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Accuracy of Reduced-Dose Computed Tomography for Ureteral Stones in Emergency Department Patients

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Abstract

Study objective—Reduced-dose computed tomography (CT) scans have been recommended for diagnosis of kidney stone but are rarely used in the emergency department (ED) setting. Test characteristics are incompletely characterized, particularly in obese patients. Our primary outcome is to determine the sensitivity and specificity of a reduced-dose CT protocol for symptomatic ureteral stones, particularly those large enough to require intervention, using a protocol stratified by patient size.

Methods—This was a prospective, blinded observational study of 201 patients at an academic medical center. Consenting subjects underwent both regular- and reduced-dose CT, stratified into a high and low body mass index (BMI) protocol based on effective abdominal diameter. Reduced-dose CT scans were interpreted by radiologists blinded to regular-dose interpretations. Follow-up for outcome and intervention was performed at 90 days.

Results—CT scans with both regular and reduced doses were conducted for 201 patients, with 63% receiving the high BMI reduced-dose protocol. Ureteral stone was identified in 102 patients (50.7%) of those receiving regular-dose CT, with a ureteral stone greater than 5 mm identified in 26 subjects (12.9%). Sensitivity of the reduced-dose CT for any ureteral stone was 90.2% (95% confidence interval [CI] 82.3% to 95.0%), with a specificity of 99.0% (95% CI 93.7% to 100.0%). For stones greater than 5 mm, sensitivity was 100% (95% CI 85.0% to 100.0%). Reduced-dose CT identified 96% of patients who required intervention for ureteral stone within 90 days. Mean

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Author contributions: CLM, MG, and GPG conceived the study and designed the trial. CLM, DS, and CPG obtained research funding. CLM and SL supervised the conduct of the trial and data collection. SL participated in recruitment of patients. GG performed overreadings of the CT scans in the trial. CLM, SL, and AM managed the data, including quality control. AM and CPG provided statistical advice. BD, GG, AM, DS, and CPG provided advisement on study design and methodology. CLM, SL, AM, and CPG analyzed the data. CLM drafted the article, and all authors contributed substantially to its revision. CLM takes responsibility for the paper as a whole.

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reduction in size-specific dose estimate was 18.6 milligray (mGy), from 21.7 mGy (SD 9.7) to 3.4 mGy (SD 0.9).

Conclusion—CT with substantial dose reduction was 90.2% (95% CI 82.3% to 95.0%) sensitive and 98.9% (95% CI 85.0% to 100.0%) specific for ureteral stones in ED patients with a wide range of BMIs. Reduced-dose CT was 96.0% (95% CI 80.5% to 99.3%) sensitive for ureteral stones requiring intervention within 90 days.

INTRODUCTION

Background and Importance

Kidney stones will afflict about 10% of people in their lifetime, and more than half of those with kidney stones will experience a recurrence.[1,2] Computed tomography (CT) scan is now obtained for more than 70% of patients receiving a diagnosis of urolithiasis in US emergency departments (EDs).[3] Although CT is accurate for diagnosis, the ionizing radiation it uses is increasingly being recognized as a public health issue.[4,5] Despite the large increase in use of CT for renal colic, patient-centered outcomes such as rates of diagnosis, admission, and intervention have not changed substantially.[6–8]

Professional societies in the United States, including the American College of Emergency Physicians and the American College of Radiology, recommend that reduced-dose techniques be used when CT is performed for suspected renal colic.[9,10] However, recent data from the National Radiology Data Registry's Dose Index Registry suggest that reduced-dose techniques are infrequently being used for renal colic protocol CT scans in the United States: the mean effective dose in 2012 was 11.2 mSv, with less than 2% of CT scans conducted with 3 mSv or less, the threshold commonly used to define a reduced-dose scan.[11]

One of the potential barriers to using low-dose CT scans is the limited data about effectiveness in actual clinical practice. There have been studies on reduced-dose CT in cadavers in the United States and in small samples of selected populations outside the country.[12–14] These studies have also often excluded or found poor performance of non–size-adjusted protocols in more obese patients, who are at increased risk for kidney stone and incur a higher radiation dose.[1,15–18] Previous studies have also not followed patients receiving reduced-dose CT to determine its ability to predict outcomes and need for intervention.

Goals of This Investigation

We sought to design and test a size-adjusted reduced-dose CT protocol on an unselected population of ED patients with suspected kidney stone. Specifically, we compared the sensitivity and specificity of reduced-dose CT for diagnosis of clinically important urologic causes of acute flank pain likely to require intervention within a 90-day follow-up period.

MATERIALS AND METHODS

Study Design and Setting

This was a prospective observational study at the Yale–New Haven Hospital ED, an urban, tertiary care academic center with greater than 90,000 adult visits per year. This study was approved by the Yale Institutional Review Board (Human Investigation Committee) and the Yale Radiation Safety Committee. This protocol was composed of a subset of subjects who were prospectively enrolled in the validation phase of a previously published clinical prediction rule[19] and was registered on clinicaltrials.gov before the beginning of enrollment (NCT01352676; http://www.clinicaltrials.gov). The study adhered to the Standards for the Reporting of Diagnostic Accuracy (STARD) guidelines[20] and enrolled patients from February 2012 to May 2013.

