Multi–Detector Row CT Urography: Comparison of Strategies for Depicting the Normal Urinary Collecting System

PURPOSE: To evaluate several protocols for depiction of the urinary collecting system with multi–detector row computed tomographic (CT) urography.

MATERIALS AND METHODS: Fifty-one patients with hematuria or a suspicious renal mass underwent CT urography, during which thinly collimated (1-mm) pyelographic phase scanning was performed 8–10 minutes after contrast medium administration. Patients were examined while prone only (n = 17) and while both prone and supine (n = 17) after a 250-mL infusion of normal saline. Each collecting system and ureter was divided into six segments that were assigned opacification scores. All acquisition techniques were compared, and the highest-scoring technique was compared with that in 17 patients who underwent conventional intravenous urography (IVU). Three reconstruction techniques (transverse, coronal, and maximal intensity projection) were also compared. Stratified analysis was performed with the paired two-tailed Student t test to compare opacification scores for both the acquisition techniques and display methods, both individually and in all possible combinations.

RESULTS: CT urography with supplemental saline administration, performed with the patient prone or supine, significantly improved mean opacification scores in the distal ureters (right, P = .004; left, P = .006). With this technique, CT urography produced a mean opacification score that was not significantly different from that with IVU in 11 of 12 segments and was significantly better than that with IVU in one of 12 segments (lower left ureter). Mean opacification scores obtained with transverse or coronal displays were equal to or higher than those obtained with maximum intensity projection reconstructions in all segments.

CONCLUSION: CT urography with a multi–detector row scanner and supplemental infusion of normal saline reliably displays the opacified urinary collecting system.

Computed tomography (CT) is widely used in radiologic evaluation of the kidneys and urinary collecting system, including renal masses (1–5), infection (6), trauma (7–9), and urinary calculi (10). As a result, CT is commonly used instead of intravenous urography (IVU) for evaluation of these clinical problems. The technical advance that enabled widespread use of CT for imaging urinary calculi was the introduction of slip-ring technology (spiral CT) in 1990 that for the first time permitted imaging of the abdomen in a single breath hold, free of respiratory misregistration (11). Despite such advances, a CT technique for evaluation of the urothelium has not yet, to our knowledge, been satisfactorily developed, and the initial image-based evaluation of hematuria in many centers still relies on IVU (12,13). The primary reasons that CT has not replaced IVU for evaluation of the urothelium are that CT has lower spatial resolution and that it is difficult to acquire a
set of images in which the intrarenal collecting systems (IRCs) and ureters are completely opacified.

With multi-detector row CT, multiple channels of data are acquired simultaneously, allowing thinly collimated images to be obtained through the entire abdomen in a single breath hold (14). This results in near-isotropic voxels and improved spatial resolution in nontransverse planes (14). During the excretory phase, the entire collecting system and ureter can be imaged with one acquisition. As with conventional IVU, visualizing the IRCs and ureter depends on opacification and distention. A fundamental problem in CT urography (or any imaging technique for imaging the entire collecting system and ureter) is that, because of peristalsis, it is difficult to obtain a single image on which all segments are opacified and distended. The purpose of our study was to evaluate several protocols for depiction of the urinary collecting system with multi-detector row CT urography.

**MATERIALS AND METHODS**

**Subjects**

This study was performed with institutional review board approval for review of images and records in patients undergoing multi-detector row CT; informed patient consent was not required.
A total of 51 consecutive patients (30 women, 21 men) with either unexplained hematuria (n = 24) or a suspicious renal mass (n = 27) underwent CT urography during a 4-month period. Abnormal findings involving the IRCS or ureters were as follows: calyceal diverticulum (n = 2), ureteropelvic junction obstruction (n = 1), ureteric stricture (n = 1), hydronephrosis with bladder mass (n = 1), hydrourerteronephrosis with no lesion identified (n = 1), diffuse bladder wall thickening (n = 1), calyceal filling defect with normal retrograde pyelogram (n = 1), and nonobstructive calculi (n = 6). In the subset of patients who underwent evaluation for a suspicious renal mass, the findings were as follows: simple cyst (n = 8), cyst with mural calcification (n = 4), renal cell carcinoma (n = 3), high-attenuating cyst (n = 3), hydronephrosis (n = 2), column of Bertin (n = 1), and pseudomass (n = 6). Seventeen patients (10 women, seven men) with unexplained hematuria underwent conventional IVU during the same period. In these patients, there were no abnormal findings involving the urinary collecting system or ureters. We chose 17 patients to undergo IVU to equal the number of patients who underwent examination with each of the CT urographic protocols.

