Radiation Dose Reduction at Multidetector CT with Adaptive Statistical Iterative Reconstruction for Evaluation of Urolithiasis: How Low Can We Go?1

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Purpose:
To evaluate the performance of computed tomographic (CT) examinations at 80 and 100 kV with tube current-time products of 75–150 mA and the effect of adaptive statistical iterative reconstruction (ASIR) on CT image quality in patients with urinary stone disease.

Materials and Methods:
In this HIPAA-compliant institutional review board–approved study, verbal consent for prospective low-dose CT and waivers of consent for retrospective review of CT scans were obtained. Between November 2010 and April 2011, 25 patients (15 men, 10 women; mean age, 35 years) with urolithiasis underwent 64-section multidetector CT with 75–150 mA and noise index of 30. Modified protocol was based on body weight (<200 lb [90 kg], 80 kV; >200 lb [90 kg], 100 kV). Images of 5-mm section thickness were reconstructed with filtered back projection (FBP) and 60% and 80% ASIR techniques, with 3-mm coronal and sagittal reformations. Two readers independently reviewed FBP and ASIR data sets for image quality (scale, 1–5), noise (scale, 1–3), and calculi (number, size, location). Confidence levels for urolithiasis and alternate diagnoses were rated (scale, 1–3). In 13 patients, FBP CT images acquired with the reference standard departmental protocol were available for comparison. Radiation dose was compared between imaging series. Statistical analysis was performed with Wilcoxon signed rank and paired t tests.

Results:
Modified-protocol FBP images showed low image quality (score, 2.5), with improvement on modified-protocol ASIR images (score, 3.4) ($P = .03$). All 33 stones (mean diameter, 6.1 mm; range, 2–28 mm) at modified-protocol CT were diagnosed by both readers. In 20 of 25 patients (80%), ASIR images were rated adequate for rendering other diagnoses in the abdomen (score, 2.0), as opposed to FBP images (score, 1.3). Mean radiation dose for modified-protocol CT was 1.8 mGy (1.3 mGy for patients < 200 lb; 2.3 mGy for patients > 200 lb) in comparison with 9.9 mGy for reference-protocol CT ($P = .001$).

Conclusion:
Image quality improvements with ASIR at reduced radiation dose of 1.8 mGy enabled effective evaluation of urinary calculi without substantially affecting diagnostic confidence.

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Urolithiasis is a common problem, with a lifetime incidence of 5%–10% in the United States. Recurrence is also common, with as many as 75% of those with a single-stone episode experiencing a recurrence during their lifetime. Recent trends have shown that the incidence of urolithiasis may be increasing (1,2). Imaging is integral to the management of acute and chronic urolithiasis. In adults, multidetector computed tomography (CT) has emerged as the first line of investigation in many centers because of its high sensitivity (95%–96%) and specificity (97%–100%) for the diagnosis of urolithiasis (3–6).

Historically, conventional abdominal radiography (of the kidneys, ureters, and bladder), intravenous excretory urography, and renal ultrasonography (US) were commonly used for evaluation of patients suspected of having renal or ureteral calculi. While these modalities continue to be useful, they have been largely replaced by multidetector CT for reasons stated previously (3–6). Purported advantages of conventional abdominal radiography and intravenous excretory urography include a substantially reduced radiation dose delivered by these techniques as compared with standard CT. Although the radiation dose from conventional imaging techniques such as two-view radiography and excretory urography ranges from 0.6 to 3.4 mSv, the stone detection rate with these modalities is substantially lower than that with CT (50%–70% for radiography, 70%–90% for urography), and excretory urography also carries the additional requirement of intravenous contrast material administration (7,8). Renal US does not deliver ionizing radiation, but its performance is limited by a patient’s body habitus, the experience of the operator, and stone size and location (kidney vs ureter) (9).