Selection of Participants

This study was performed on consecutive consenting adult patients undergoing CT scan for suspected kidney stone as part of usual ED care during defined periods of enrollment, which occurred when research associate coverage was available, approximately 80% of hours during the study period, including overnights and weekends. Subjects were eligible if they were aged 18 years or older and capable of providing written informed consent. Research associates circulated in the ED to seek eligible subjects and were also notified automatically by pager whenever a renal colic CT scan was ordered from the ED. All CT scans conducted during enrollment periods were reviewed retrospectively to identify any patients missed for enrollment.

Patients were aware that they would be receiving an additional radiation dose of 10% to 15% and provided written informed consent for the additional radiation. In addition to receiving institutional review board approval, this protocol was approved by the Radiation Safety Committee at our institution in accordance with our intent to use this protocol clinically if results were favorable, which would ultimately decrease future overall population radiation exposure.

Interventions

After providing written informed consent, eligible subjects had a “regular”-dose CT performed and then underwent a second pass on the scanner to obtain the reduced-dose images (see Figure 1 for an example of regular- versus reduced-dose CT). Demographic and clinical data were collected prospectively by research associates as part of a larger, previously published study.[19]

The reduced-dose CT protocol was dichotomized into low and high body mass index (BMI) protocols according to effective abdominal diameter: the maximum abdominal width (lateral) added to the maximum abdominal anteroposterior distance, as measured on the CT scout image in accordance with recommendations of the American Association of Physicists in Medicine.[21] Patients with these 2 abdominal measurements adding up to less than 600 mm received the low-BMI protocol. This cutoff was chosen according to pilot data from patients at our institution who underwent CT. The 600-mm measure was found to occur at a BMI of approximately 30 kg/m^2, a commonly used cutoff for obesity.

All CT scans were performed without intravenous or oral contrast on a 64-slice LightSpeed Scanner (GE Healthcare, Milwaukee, WI) using automated tube current modulation (SmartmA with noise index of 35 for 2.5-mm slice thickness), 0.5 second rotation time, and a pitch of 1.375. The range of the tube current for the low-BMI protocol was set as 50 to 100 mA and the tube voltage as 80 kV from the top of the kidneys to the iliac crests, and 100 kV from the iliac crests through the pelvis. The high-BMI protocol used between 50 and 150 mA, with 100 kV from the top of the kidneys through the pelvis.

The regular-dose CT was used for diagnostic purposes, with the dictated report used as the reference standard for all results. Regular-dose CT images were read by one of more than 30 radiologists, depending on who was on duty for CT readings in the ED. The reduced-dose images were placed in a separate folder in our hospital Picture Archival and Communication System (Fuji Synapse, FUJIFILM Medical Systems, Stamford CT) and were not used clinically.

Later, the reduced-dose CT scans were interpreted by one of 3 radiologists blinded to the initial images and report, all of whom were board-certified, with 1 year of fellowship training in body imaging and 2 to 4 years of experience as an attending radiologist. Interpretations of the reduced-dose CT were entered onto a standard form that specifically queried for the presence, size, and location of all kidney stones; presence and degree of any hydronephrosis or hydroureter; presence of any perinephric or periureteral fat stranding; alternative cause(s) of symptoms; and any incidental findings that would merit follow-up imaging. Forty of the reduced-dose CT scans were randomly selected for blinded rereading by a different radiologist, with interobserver variability for ureteral stone, hydronephrosis, and stranding calculated. Dose information as dose-length-product in milligray-centimeters for both regular- and reduced-dose CT scans was obtained from the estimated dose report generated by the CT scanner. Quality of images from the reduced-dose CT was rated by each reader as “good,” “reasonable,” “fair,” or “poor” and diagnostic confidence based on interpretation of the reduced-dose CT scan was rated from low to high with a 7-point ordinal scale (1 being low confidence and 7 being high confidence).

Outcome Measures

A symptomatic ureteral stone (the primary outcome) was defined as a stone located in the ureter from the ureteropelvic junction to the ureterovesical junction as mentioned on the written CT report. Secondary signs of ureteral stone (hydronephrosis or stranding) were also noted. Stones in the renal parenchyma were noted but were not considered symptomatic. Large stones (>5 mm) were specified a priori as a secondary outcome. An acutely important alternative cause of symptoms was defined as a CT finding related to symptoms (ie, causing pain) that would require therapy or intervention. An incidental finding was defined as a CT finding that was not thought to be responsible for symptoms but for which the report recommended imaging follow-up. CT data were extracted from the written report by a research associate blinded to the reduced-dose CT and read, with any questionable interpretations reviewed by an MD study author blinded to reduced-dose CT readings. A subset of regular-dose CT interpretations was blindly re-extracted by a separate research associate to determine interobserver variability.[19]

CT dose was reported with size-specific dose estimates in milligray, estimated from the CT dose index and effective abdominal diameter.[21] Although such estimates are now recommended for reporting patient dose, we also included mean dose-length-product, mean volume CT dose index (CTDIvol), and estimated effective dose in millisieverts, using a conversion factor of 0.016 (for the abdomen pelvis) multiplied by the dose-length-product.

Follow-up was attempted for all patients to determine whether any urologic or other surgical intervention was performed within 90 days. The primary method of follow-up was through a telephone call, though e-mail, through regular mail, and by analysis of hospital and clinic records when available. A scripted form was used by the research associate to collect follow-up data, and any data from hospital or clinical records were abstracted into a standard form.