CT Urographic Acquisition Techniques

By using a multi-detector row CT scanner (Somatom Volume Zoom; Siemens Medical Systems, Forcheim, Germany), a three-phase CT urographic protocol was used. For the unenhanced phase, 4.0 × 2.5-mm collimation was used, with a pitch of 6. The nephographic phase was reached 100 seconds after intravenous administration of 100 mL of contrast material (ioxilan, Oxilan 300; Cook, Bloomington, Ind) at a rate of 3 mL/sec, with 4.0 × 2.5-mm collimation and a pitch of 6. The pyelographic phase was reached after an 8–10 minute delay, with 4 × 1-mm collimation and a pitch of 6. An 8-minute delay, which would allow enough time for administration of supplemental saline and adequate contrast
material excretion into the urinary collecting system, was chosen for pyelographic phase imaging. During the examination, the actual delay was 8–10 minutes as a result of technologist-related variation. A 0.5-second gantry rotation was used. For almost all scanning, 165 mAs was used (range, 165–200 mAs), and 120 kV was used in all patients. Only pyelographic phase data were analyzed for this research study.

Of the 51 patients examined with CT urography, the first 17 were positioned prone, the second 17 were positioned prone and received supplemental saline, and the third 17 were positioned supine and received supplemental saline. A technologist administered the normal saline by hanging a 250-mL bag immediately after injecting contrast medium and allowing it to infuse with gravity.

CT Urographic Display Methods

Three different display methods were used in each case: transverse (1.25-mm thick section, 1-mm increment [Fig 1]), coronal (3-mm thick and 3-mm increment, generated from transverse data [Fig 2]), and maximum intensity projection (MIP) reconstructions (generated from transverse data [Fig 3]). Coronal reconstructions were created by the technologist at the CT console, and MIP reconstructions were created by a radiologist (M.J.) at a CT and magnetic resonance (MR) imaging workstation (3D Virtuoso; Siemens Medical Systems). MIP reconstructions were obtained in an anteroposterior projection and used the entire volume of data.

IVU Technique

Our IVU technique required 1.0 mL per kilogram of body weight of the previously mentioned contrast material, followed by acquisition of five to seven anteroposterior nephrotomograms (nephrographic phase); a single coned-down renal image obtained during lower abdominal compression (pyelographic phase); and anteroposterior, oblique, and postvoiding abdominal radio-
graphs obtained after removal of the compression device.

Image Analysis
Each collecting system and ureter was divided into six anatomic segments: upper and lower IRCS, renal pelvis, and proximal (above the iliac crest), lower (to the level of the sciatic notch), and distal ureter (below the sciatic notch). This resulted in 12 anatomic segments per patient, or a total of 36 segments per patient when all three display methods were considered. In consensus, three readers (J.D.M., M.J., S.G.S.) reviewed all images and assigned an opacification score of 0–3 for each display method in each patient. The scoring system was as follows: 0, unopacified; 1, less than 50% of segment opacified; or 3, entire segment opacified (Fig 4). We used opacification and not distention of the collecting system and ureters as the criterion to be evaluated in this study, as it is the primary determinant of whether or not a segment can be identified and evaluated for abnormal findings. Images were reviewed at either a picture archiving and communication system (IMPAX 3.5; Agfa Medical Imaging, Greenville, SC) or three-dimensional-viewing workstation (3D Virtuoso; Siemens Medical Systems). Images were viewed at a window level of 100 HU and a window width of 600 HU, which allowed reliable visualization of the range of contrast material attenuation on the images. These window settings, which were preferred by the readers in this study for viewing the opacified collecting systems and ureters, lie between those typically used for soft-tissue and bone viewing.

IVU images were reviewed in the same way. By consensus, the same three readers reviewed all images and assigned an opacification score of 0–3 for each patient.

Statistical Analysis
There were two components of data analysis. In the first component, patients were grouped according to the acquisition technique used in their examination. For each acquisition technique (prone, prone with postcontrast saline bolus, or supine with postcontrast saline bolus), the mean score for the group of 17 patients was calculated for each segment in all 51 patients by using all acquisition techniques. We further derived all possible combinations of both the acquisition techniques and display methods on the basis of the maximum scores from the combined groups. Stratified comparisons of mean scores were performed by using the paired two-tailed Student t test. By using the two-sample two-tailed Student t test, each combination was also compared with scores in an additional group of patients who underwent IVU.