On the other hand, multidetector CT has a high sensitivity (95%–96%) and specificity (97%–100%) for the detection of urolithiasis and may also demonstrate an alternate cause of abdominal and/or flank pain (7–11). However, multidetector CT exposes the patient to substantial ionizing radiation. The lifetime risk from cumulative radiation exposure is elevated further in young patients, who often require multiple CT examinations to treat the urolithiasis (2,12–16). Some investigators have calculated the median effective radiation dose from a single unenhanced abdominal and pelvic CT examination to be 15 mSv (range, 10–20 mSv), with an estimated mean lifetime cancer risk as high as 20 cancer incidents per 10000 CT examinations when exposed at 3 years of age to as low as three cancers per 10000 CT examinations when exposed at 70 years of age. However, a statement from the American Association of Physicists in Medicine does not encourage the estimate of lifetime cancer risk on the basis of radiation dose at this low range (17). In spite of this factor, there continues to be fear of introducing cancer risk, which decreases the use of CT for a variety of indications, especially in young patients. Therefore, radiation dose reduction is essential for minimization of concerns about CT for both patients and physicians (18–20).

Efforts have already been made to decrease the CT radiation dose for CT examination of urinary calculi, with a few investigators (21–25) reporting an estimated dose in the range of 0.7–4.2 mSv. However, low-dose approaches introduce excessive noise on images reconstructed with a conventional filtered back projection (FBP) technique, which can negatively affect the reader’s confidence in rendering a diagnostic interpretation. To improve image quality, iterative reconstruction techniques have been made available commercially by few vendors (19,20). Owing to the demanding computation process required with iterative techniques, a partial iterative approach, such as adaptive statistical iterative reconstruction (ASIR), was introduced. This technique functions by modeling the statistical variations in the distribution of the image noise to improve signal-to-noise ratio, while preserving the image contrast (19,20). Indeed, several investigators have validated the use of ASIR in improving the image quality of images obtained at abdominal CT examinations performed at a 20%–50% lower radiation dose (18–20).

The purpose of our study was to evaluate the performance of CT examinations at 80 and 100 kV with 75–150 mA and the effect of ASIR on CT image quality in patients with urinary stone disease.

**Advances in Knowledge**

- Adaptive statistical iterative reconstruction improves the image quality of CT performed with 80 and 100 kV and a tube current–time product of 75–150 mA at a mean radiation dose of 1.8 mGy, as compared with the filtered back projection (FBP) technique for effective evaluation of calculi in the urinary tract.
- Use of our modified CT approach in an average-sized patient (less than 200 lb [90 kg]) substantially reduces radiation dose to as low as 1.3 mGy in the abdomen and pelvis.

**Implication for Patient Care**

- Patients with urolithiasis can be evaluated with CT at a substantially reduced radiation dose, thereby minimizing risks to the patient from radiation exposure while providing the diagnostic benefits of CT.

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**Published online before print**
10.1148/radiol.12112470  Content code: GU

**Radiology 2012; 265:158–166**

**Abbreviations:**
ASIR = adaptive statistical iterative reconstruction
FBP = filtered back projection

**Author contributions:**
Guarantors of integrity of entire study, N.M.K., D.V.S.; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; approval of final version of submitted manuscript, all authors; literature research, N.M.K., D.V.S.; clinical studies, N.M.K., B.H.E., D.V.S.; statistical analysis, N.M.K.; and manuscript editing, all authors

Potential conflicts of interest are listed at the end of this article.
Study Design
This was a Health Insurance Portability and Accountability Act–compliant, institutional review board–approved study. We acquired verbal patient consent to undergo prospective low-dose CT and a waiver of consent to conduct retrospective review of CT images. Between November 2010 and April 2011, 25 consecutive patients suspected of having or known to have urolithiasis were recruited for this study. All patients were being treated in our institution’s Kidney Stone Program and were scheduled to undergo unenhanced CT. Exclusion criteria included age younger than 18 years, pregnant women, those presenting in the emergency department, and those undergoing evaluation to assess complications from interventional procedures to treat urinary stone disease (no patients were excluded). The 25 patients were scheduled to undergo CT examination with scanners that had iterative image reconstruction capability. A modified CT protocol was used in all 25 patients. In 13 of 25 patients, prior unenhanced CT images acquired with the reference-standard protocol as defined by our institution (interval, 1–6 months; mean, 4 months) were available for comparison.

CT Technique
The examinations with the modified protocol were performed with a 64-section multidetector CT scanner (Discovery CT750 HD; GE Healthcare, Milwaukee, Wis), while the examinations with the reference protocol were performed with a 16-section multidetector CT scanner (LightSpeed 16; GE Healthcare) and a conventional FBP reconstruction technique.