Primary Data Analysis

Our primary outcome was the presence of symptomatic ureteral stone visualized on reduced-dose CT imaging, using ureteral stone mentioned on the dictated report from the regular-dose CT as the reference standard. A priori, we specified that we would also compare the presence of any stone observed on reduced-dose CT with the presence of a large stone observed on regular-dose CT. We also reported when the reduced-dose CT identified conditions requiring intervention, though our study was not powered to determine this definitively. Presence of secondary signs of ureteral stone (hydronephrosis or stranding) was also compared between CT modalities and may have been used by the radiologist to help determine the presence of ureteral stone but was not used independently to determine its presence.

Our sample size was determined in conjunction with the radiation safety committee and sought to have less than a 10% confidence interval (CI) with a lower sensitivity bound of 95% for large stones.[22] In accordance with previous data from our institution, we estimated that 50% of patients undergoing CT would have a ureteral stone, and 20% of these (10% of overall subjects) would have a large stone. A sample size of 182 was estimated as a minimum for these criteria, and we sought to enroll 200 subjects to provide a reasonable balance between the CI of the test characteristics and exposure of patients to additional radiation.

Data were analyzed with JMP 10 (SAS Institute, Inc., Cary, NC). Results are expressed as means with SDs, and proportions for sensitivity, specificity, and κ with 95% CIs.

RESULTS

Characteristics of Study Subjects

The final sample included 201 patients with mean age 44 years, with 52% being men (Figure 2 and Table 1). The mean BMI was 29.1 kg/m^2 (SD 7.8), and 58.7% received the high-BMI protocol (Table 2). According to the report from the regular-dose CT, 50.7% of subjects (102/201) had a symptomatic ureteral stone, and 27.2% of ureteral stones (26/102) were large (>5 mm) (Table 3). There were 5 patients (2.5%) with an acutely important alternative cause of symptoms noted on their regular-dose CT scan: 3 diverticulitis, 1 appendicitis, and 1 severe hydronephrosis without ureteral stone.

Main Results

Of the 102 stones identified on regular-dose CT, 92 were observed on reduced-dose CT, yielding a sensitivity of the reduced-dose protocols for any ureteral stone of 90.3% (95% CI 82.3% to 95.0%) (Table 4). Of the 10 ureteral stones not observed on reduced-dose CT, 4 were 2 mm, 3 were 3 mm, 2 were 4 mm, and 1 was 5 mm. There was 1 3-mm ureteral stone observed on reduced-dose CT that was not reported in the information from regular-dose CT (a false positive), yielding a specificity of reduced-dose CT for ureteral stone of 99.0% (95% CI 93.7% to 100.0%). Review of the regular-dose CT result on this patient by an independent radiologist appeared to show a ureteral stone not originally appreciated in the dictated report of the regular-dose CT.

In the subgroup analysis of large stones (>5 mm) observed on regular-dose CT, the sensitivity of finding any stone on reduced-dose CT was 100% (95% CI 85.0% to 100%), with a specificity of 63.0% (95% CI 55.3% to 70.1%). The mean ureteral stone diameter on regular-dose CT was 5.0 mm (SD 2.6 mm), with a mean difference in measurements between regular- and reduced-dose CT of 1.3 mm (in either direction).

For secondary signs of obstruction, the reduced-dose CT showed a sensitivity of 89.3% (95% CI 81.7% to 91.4%) and specificity of 97.8% (95% CI 91.4% to 99.6%) for hydronephrosis, with a sensitivity of 78.4% (95% CI 68.6% to 85.8%) and specificity of 95.8% (95% CI 52.9% to 97.8%) for stranding (Table 4).

Of the 5 acutely important alternative findings identified on regular-dose CT (2.5% of CT scans), 4 were identified on reduced-dose CT. The one not identified by the reduced-dose CT was described as mild colitis on regular-dose CT, and the patient was treated with antibiotics as an outpatient. Incidental findings for which follow-up was recommended were less commonly identified with reduced-dose CT (7 incidental findings; 3.5% of scans) versus the regular-dose CT (20 incidental findings; 10.0%), though specificity of an incidental finding on the reduced-dose CT for incidental finding on the regular-dose CT was high (99.5%; 95% CI 96.5% to 100%).

Image quality of the reduced-dose CT scans was rated as "good" or "reasonable" in 67.5% of studies, with diagnostic confidence yielding a median rating of 5 (interquartile range 4 to 6), toward the high end of the 7-point ordinal scale, and did not differ substantially by protocol (Table E1, available online at http://www.annemergmed.com).

Interobserver variability of reduced-dose CT rereadings yielded κs for ureteral stone, hydronephrosis, and stranding of 0.85 (95% CI 0.68 to 1.0), 0.85 (95% CI 0.67 to 1.0), and 0.74 (95% CI 0.54 to 0.95), respectively. The high-BMI protocol appeared to perform comparably to the low-BMI protocol (Table 4).

The mean size-specific dose estimate for the regular-dose CT scans was 21.6 mGy (SD 9.6; range 6.7 to 76.6 mGy) and for the reduced-dose CT scans was 3.4 mGy (SD 0.9; range 1.8

to 10.0 mGy), representing a mean dose reduction of 18.2 mGy (95% CI 16.9–19.5 mGy) (Table 2). Figure 1 shows a representative scan of a low-BMI patient with a 2-mm stone at the right ureterovesical junction, visualized on both the regular- and reduced-dose CT images, with an 80% reduction in size-specific dose estimates. The estimated effective dose was reduced from 12.7 mSv (SD 6.3) to 1.6 mSv (SD 0.6). Figure 3 shows the reduction in size-specific dose estimates as a function of the estimates on the regular-dose CT.