RESULTS

Comparison of CT Urographic Acquisition Techniques
CT urography with thin (1-mm) collimation allowed the entire collecting system and ureters to be imaged with one acquisition. Saline administration (combining prone and supine positioning) significantly improved opacification of both the right ($P = .004$) and left ($P = .006$) distal ureter over that with prone positioning without saline administration (Fig 5). There was no significant difference between mean opacification scores achieved with prone positioning and those achieved with supine positioning. Patients who received a saline infusion had a mean score of 2.2 for the distal ureters, while those who did not had a mean score of 1.6. Overall, the distal ureter was the most difficult segment to
opacify, with a mean score of 2.0 when scores from the three acquisition techniques were combined. By using supplemental saline, with the patient either supine or prone, an opacification score of 2.0 or higher (opacification > 50%) was achieved in 94% (374 of 396) of all evaluable segments (Fig 6). Saline infusion was easily implemented by a technologist and well tolerated by all patients.

Comparison of CT Urography and IVU

By comparing CT urography with supplemental saline administration and IVU, only one segment demonstrated a significant difference in mean opacification scores. In the lower left ureter, CT urography resulted in significantly higher opacification scores than did IVU (P = .03); there was no statistically significant difference for the remaining 11 segments.

Comparison of CT Urographic Reconstruction Techniques

Mean opacification scores for both transverse and coronal reconstructions were equal to or higher than those obtained by using MIP display in all segments (Fig 7). The transverse display had significantly higher opacification scores than did the MIP display in the right (P = .004) and left lower IRCS (P = .006); there was no statistically significant difference in the remaining segments. The coronal display had significantly higher opacification scores than did the MIP display in the right lower IRCS (P = .003), the right upper ureter (P = .03), the left upper IRCS (P = .01), the left lower IRCS (P = .008), the left renal pelvis (P = .04), and the left upper ureter (P = .047); there was no statistically significant difference in the remaining segments. Mean opacification scores for coronal reconstructions were higher than those for transverse images but were not considered to indicate a statistically significant difference. Coronal reconstructions consistently depicted the ureters and collecting system with fewer images because of the craniocaudal course of these structures. In general, while coronal sections displayed longer segments of the upper and lower ureters on a single image, transverse sections usually displayed longer segments of the distal ureters on a single image (Fig 8). This is potentially important, because evaluating an image that displays a long segment of ureter may be the best way to appreciate subtle changes in ureteral caliber and display unopacified segments of ureter (Fig 9). Combining transverse and coronal images resulted in significantly higher mean opacification scores than did using either method alone in the upper right ureter (P = .01) and lower left IRCS (P = .04); there was no statistically significant difference in the remaining segments.

Radiation Dose Estimation

Patient skin doses for the multi–detector row CT protocol used in this study were estimated from pencil-chamber measurements of the CT dose index, or CTDI, at 1-cm depth on a Lucite pelvic phantom with a 32-cm diameter. For this three-phase multi–detector row CT protocol, the estimated skin dose was 74.1 mGy and the estimated total effective dose was 22.6 mGy. For our IVU protocol, the estimated skin dose was 81.2 mGy and the estimated total effective dose was 11.4 mGy, estimated from the entrance skin exposure to the same pelvic phantom by using a standard technique for a patient of average size. For
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both CT and IVU, the effective dose was estimated by using organ doses determined from tabular data (15, 16) and appropriate organ weighting factors (17).

DISCUSSION

CT urography has been proposed as a possible replacement for IVU in the examination of patients with hematuria (18). However, a CT technique for reliable depiction of the IRCS and ureters has been elusive. This has been a result of two technical problems. One problem is that the spatial resolution of CT is less than that of IVU. There is, therefore, a theoretical concern that small urothelial lesions may be missed. With single-detector row CT, imaging the entire urinary collecting system with narrow collimation to achieve high spatial resolution was not possible in a single breath hold. The second problem is that it is difficult to obtain a single set of images on which the IRCS and ureters are completely opacified.

Performance of multi-detector row CT addresses the problems of spatial resolution and image acquisition. Currently available multi-detector row CT scanners depict the entire kidneys, ureters, and bladder with thin collimation during a single breath hold. This, therefore, results in depiction of the entire IRCS, ureters, and bladder with one set of images and with spatial resolution greater than that obtained at single-detector row CT and closer to that obtained at IVU. Furthermore, relative to single-detector row CT, spatial resolution is improved in both transverse and nontransverse planes. Coronal reformations, which provide IVU-like images, display spatial resolution comparable with that of transverse images (14). The CT urographic protocol used in the current study involved 1-mm collimation and resulted in depiction of the entire urinary collecting system in less than 30 seconds.