The reference protocol (n = 13) in our standard practice involved the use of the FBP technique at a tube potential (tube voltage) of 120 kV and a weight-based automated tube-current modulation technique with a tube current range of 75–250 mA for patients weighing less than 200 lb (90 kg) and 75–350 mA for those weighing more than 200 lb (90 kg) (hereafter, only the conventional unit will appear for this weight). The noise index was 25 for both weight categories.

In the modified protocol (n = 25), the tube voltage was decreased from 120 to 80 kV for patients weighing less than 200 lb and to 100 kV for those weighing more than 200 lb. The automated tube-current modulation technique was also used with a tube current range of 75–150 mA, and the noise index was set to 30 for patients in both weight groups.

Other scanning parameters that remained identical for the reference protocol and the modified protocol were as follows: section thickness, 5 mm; gantry rotation time, 0.5 second; and pitch, 1.375. A standard reconstruction kernel was used.

Patients were placed in the supine position, and scanning was performed in the craniocaudal direction in a single breath hold from the level of the lower border of the T12 vertebra to the lower margin of the symphysis pubis.

Image Reconstruction
In patients examined with the modified protocol (n = 25), three sets of image series were reconstructed—one FBP and two ASIR image series—by applying 60% and 80% ASIR to the two ASIR sets (modified-protocol ASIR 60% and modified-protocol ASIR 80% series, respectively). The ASIR percentage represented a blended image, with contributions from both ASIR and FBP. For example, a 60% ASIR option yields a blended image set reconstructed by using 60% ASIR and 40% FBP. In the subset of 13 patients who also had undergone prior CT examinations by using the reference protocol, only a single FBP image series was available (reference-protocol FBP) (Fig 1).

The noise index and ASIR level selected for this study were based on our 2-year experience with the use of ASIR for various indications in the abdomen, as well as general agreement about image-quality expectations among the subspecialty radiologists. For high-attenuation diagnostic examinations, such as CT angiography, CT urography, CT cholangiography, and urinary stone CT protocols, a higher ASIR of 40%–60% is more acceptable, while for routine contrast material–enhanced abdominal CT examinations, ASIR of 20%–40% is considered more suitable to our radiologists.

In all patients, the operating technologist reconstructed images on the scanner console immediately after completion of CT examinations. Images were reconstructed in the coronal and sagittal planes by using a 3-mm section thickness. All the image data sets were then transmitted to the picture archiving and communication system, or PACS, for image interpretation. In the first 10 patients, a radiologist with 5 years of experience in reading abdominal CT scans (N.M.K.) monitored each scan on the scanner console to ensure that image quality of the scans obtained with the modified-protocol CT examinations was adequate for interpretation.

Image Analysis
A total of 38 CT studies (modified-protocol CT reconstructed with ASIR and FBP [n = 25] and reference-protocol...
CT reconstructed with FBP [n = 13]) were reviewed on a PACS workstation (AGFA, Richmond, Va). The images were randomized and presented for independent review by two experienced readers (D.V.S. and R.N.U., with 11 and 8 years of experience in interpreting abdominal CT, respectively), who were unaware of the technical scanning parameters and clinical details. To ensure blinding to technical scanning parameters while interpreting images on the PACS, an image display with options to hide scanning parameters was used. There was a 2-week interval between evaluation of the reference-protocol FBP series, modified-protocol FBP series, and modified-protocol ASIR series.

A template was used for image analysis, which included assessment of image quality, sharpness, noise, artifact, confidence in assigning a diagnosis of urinary tract stones, and alternate diagnoses not related to urinary stone disease. The image quality assessment included evaluation of both axial images and reformatted images in concordance with the European guidelines on quality criteria for abdominal CT examinations (26).

Subjective assessment.—During the subjective image-quality assessment, readers graded the image quality on a five-point scale, as related to urinary stone evaluation (score 1, poor image quality—not diagnostically acceptable for interpretation; score 2, suboptimal image quality—worse-than-acceptable quality; score 3, acceptable image quality—diagnostic interpretation possible; score 4, good image quality; and score 5, excellent image quality). A CT image that had an image-quality score of 3 or higher was considered acceptable for rendering an interpretation. A subjective assessment of image noise and artifact evaluation was performed on a three-point scale (score 1, minimal; score 2, acceptable; and score 3, excessive—rendering diagnostic interpretation impossible). Each reader’s confidence level for diagnosing or ruling out calculus disease and/or alternate diagnoses was rated with a three-point scale (score 1, no confidence; score 2, confidence with reservations; and score 3, highly confident).