Follow-up evaluations were completed for 181 subjects (90%), of whom 34 (18.8%) underwent urologic intervention (lithotripsy, stent placement, surgical stone removal, or nephrostomy tube placement), with 31 interventions for ureteral stone (19 with large stones, 12 with small stones), 2 interventions for hydronephrosis without ureteral stone, and 1 intervention for parenchymal stones. Of patients requiring urologic intervention for ureteral stone, 31 of 32 (97%) were correctly identified as having a kidney stone on the reduced-dose CT. The one patient missed had a 5-mm kidney stone that was not identified on the original reduced-dose CT (though it was identified on a blinded rereading of the same reduced-dose CT). Other urologic interventions not performed for ureteral stone included 2 patients who had a stent placed for hydronephrosis (one identified on the reduced-dose CT) without obstructing stone, and a patient who had a surgical removal of a nonureteral stone in the renal parenchyma (also observed on reduced-dose CT). One patient underwent a nonurologic surgical procedure (appendectomy; appendicitis identified on reduced-dose CT).

LIMITATIONS

Our study implemented our protocol on only one type of CT scanner from a single manufacturer in a single center, and these results may not be generalizable to other institutions. Other centers may have clinicians with different tolerances for obtaining a CT scan for a renal colic patient, and thresholds for intervention by urologists may differ. The CT scans were read in batches and were read by only 3 radiologists. It is possible that the accuracy reported here is different from that of radiologists without specialty training who are reading scans as part of routine clinical care. Our protocol was designed by a medical physicist and resulted in a lower effective dose (≈ 1.6 mSv) than the typical threshold for low dose (3 mSv) and this may have made images more noisy than those obtained under other protocols. It is possible that newer techniques such as adaptive statistical iterative reconstruction allow even better images and should be evaluated, but were not evaluated in this study.[23] Although most important alternative causes of symptoms were detected in this study, further investigation is warranted to determine the overall accuracy of reduced-dose techniques for important alternative findings and to determine the generalizability of these protocols. The number of subjects lost to follow-up (n¼19; 10%) was relatively low but is a limitation of the results.

DISCUSSION

To our knowledge, this is the first study in the United States of substantially reduced-dose CT techniques on ED patients imaged for suspected kidney stone, and the first to include comprehensive follow-up data. We have shown that a CT protocol for patients of diverse

BMIs with a mean dose reduction of 84% is moderately sensitive (90.2%) and highly specific (99.0%) for ureteral stone, with near-perfect sensitivity for larger stones that may require intervention. The 10 stones not observed on reduced-dose CT were generally small and would be expected to pass spontaneously in most cases.

Although dose reduction could be considered the domain of physicists and radiologists, emergency clinicians represent an important part of collaborative efforts to appropriately reduce radiation and should strive for the “as low as reasonably achievable” principle.[9,24,25] What is reasonable or acceptable in terms of diagnostic accuracy may change according to the clinical scenario, as well as the tolerance of the clinician and imaging specialist (and perhaps patient in a shared decision making model) for any uncertainty.[26,27] Although a reduced-dose CT may not be the most appropriate study in an elderly patient with a high potential for alternative causes of symptoms, it may be the best for determining need for intervention in young patients, many of whom receive repeated examinations with substantial radiation.[28] Gestalt pretest probability of kidney stone or an objective clinical prediction rule such as the Size Timing Onset Nausea Erthrocytes (STONE) score[19] may help select the most appropriate patients for substantial dose reduction.

Particularly in younger patients with a high likelihood of ureteral stone and in patients with recurrent stone disease, if a CT is conducted at all, the “reason” for it is usually to determine the size and location of any stone, with implications for prognosis, treatment, and follow-up. For these patients, a reduced-dose CT, although imperfectly sensitive for small stones, may represent a good option. Imaging in suspected renal colic is an area in which there is wide practice variability; given a similar patient with a high likelihood of kidney stone and low likelihood of alternative diagnosis, a clinician may opt for a regular-dose CT, reduced-dose CT, radiograph, ultrasonography, or no imaging at all.[29–32] Some have advocated that the radiograph be abandoned entirely, given the possibility of conducting a reduced-dose CT.[33] CT (regular or reduced dose) is less likely to be performed for kidney stone outside of the United States.[30,34–36] It is also arguable that many of these patients could be appropriately managed without imaging in the acute setting if the clinician is confident in the diagnosis. Approximately 80% of ureteral stones will pass spontaneously, and patients with stones that do not would be expected to follow up for appropriate therapy. Campaigns such as the *British Medical Journal*’s “Too Much Medicine” and “Choosing Wisely” have highlighted the harms of overdiagnosis.[37,38]

Although the number of patients requiring intervention was relatively small, the reduced-dose CT scan identified nearly all patients needing intervention, which could be considered the true criterion standard reason to obtain a CT. To our knowledge, this is the only study to date that has performed follow-up on patients receiving reduced-dose CT to determine whether intervention was required that could have been identified on CT. Of patients who ultimately underwent a urologic intervention, 26 of 27 abnormalities (96.3%) were identified on the reduced-dose CT scan.

