol} (mGy)	10.3 ± 0.2	8.9 ± 0.2	< 0.001
Effective dose (mSv)	4.9 ± 0.4	4.5 ± 0.3	< 0.001

Note—Excluding mAs and *p* values, data are mean ± SD. CM = contrast medium, CTDI_{vol} = volume CT dose index.

^a370 mg I/mL.

^b300 mg I/mL.

^cDifference is significant when the *p* value is < 0.05.

TABLE 3: Subjective Scoring of Two CT Angiography Protocols Using Pooled Data From Two Observers

Parameter	Score (Mean \pm SD)		p^a
	120-kVp Protocol	80-kVp Protocol	
Arterial enhancement ^b	3.4 \pm 0.5	4.2 \pm 0.7	<0.001
Sharpness of artery boundary ^b	3.7 \pm 0.7	4.2 \pm 0.6	<0.001
Image noise ^c	3.9 \pm 0.4	3.8 \pm 0.6	0.304
Overall diagnostic quality ^d	3.6 \pm 0.5	4.3 \pm 0.7	<0.001
Total score	3.6 \pm 0.6	4.1 \pm 0.7	<0.001

^aDifference is significant when p value is < 0.05.

^b1, bad; 2, poor; 3, moderate; 4, good; or 5, excellent.

^c1, major, no diagnosis possible; 2, substantial; 3, moderate, acceptable; 4, minor; or 5, no graininess.

^d1, nondiagnostic image quality; 2, substandard image quality; 3, standard image quality; 4, better-than-standard image quality; or 5, excellent image quality.

with the 120-kVp setting but led to a substantial increase in noise, which explains the reduced image quality at the lower tube voltage setting [13].

An increase of the CT attenuation of iodine achieved by reducing tube voltage will inevitably be accompanied by an increase in image noise, whereas lowering the tube voltage also substantially reduces patient exposure. Although we increased the tube current-time product at the lower tube voltage setting to compensate for increased image noise, the SD of the psoas muscle, which was a quantitative marker of the image noise, was 8.4 HU higher in the 80-kVp protocol than in the 120-kVp protocol ($p < 0.001$). The subjective score for image noise in the 120-kVp protocol was also better than that in the 80-kVp protocol, but the difference was not statistically significant. Although a lower concentration of iodinated CM was used for the 80-kVp protocol, there was no significant difference in SNR or CNR between the 80-kVp protocol and the 120-kVp protocol.

Three major pathways have been proposed to explain the mechanism of CIN by the effect of CM [25–27]: hemodynamic effects with decreased renal blood flow that induces renal medullary hypoxia; direct CM-mediated molecular toxicity to the renal tubular epithelial cells; and endogenous biochemical disturbances, such as an increase in oxygen-free radicals [26, 28, 29]. Investigators have suggested that the osmotic diuresis caused by hyperosmolar CM might be greater, which may lead to prolonged reduction of renal blood flow with increased medullary work and consequent renal hypoxia [9, 10]. Meanwhile, high-viscosity CM also causes significantly more cases of CIN than CM with a lower viscosity [8, 11]. The renal medulla is supplied by very long-reaching vasa recta that depend on a reduction

in blood viscosity to maintain their low vascular resistance (Fahraeus-Lindqvist effect). CM seems to directly diminish renal medullary blood flow by increasing plasma viscosity. Moreover, because CM is freely filtered to the renal tubules without being reabsorbed, tubular fluid becomes viscous and may cease to flow [8, 30]. Slow tubular flow also increases the exposure time of CM to the epithelial surface and renal tubular damage. As a result, increased plasma viscosity by CM directly impairs blood flow to the renal medulla by vascular and tubular mechanisms [8], which may induce renal medullary hypoxia and CIN.

Because osmolality measures the concentration of particles in solution, the osmolality of CM is proportional to its concentration and the relationship between concentration and viscosity is exponential [30, 31]. The high-concentration CM used in this study had 30.5% higher osmolality and 112.8% higher viscosity than the moderate-concentration CM. The use of high-concentration CM provides greater arterial enhancement and image quality in CTA when compared with the use of moderate-concentration CM [2]. However, high-concentration CM might increase the risk of CIN, especially in patients at high risk of CIN, because it has higher osmolality and viscosity. When moderate-concentration CM was used in this study, we applied a lower tube voltage (80 kVp) and found that arterial attenuation was higher than that when using the 120-kVp protocol with high-concentration CM.

Our study had some limitations. First, all of the enrolled patients in this study were of normal weight or were overweight; none of the participants were obese. Therefore, in the case of an obese patient with arteriosclerosis and stenosis of the renal artery, we should consider either adjusting tube voltage or current or

applying an iterative reconstruction to reduce image noise; this issue needs further investigation. Second, this study did not include patients at high risk for CIN and evaluations of renal function after the administration of high-concentration CM and of moderate-concentration CM were not performed. We wanted to verify the value of the lower tube voltage setting (80-kVp protocol) with moderate-concentration CM first in patients with normal renal function before taking the risk with high-risk patients. Further practical studies are needed to compare the effects of high-concentration CM and moderate-concentration CM administration on renal function. Third, because there was only one patient with renal artery stenosis, which was different from our expectation, we could not compare diagnostic accuracy of CTA for renal artery stenosis between 80- and 120-kVp protocols. In addition, there were no patients with atherosclerotic calcifications at the renal artery in this study because there were only a few elderly patients in our study group given the nature of our institution. However, because a 80-kVp protocol showed no difference in detection and quantification of coronary artery calcification and image quality and a 65% reduction of the radiation dose when compared with a 120-kVp protocol in a previous report [32], we expected that the 80-kVp setting for CTA of the renal artery would not affect diagnostic image quality in patients with atherosclerotic calcifications.

In conclusion, the use of 80 kVp with a moderate-concentration CM for CTA of the renal artery substantially improved arterial enhancement, showing similar SNR and CNR when compared with images acquired using a 120-kVp protocol with a high-concentration CM, even though the amount of iodine was reduced by 18.9%. Furthermore, the 80-kVp protocol showed subjective image quality superior to the 120-kVp protocol even though the effective dose was reduced by 8.2%. We expect that the use of moderate-concentration CM could reduce CIN in high-risk patients because high-concentration CM has higher osmolality and higher viscosity than moderate-concentration CM.

Acknowledgments

We thank J. H. Seo for vital assistance in initiating this study and Y. S. Lee for expert technical assistance.

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