Objective measurement.—One author (N.M.K) performed an objective measurement of image noise (standard deviation of the mean CT number) by placing a circular region of interest of 70–110 mm² in the subcutaneous fat, the right lobe of the liver, and the psoas muscle.

For diagnostic performance, each reader recorded the number, location, and size of urinary calculi, as well as the presence or absence of urinary obstruction. Bone window presets (window width, 1120 HU; window level, 300 HU) were applied for image interpretation, and a magnification factor of ×2 to ×3 was used for measurement of each urinary stone (27). Additional findings or alternate diagnoses, if any, were also recorded. Readers rated their confidence level for identifying stones and alternate diagnoses, as described before. The stone characteristics were recorded and compared with reference standards for stone diagnosis. One of the following methods served as a reference standard for stone diagnosis, either independently or in combination (as recorded from the electronic medical database by an independent observer): direct demonstration of the calculus after spontaneous passage (two patients) or extraction (three patients) or identification at follow-up CT and/or at clinical follow-up (13 patients).

Radiation Dose
The radiation dose was recorded as the CT dose index (volume-weighted CT dose index in milligrays).

Statistical Analysis
Statistical analysis was performed by using software (SAS system release 8.2; SAS, Cary, NC) and spreadsheet software (Microsoft Excel 2003; Microsoft, Richmond, Va). For the purpose of data analysis and comparison, averaged values of image-quality scores were presented. The subjective assessment (image quality, image noise and artifact, and confidence level in assigning a diagnosis of urinary stone disease and alternate diagnoses) and objective image noise measurements were estimated for the CT images obtained with the modified protocol and the reference protocol and were compared by using the Wilcoxon signed rank test and the paired t test. Interobserver agreement between the two readers was determined by using the Cohen κ test. Interobserver agreement was considered poor for κ of 0.19 or lower; fair for κ of 0.20–0.39; moderate for κ of 0.40–0.59, substantial for κ of 0.60–0.79, and almost perfect for κ of 0.80–1.00.

Results
Patient Groups
For the 25 patients who underwent modified-protocol CT, the mean age was 35.3 years and the age range was 22–65 years. For the 13 patients who had undergone previous reference-protocol CT, the mean age was 37 years and the age range was 23–68 years. Comparison of the two groups yielded a P value of .81. There were 15 men and 10 women in the modified-protocol group and nine men and four women in the reference-protocol group. The mean body weights and ranges were also comparable, with a mean body weight of 149 lb (67 kg) and range of 101–243 lb (46–109 kg) for the modified-protocol group and a mean of 156 lb (70 kg) and range of 105–254 lb (48–114 kg) for the reference-protocol group (P = .74). In the modified-protocol group, 18 of 25 patients weighed less than 200 lb, and seven of 25 patients weighed more than 200 lb. In the reference-protocol group (n = 13), nine patients weighed less than 200 lb, and four weighed more than 200 lb.

CT Findings
In the modified-protocol CT group (n = 25), 33 calculi were diagnosed in 17 patients. In the remaining eight patients, no urinary stones were identified. The mean calculus diameter according to measurement at CT was 6.1 mm (range, 2–28 mm). Two stones were located in the distal ureter, one was in the bladder, and the other 30 were in the kidneys (eight stones were 1–2 mm;
were 3–5 mm; and nine were larger than 5 mm).

**Subjective Assessment**

**Image quality.**—All reference-protocol CT images reconstructed with FBP and modified-protocol CT images reconstructed with 60% and 80% ASIR were rated as diagnostically acceptable, with mean scores of 4.2, 3.2, and 3.4, respectively. There was moderate interobserver agreement for assessment of image quality between the two readers (κ = 0.54–0.60). There was no significant difference in image quality between modified-protocol 60% ASIR and 80% ASIR (P = .72). In comparison to the ASIR series, modified-protocol FBP images were deemed to have lower image quality (mean score, 2.5) and were nondiagnostic in 20 of 25 patients (80%) (Table 1; Figs 2, 3).

**Image noise.**—Subjectively, the image noise was deemed least on reference-protocol CT images reconstructed with FBP (mean score, 1.1). Modified-protocol CT images reconstructed with FBP were rated to have higher image noise (mean score, 2.1; P = .02) than those reconstructed with 60% ASIR (mean score, 1.7; P = .03) and 80% ASIR (mean score, 1.6; P = .04), but there was no significant difference between modified-protocol FBP images and ASIR images (P = .08 for 60% ASIR and P = .11 for 80% ASIR). The image noise for both 60% and 80% ASIR series was higher compared with reference-protocol CT FBP images (Table 1; Figs 2, 3).