In addition to determining whether there is a stone large enough to require intervention, CT may detect an alternative cause of symptoms that mimic renal colic. Although this study was not powered to determine the accuracy of a reduced-dose CT protocol for alternative causes of symptoms, 4 of the 5 patients who had these alternative causes in our series were identified, with 1 missed “mild” diverticulitis/colitis. The only condition requiring nonurologic intervention (an appendectomy) was detected by the reduced-dose protocol. A recent study examining low-dose CT for diagnosis of appendicitis found that it was noninferior to regular dose,[39] although this study was conducted in Korea, where BMIs are lower than is typical in the United States. Because the prevalence of acutely important alternative findings is low in CT scans for kidney stone,[40] it will take larger numbers of patients to determine the accuracy of reduced-dose protocols for these conditions. There was only 1 patient in this study with a small aortic aneurysm, but aortic pathology should be appreciated as an uncommon but lethal cause of pain that may mimic renal colic.

The reduced-dose CT scan identified fewer “incidental” findings than the regular-dose CT (5.0% versus 11.4%), though when findings were observed on reduced-dose CT they were very specific (99%) for incidental findings on regular-dose CT. This may be a further advantage of a reduced-dose technique because most incidental findings lead to further testing and anxiety without benefit to the patient.[37,41,42] On the other hand, occasionally incidental findings may be important (such as in early detection of a curable cancer). Future work should explore the benefits and harms associated with incidental findings on both reduced- and regular-dose CT.

Reduced-dose CT is not a perfect test (nor is regular-dose CT, though it was the reference standard for this study). Therefore, if the clinician or patient would be uncomfortable with a negative study result (when there may actually be a small stone or other finding), reduced-dose CT should not be conducted. Further study that incorporates test characteristics, radiation risk, and patient outcomes may help to determine a test threshold for various options.[43]

Although reduced-dose techniques are encouraged by professional societies such as the American College of Emergency Physicians and American College of Radiology, recent data from the National Radiology Data Registry’s Dose Index Registry indicate that only 2% of renal colic protocol CT scans could be considered low dose.[9,10,29,44] It is our hope that these data on actual ED patients, including complete follow-up information, can help lead to appropriate adoption of reduced-dose CT protocols, as well as enhance physician awareness of dose issues.[45–47]

We have reported our dosing as size-specific dose estimates, as recommended by the American Association of Physicists in Medicine. These estimates account for the fact that larger patients receiving the same radiation would have a lower organ dose. We have also reported effective dose in millisieverts for comparison purposes to other literature. The mean effective dose of our protocol could be estimated at about 1.6 mSv (using mean dose-length-product of 103 mGy-cm and an ED/dose-length-product conversion factor[48] of 0.016), or half the effective dose of a “low-dose” renal colic CT (typically considered to be an effective dose of 3 mSv or less), and 86% lower than the current national mean effective dose of approximately 11.2 mSv.[44] Our regular-dose CT had an effective dose of approximately 12.6 mSv, only slightly higher than the national average.

While we await better and more definitive epidemiologic data on the risk of low-dose ionizing radiation, the most widely accepted model for risk of cancer from CT is "linear no threshold," which states that the reduction in dose will be linearly related to the reduction in cancer risk.[49] Although actual numbers are controversial, it has been estimated that there will be 29,000 additional malignancies from the CT scans conducted in the United States in 2007 alone,[50] with regular-dose CT scans for kidney stone resulting in an additional malignancy for every 500 to 1,400 CT scans performed.[51] With more than 2 million ED visits for flank or back pain concerning for kidney stone[7] and more than 70% of patients with diagnosed kidney stones receiving a CT,[3] it is likely there are approximately a million renal colic CT scans conducted annually, with patients aged 25 to 44 years representing the largest group undergoing CT.[3] This could result in as many as 1,000 additional malignancies yearly (using a risk[51] of approximately 1 in 1,000). An overall dose reduction of 80% could thus be estimated to result in approximately 800 fewer additional malignancies annually with the linear no threshold model.

Our protocol is also innovative because it is stratified by patient size. Obesity in the United States (and elsewhere) is well understood to limit the diagnostic evaluation of patients both through physical examination and radiologic imaging, and diagnostic strategies need to accommodate this.[52–54] Obesity is an independent risk factor for kidney stone formation, with 59% of our subjects stratified as having high BMI.[17,55] Our study suggests that a high-BMI protocol is a feasible way to include all patients while still achieving substantial dose reduction. The only US study of a reduced-dose protocol that we are aware of was conducted on a convenience sample of 50 patients who weighed less than 200 pounds (90.7 kilograms); it reported an accuracy of 94% for ureterolithiasis while achieving a dose reduction of 25% to 42%. In contrast, our study did not exclude obese patients and achieved a more substantial dose reduction while maintaining high accuracy.[56]

In summary, a markedly reduced dose index protocol is not a perfect test but may represent a feasible alternative to regular-dose CT for suspected kidney stone, particularly in younger patients with low likelihood of alternative diagnoses. Reduced-dose CT is more accurate for detecting large stones that may require intervention. Appropriate implementation of reduced-dose CT techniques for diagnosis of kidney stone could safely and substantially decrease radiation exposure on a population basis but requires further study in clinical settings.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Editor's Capsule Summary

What is already known on this topic

Although professional societies recommend reduced-dose computed tomography (CT) in renal colic protocols, 98% of scans in the United States use conventional radiation doses.

What question this study addressed

Does reduced-dose CT perform comparably to regular-dose CT in detecting stones in symptomatic emergency department patients?