Acquiring a set of images with the entire IRCS and ureters fully opacified is yet another challenge. As has been the case with IVU, the entirety of both ureters and collecting systems is rarely opacified on a single image obtained after intravenous injection of a bolus of contrast material. For this reason, IVU protocols have historically used multiple image acquisitions, abdominal compression, and, occasionally, prone positioning to depict all segments. A multiple-acquisition approach is not feasible with CT urography because of the high radiation dose that would result. We investigated the effect of altering patient position and supplementally infusing normal saline after injecting contrast medium. The rationale for examining patients in the prone position was to distend the lumbar ureters, as has been described previously (19). The rationale for saline infusion was as follows: First, normal saline increases the amount of fluid presented to the collecting systems and ureters and improves distention, similar to drip-infusion pyelography, during which diluted contrast material is used to opacify the urinary system without compression devices (20). Second, because CT easily depicts the high attenuation produced by contrast material, diluting the contrast material does not substantially affect perceived opacification. Third, normal saline is easily administered by technologists and well tolerated by patients. Our decision to not evaluate the effect of compression devices was due to their cumbersome nature and their prevention of scanning of the entire urinary tract in one acquisition.

Our results demonstrate that administration of normal saline significantly improves mean opacification scores in the distal ureters. The other segments of the urinary collecting system opacified equally well with each of the three acquisition techniques evaluated. As have other investigators, we found that the distal ureter was the most difficult segment to opacify (19). We could not confirm the findings of a previous study in which prone positioning improved opacification of the distal ureter (19). With supplemental saline administration, CT urography depicted opacified segments of the urinary collecting system and ureters as well as IVU did. This represents an important first step in assessment of CT urography for evaluation of the urothelium, since detection of urothelial lesions with IVU has traditionally relied on visualization of the opacified collecting system. As a result of this study, we now perform CT urography with the patient supine, with 1-mm collimation, and with supplemental intravenous infusion of normal saline.

In comparing the three display methods evaluated in this study (transverse and coronal images and MIP), we found that thin-section transverse images and
coronal reconstructions were complementary and demonstrated some segments of the urinary collecting system significantly better than did either method alone. MIP images provide a single-image overview of the collecting system and mimic IVU images. While this could lead to faster interpretation than could either of the other two display methods, our analysis demonstrated lower opacification scores with MIP reconstructions. Often, thin segments of the IRCS that were opacified on transverse or coronal sections appeared non-opacified on MIP reconstructions. For these reasons, we now interpret CT urographic findings on both transverse and coronal images.

The current study includes a dedicated multi-detector row CT urographic protocol with timed single-image acquisition in the urographic phase. Several other methods of CT urography have been described. With single-detector row technology, CT urography has been described in which the pyelographic phase of contrast material excretion is imaged with two acquisitions: one in the upper tract, with an abdominal compression device, and one in the lower tract, after the device has been removed (19, 21). The authors of two recent studies (22, 23) have shown improved distention of the upper tracts by using a compression device. Our technique does not require a compression device and requires only a single acquisition. A CT urographic examination composed of CT of the urinary tract followed by either abdominal radiography or CT topography has also been described (18). This strategy combines the advantages of CT in imaging the kidneys and of radiography in imaging the urinary collecting system. It remains to be seen, however, whether the image quality of CT topography is sufficient to view the urothelium. If radiography is used, patients need to undergo imaging in a different location. Alternatively, a multi-detector row CT scanner configured with a special tabletop apparatus has been used to obtain both CT and radiographic images without moving the patient (24). Multi-detector row CT with a split dose of contrast medium has been described (25), although this requires two contrast material administrations and two CT examinations separated by 15 minutes.

An important issue related to the choice of CT urographic technique is radiation exposure. Dose estimates for our CT urographic and IVU protocols suggest that the skin doses are similar and that the total effective dose at CT urography is approximately double that at IVU. This issue deserves further study.

In summary, technical advances have led to CT being the examination of choice in the evaluation of most anatomic renal abnormalities. Despite this, satisfactory evaluation of the urinary collecting system with CT, other than for urinary calculi, has been elusive. Findings of the current study have demonstrated that with multi-detector row technology, CT urography supplemented with intravenous infusion of normal saline reliably depicts the opacified urinary collecting system, without multiple acquisitions or compression devices. Because of its depiction of both the renal parenchyma and urinary collecting system, CT urography may enable complete examination of the kidneys and urinary collecting system. While our referring urologists have embraced this technique and now request CT urography in lieu of IVU, further study is warranted to evaluate the role of CT urography in examining patients with painless hematuria.

References