**Image artifact.**—The image artifact scores on CT images acquired with the reference protocol and reconstructed with FBP (mean score, 1.0) and those acquired with the modified protocol and reconstructed with 60% ASIR (mean score, 1.4; P = .43), 80% ASIR (mean score, 1.5; P = .1), and FBP (mean score, 1.6; P = .22) were similar, without any significant differences between them (Table 1).

**Diagnostic confidence.**—For detection of urolithiasis on modified-protocol CT images, the diagnostic confidence score was higher for 60% ASIR images (mean score, 3.0) and 80% ASIR (Table 1; Figs 2, 3).

#### Table 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>All patients</th>
<th>Patients ≤ 200 lb</th>
<th>Patients &gt; 200 lb</th>
<th>All patients</th>
<th>Patients ≤ 200 lb</th>
<th>Patients &gt; 200 lb</th>
<th>All patients</th>
<th>Patients ≤ 200 lb</th>
<th>Patients &gt; 200 lb</th>
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<tr>
<td>Image quality</td>
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<td>4.5</td>
<td>4.6</td>
<td>4.2</td>
<td>4.5</td>
<td>4.6</td>
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<td>3.4</td>
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<tr>
<td>Modified protocol 80% ASIR</td>
<td>3.2</td>
<td>3.4</td>
<td>3.3</td>
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Note.—The scores represent the mean image quality scores of the two readers. To convert pounds to kilograms, multiply by 0.45. MP = modified CT protocol; RP = reference CT protocol.
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Figure 2: Axial CT images acquired in a 31-year-old man (body weight, 68 kg) with renal stone disease. Baseline reference-protocol (RP) CT image (top left) shows a 7-mm calculus (arrow) in the right kidney. At follow-up CT performed 6 months later with the modified protocol (MP), representative images reconstructed with FBP (top right) and ASIR (bottom left and right) show that the stone is no longer apparent. In contrast to the modified-protocol FBP image, there is substantial improvement in image noise and quality on modified-protocol ASIR images, as compared with reference-protocol CT images. The radiation dose for reference-protocol CT was 9.6 mGy. There was a substantial reduction in radiation dose (80%) with the modified protocol, which delivered a dose of 1.2 mGy.

Figure 3: Coronal CT images acquired in a 28-year-old man (body weight, 73 kg) with renal stone disease. A, Baseline reference-protocol (RP) CT image shows two 2–3-mm calculi in the right kidney. B, Follow-up modified-protocol (MP) CT image obtained 6 months later and reconstructed with 60% ASIR demonstrated two new tiny stones in the left kidney and a single calculus in the right kidney. The patient probably passed the inferiorly located calculus, which was not visualized at follow-up CT. The tiny renal calculi are depicted equally well on ASIR-reconstructed images and baseline CT images.
Objective Assessment

Image noise was measured objectively as the standard deviation of the mean CT number and was highest on modified-protocol FBP images ($P < .0001$), with a significant decrease on modified-protocol 60% ASIR ($P = .001$) and 80% ASIR ($P = .001$) images. The image noise was lowest on reference-protocol FBP images (Table 3).

Radiation Dose

The mean estimated radiation dose represented as the volume-weighted CT dose index for the reference-protocol CT scans was 9.9 mGy ± 5.6 (standard deviation). There was a considerable reduction in radiation dose of up to 84% for CT scans obtained with the modified protocol (CT dose index volume of 1.8 mGy ± 0.7; $P < .001$). The reduction in radiation dose was substantial for the patients weighing less than 200 lb (dose reduction of 87%, with a mean volume-weighted CT dose index of 1.3 mGy ± 0.6) compared with those weighing more than 200 lb (dose reduction of 80%, with a mean volume-weighted CT dose index of 2.3 mGy ± 1.4).