What this study adds to our knowledge

In 201 patients with a range of body mass indexes who received both scans contemporaneously, reduced-dose CT was 90% sensitive and 99% specific compared with regular-dose CT, and 96% sensitive for stones requiring intervention. Radiation dose was substantially lower, 3.4 versus 21.6 mGy.

How this is relevant to clinical practice

Low-dose CT appears to be a reasonable choice for patients who need a CT for potential ureteral stones, particularly those with low likelihood for alternative diagnoses.

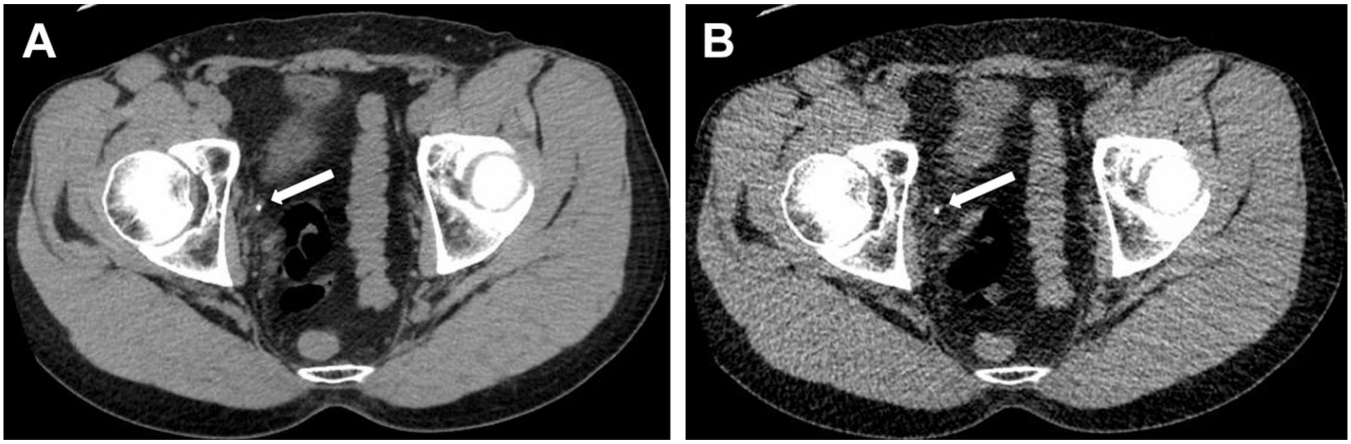
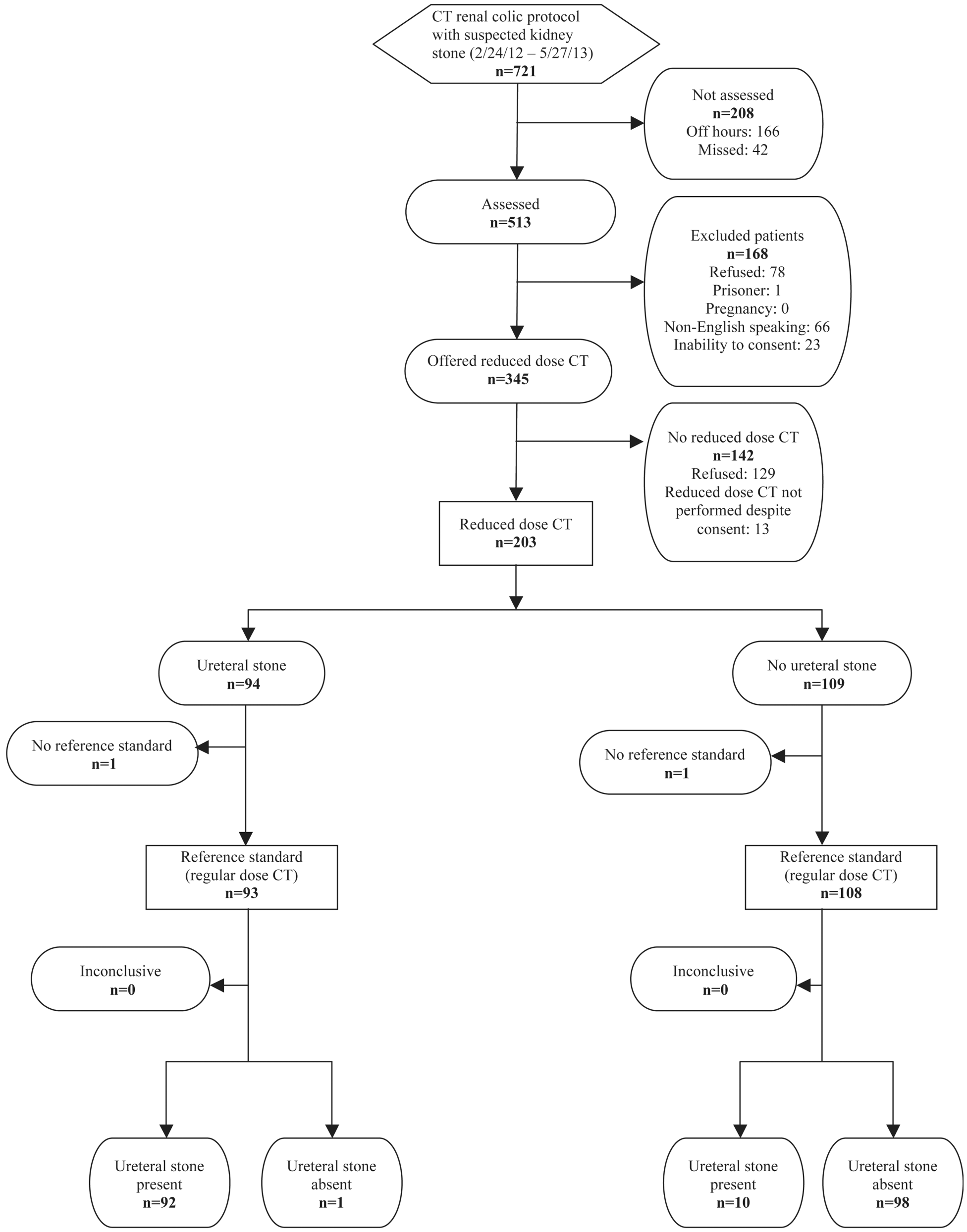