Discussion

The increasing use of multidetector CT in the evaluation of patients with urinary stone disease has raised concerns over the potential long-term adverse effects of repeated radiation exposure (19). The results of our pilot study show that CT examination with a modified protocol and use of ASIR provides diagnostic-quality images that can be used for evaluating urinary calculi at a substantially reduced radiation dose. Investigators in prior studies (23,25,28) have already confirmed the effects of CT scanning with parameter-modification approaches, such as decreasing the tube current and routinely using the automatic tube-current modulation to optimize radiation dose in evaluating urolithiasis. However, performing CT examinations with the FBP reconstruction technique at a substantially reduced radiation dose is challenging, with major implications in terms of image-quality ramifications. Although a decreased tube voltage approach is more effective in reducing radiation dose, it is applied less frequently in adult patients because of the degraded image-quality inherent to the FBP technique. Klüner et al (21) investigated the fixed scanning parameters of 120 kV and 20 mA with FBP to achieve CT doses in the range of 0.5 to 0.7 mSv, with excellent performance in urinary stone detection. However, the FBP images from CT protocols with markedly reduced radiation dose are often of suboptimal quality for

Table 2

<table>
<thead>
<tr>
<th>Noncalculus Findings at CT Examination</th>
<th>No. of Patients</th>
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<tr>
<td>Simple renal cysts</td>
<td>5</td>
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<tr>
<td>Hypertension and calcified renal cysts</td>
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</tr>
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<td>Renal hematoma (after undergoing biopsy)</td>
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<tr>
<td>Hydronephrosis (after undergoing ileal conduit surgery)</td>
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<tr>
<td>Bladder diverticula</td>
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<td>Aortic aneurysm</td>
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<td>Cholelithiasis</td>
<td>2</td>
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<tr>
<td>Inguinal hernia</td>
<td>3</td>
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<tr>
<td>Metastasis to iliac bone</td>
<td>1</td>
</tr>
<tr>
<td>Colon diverticulosis</td>
<td>2</td>
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Table 3

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<th>Comparison of Objective Image Noise Assessment for Different CT Series</th>
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<td>Assessment Location</td>
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<td>Liver</td>
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<td>Muscle</td>
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Note—Scores are means ± standard deviations. RF FBP vs MP FBP, $P < .001$; RP FBP vs MP 60% ASIR, $P = .001$; RP FBP vs MP 60% ASIR, $P = .001$; MP 60% ASIR vs MP FBP, $P = .02$; and MP 60% ASIR vs MP 80% ASIR, $P = .53$. MP = modified protocol, RF = reference protocol.
rendering diagnostic interpretation. Indeed, in the current study, images from as many as 80% of CT examinations performed with the modified protocol and reconstructed with FBP were considered to have suboptimal image quality. In addition to urolithiasis detection, it is also imperative to maintain acceptable image quality for the identification of alternate diagnoses in patients who do not have urinary tract calculi (23,25). Moreover, different patterns of practice and image-quality expectations at various institutions may further affect the choice of CT protocols. Images reconstructed iteratively with techniques such as ASIR have been shown to improve image quality on low-dose images acquired in the abdomen for different indications (18–20,29). However, the role of ASIR in improving image quality for CT protocols with substantially lower radiation doses remains unknown (28).

In comparison with the radiation exposure from our reference-protocol CT, the radiation exposure from the modified-protocol scanning was 84% lower (9.9 versus 1.8 mGy). With the ASIR approach, images were deemed diagnostically acceptable for reliable detection of urinary stones. Our pilot data support the proposal that a modified CT protocol involving a substantially lower radiation dose can be introduced into clinical practice for urinary stone evaluation if there are tools such as ASIR to improve image quality. The image readers also felt more confident in evaluating the rest of the abdomen and pelvis for noncalculous findings on ASIR images when compared with FBP images. Although image-quality characteristics were assessed for FBP and ASIR series acquired with a modified CT protocol, performance in stone detection was based on 60% and 80% ASIR images. Because 80% of FBP-reconstructed CT images acquired with the modified CT protocol were deemed nondiagnostic, they were not assessed for competence in stone detection.

The selection of body weight–based automated tube current, noise index levels, and corresponding ASIR level (60% or 80%) was based on our initial clinical experience with ASIR for a variety of CT protocols. An ASIR percentage of 20%–60% has been found to be optimal for image quality and noise distribution (27). A higher ASIR level (>50%) is applied to CT indications with high intrinsic attenuation, such as CT angiography, urinary stone CT protocols, and CT colonography. To investigate the image quality of CT examinations performed with a modified protocol and ASIR, comparison was also performed with prior CT images acquired with our reference protocol in 13 patients. Because CT is a highly reliable technique for urinary stone diagnosis, and most previous investigators in the literature have used established CT criteria for diagnosis of urinary stones, in the current study we also reviewed CT images acquired with the reference protocol at our institution as the standard for comparison of image quality and diagnostic confidence. The diagnosis of large stones (>5 mm) is rarely challenging, but it is conceivable that any image-quality limitations of CT at lower radiation doses can impede detection of small (<3 mm) stones, where stone extraction is not usually considered (5,20–22). In the modified-protocol group, images from both 60% and 80% ASIR techniques performed consistently better than did FBP images for various quality characteristics. Modified-protocol ASIR images were rated as comparable to reference-protocol FBP images. Moreover, diagnostic confidence for stone detection on 60% and 80% ASIR images was better than that for FBP images.

As evidenced by our observations, use of our modified scanning protocol and application of the ASIR technique can enable substantial radiation dose reduction without introducing image-quality concerns for urinary stone diagnosis. In 18 patients weighing less than 200 lb (72% of the study cohort), the mean radiation dose was 1.3 mGy, while in those weighing more than 200 lb, the radiation dose was 2.3 mGy. The higher dose reduction for the lighter-weight group, as compared with the heavier group, results from the lower tube potential (80 kV) used for scanning; also, tube current often reached the set maximum (150 mA) in larger patients, therefore delivering a higher radiation dose. It remains to be determined whether a further reduction of radiation exposure can be achieved through a combination of ASIR and other approaches, such as two-dimensional adaptive filters and automated tube-voltage optimization. Advanced iterative reconstruction techniques such as model-based iterative reconstruction (MBIR; GE Healthcare) and sinogram affirmed iterative reconstruction (SAFIRE; Siemens Healthcare), which apply several more iterations, have recently received approval from the U.S. Food and Drug Administration for clinical use in the United States. Other manufacturers are also introducing their approaches for image reconstruction, which are likely to contribute further to image-quality refinements and will conceivably facilitate CT protocols featuring substantially reduced radiation dose in all weight groups (30–32).

There were several limitations to our pilot study. First, the patients were not randomized to CT reconstruction techniques. Second, a standard-of-reference confirmation of each calculus, either in the form of extraction or natural excretion, was not available for most patients, especially in the case of very small calculi that are usually not treated. In patients in whom follow-up CT images were available, however, there was excellent concordance with CT findings on the basis of the modified protocol for stone detection. We acknowledge that ASIR is vendor and machine specific and is not the current standard of care in most clinical practices. It is important to emphasize that, for patients with lower body weight, the actual absorbed organ radiation dose could be higher, even when the same scanning parameters are used, whereas in heavier patients, the absorbed organ radiation dose can be lower. Finally, our cohort for this pilot study was relatively small, with fewer patients in the higher-weight category. Since this is an ongoing study, we are continuing to expand the cohort for further evaluation.

In summary, CT radiation dose reduction to 1.8 mGy can be achieved with ASIR image reconstruction for evaluation of urolithiasis, while maintaining...
acceptable image quality and diagnostic confidence comparable to that with CT protocols with a radiation dose of 9.9 mGy.

Acknowledgment: We acknowledge Peter F. Hahn, MD, PhD, Massachusetts General Hospital, Division of Abdominal Imaging and Intervention, Boston, Mass, for his contributions in editing the manuscript and providing valuable inputs.

Disclosures of Potential Conflicts of Interest: N.M.K. No potential conflicts of interest to disclose. R.N.U. Financial activities related to the present article: none to disclose. Financial activities not related to the present article: received payment as an expert reviewer on a legal case by Robison, Carphey & O’Connell; received a grant for study on quantifying abdominal fat from SGR and received the AJR/ARRS Figley Fellowship. Other relationships: none to disclose. B.H.E. Financial activities related to the present article: none to disclose. Financial activities not related to the present article: none to disclose. Other relationships: is a consultant for Boston Scientific, PercSys, Olympus/ACMI Owner, Ravine Group. D.V.S. Financial activities related to the present article: received royalties from Elsevier for consultancy from Bracco Diagnostics; institutional relationships: is a consultant for Servier, Devicor; institutional relationships not related to the present article: none to disclose. Other relationships: none to disclose. Financial activities not related to the present article: received study on quantifying abdominal fat from SGR and received the AJR/ARRS Figley Fellowship.

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