Figure 1.
Images from the regular-dose (*A*) and reduced-dose CT (*B*), both showing a 2-mm stone in the distal right ureter (arrows). Reduction in size-specific dose estimate was from 19 to 3.8 mGy, an 80% decrease.



*In two patients a reduced dose CT was done without a regular CT, which was a protocol violation. However, the radiologist and/or clinician felt the reduced dose CT was diagnostic (7mm stone and no alternative cause of pain) and a regular CT was not performed.

Figure 2.
Standards for the Reporting of Diagnostic Accuracy studies enrollment flow diagram.
*In two patients a reduced dose CT was done without a regular CT, which was a protocol violation. However, the radiologist and/or clinician felt the reduced dose CT was diagnostic (7mm stone and no alternative cause of pain) and a regular CT was not performed.

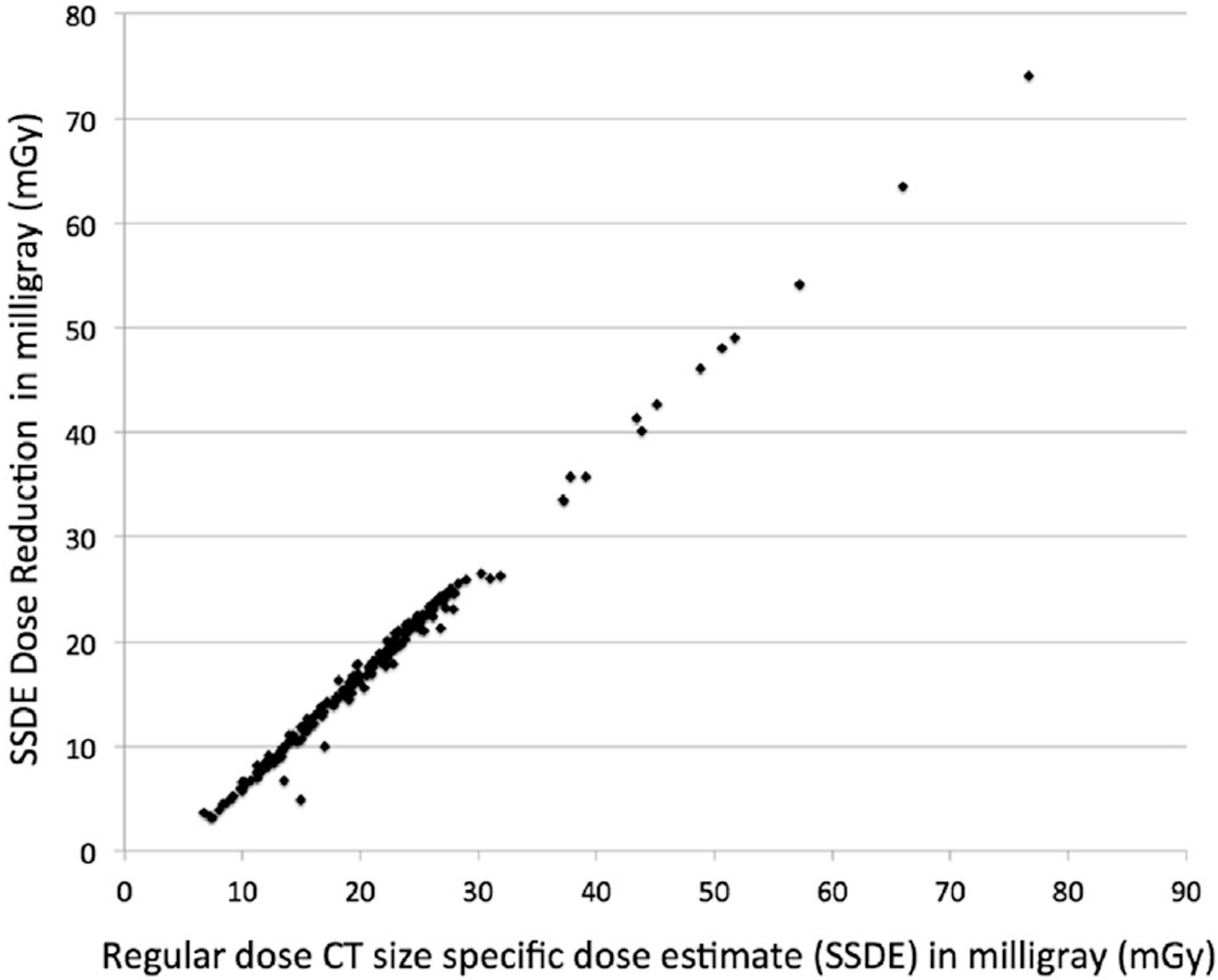


Figure 3.
Graph of reduction in size-specific dose estimate (in milligray) compared with that of regular-dose CT.

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Table 1

Demographic characteristics of patients.

Characteristic	Result
Mean age (SD), y	43.6 (14.7)
Male sex, No. (%)	105 (52.2)
BMI (SD), kg/m^2	29.1 (8.1)
Abdominal AP + lateral diameter, No. (%) *	
>600 mm	118 (58.7)
<600 mm	83 (41.3)
Race, No. (%)	
Black	27 (13.4)
White	165 (82.1)
Other or not reported	9 (4.5)
Ethnicity, No. (%)	
Hispanic	54 (26.9)
Non-Hispanic	147 (73.1)
Hematuria	146 (72.6)
History of ureteral stone, No. (%)	90 (44.8)

AP, Anteroposterior.

* The abdominal AP diameter in millimeters was added to the lateral diameter, with a cutoff of more than 600 mm used to determine use of high-BMI reduced-dose CT protocol.

Table 2

CT dose information.*

Dose/findings	All (n = 201)	High-BMI Protocol (n = 118)	Low-BMI Protocol (n = 183)
SSDE for regular-dose CT, mGy	21.6 (9.6)	28.1 (31.7)	16.4 (6.9)
SSDE for reduced-dose CT, mGy	3.4 (0.9)	3.1 (1.0)	3.9 (0.5)
Mean SSDE reduction, mGy	18.2 (10.0)	22.2 (9.8)	12.5 (7.0)
Mean DLP for regular-dose CT, mGy-cm	791.1 (395.3)	1,031.9 (322.3)	448.9 (176.0)
Estimated effective dose for regular-dose CT, mSv	12.7 (6.3)	16.5 (5.2)	7.2 (0.1)
Mean DLP for reduced-dose CT, mGy-cm	102.6 (35.7)	125.7 (27.4)	69.8 (13.2)
Estimated effective dose for reduced dose, mSv	1.6 (0.6)	2.0 (0.4)	1.1 (0.2)
Mean reduction in DLP	688.5 (375.7)	906.2 (324.1)	379.1 (171.1)
Estimated dose reduction, mSv	11.0 (6.0)	14.5 (5.2)	6.1 (2.7)

SSDE, Size-specific dose estimates; *DLP*, dose-length-product.

*Results are presented as mean (SD).

Table 3

Findings on regular-dose CT and follow-up.

Regular-dose CT Findings and Follow-up	All (n = 201)
Any ureteral stone observed on regular-dose CT and location of stone, No. (%)	102 (50.7)
Small stone (≤5 mm), No. (%)	76 (37.8)
Proximal ureter (including UPJ)	6
Midureter	11
Distal ureter (including UVJ)	58
Location unknown	1
Large stone (>5 mm), No. (%)	26 (12.9)
Proximal ureter (including UPJ)	13
Midureter	3
Distal ureter (including UVJ)	9
Location unknown	1
Acutely important alternate cause of symptoms observed on regular-dose CT, No. (%)	5 (2.5)
Incidental finding (follow-up imaging recommended) observed on regular-dose CT, No. (%)	22 (10.9)
Interventions within 90 days out of 181 completed follow-ups	n=181
Urologic intervention, No. (%)	34 (18.7)
Other surgical intervention, No. (%)	1 (0.6)
Patients admitted at their initial ED visit	32 (15.9)

UPJ, Ureteropelvic junction; *UJV*, ureterovesical junction.

Table 4

Test characteristics of reduced-dose CT for primary and secondary findings, with regular-dose CT as reference standard.

	All (95% CI), %		Low-BMI Protocol (95% CI), %		High-BMI Protocol (95% CI), %	
CT Finding	**Sensitivity**	**Specificity**	**Sensitivity**	**Specificity**	**Sensitivity**	**Specificity**
Any ureteral stone	90.2 (82.3–95.0)*	99.0 (93.7–99.9)	88.9 (75.2–95.8)	97.4 (84.6–99.9)	91.2 (80.0–96.7)	100.0 (92.6–100.0)
Any stone on reduced-dose CT when large stone observed on regular-dose CT	100.0 (85.0–100.0)	63.0 (55.3–70.1)	100.0 (74.7–100.0)	61.8 (49.1–73.0)	100.0 (71.7–100.0)	64.2 (54.2–73.1)
Hydronephrosis	89.3 (81.7–94.1)	97.8 (91.4–99.6)	95.8 (84.6–99.3)	100.0 (87.7–100.0)	84.4 (72.7–91.9)	96.3 (86.2–99.4)
Stranding (n=192)	78.4 (68.6–85.8)	95.8 (89.0–98.6)	81.6 (65.1–91.7)	92.7 (79.0–98.1)	76.2 (63.1–85.0)	98.1 (88.8–99.9)
Acutely important alternate finding	80.0 (29.9–98.9)	100.0 (97.6–100.0)	50.0 (2.7–97.3)	100.0 (94.4–100.0)	100.0 (31.0–100.0)	100.0 (96.0–100.0)
Incidental finding with follow-up imaging recommended	35.0 (16.3–59.1)	99.5 (96.5–100.0)	42.9 (11.8–79.8)	100.0 (93.9–100.0)	30.8 (10.4–61.1)	99.0 (94.0–100.0)

* Of the 10 stones not observed on the reduced-dose CT, 4 were 2 mm, 3 were 3 mm, 2 were 4 mm, and 1 was 5 mm.