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Multi-Institutional Variation in Performance of Low-Dose Computed Tomography for the Evaluation of Suspected Nephrolithiasis

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Abstract

Introduction and Objective: Guidelines from the American Urological Association (AUA) and American College of Radiology (ACR) recommend that patients with suspected nephrolithiasis undergo low-dose CT of the kidney, ureter, and bladder (LD CT KUB) as opposed to higher dose conventional imaging. We hypothesized that even at institutions with established LD protocols, higher dose imaging is common.

Materials and Methods: We identified four academic medical centers where LD CT KUB protocols were implemented to yield an effective dose (EDose) consistent with national guidelines. Fifty consecutive adult patients who underwent CT KUB specifically for the evaluation of nephrolithiasis were retrospectively reviewed at each site. Patient age, sex, body mass index (BMI), imaging location, and EDose (millisieverts [mSv]) were recorded.

Results: Two hundred patients with a mean age of 54 years were identified. Forty-six patients (23%) underwent CT KUB with an EDose ≤4 mSv, accounting for 10% to 48% of each institution's cohort. One hundred sixteen patients had a BMI <30, and would have been expected to receive LD CTs by the AUA criteria for LD CT KUB. Within this subset, only 37 patients (32%) actually underwent LD CT KUB. The highest dose CT KUB at each institution resulted in an EDose of 33.8 to 44.6 mSv, exceeding the recommended exposure of LD CT KUB by 10-fold.

Conclusions: At academic institutions where LD CT KUB was implemented for the evaluation of nephrolithiasis, a minority of patients with BMI <30 received guideline-concordant imaging. Differences in patient BMI did not account for the variation in radiation exposure. Further research is necessary to elucidate barriers to LD CT implementation.

Keywords: imaging, CT, low dose, nephrolithiasis

Introduction

Nephrolithiasis is one of the most common urologic disorders, resulting in more than 1 million patient visits to the emergency departments (EDs) each year and affecting 8.8% of the U.S. population.[1] The evaluation of renal colic often exposes patients to significant amounts of imaging-related ionizing radiation.[2,3] The specific way that such imaging is performed has important implications for patients' risk of secondary malignancy.[4,5]

Since 2012, the American Urological Association (AUA) and American College of Radiology (ACR) have recommended low-dose (LD) (≤3–4 millisieverts [mSv]) CT of the kidney, ureter, and bladder (CT KUB), as opposed to

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higher dose conventional CT KUB, for patients with suspected nephrolithiasis.[4,6] Despite this strong endorsement, LD CT KUB is utilized only 8% of the time in community practice and represents only 2% of all the CT KUBs performed nationwide.[7,8]

We hypothesized that wide variability in radiation exposure persists even at those academic centers that have made concerted efforts to address this critical safety need. We performed a multi-institutional review of CT KUB imaging practices at four academic institutions with established LD protocols.

Materials and Methods

This study was approved by the Institutional Review Board. We identified four academic medical centers that had implemented LD CT KUB for the evaluation of patients with suspected nephrolithiasis for at least 1 year (range 1–2 years). These were defined as sites where radiologists and urologists had collaboratively developed LD CT KUB protocols to yield an effective dose (EDose) consistent with guidelines from the AUA and ACR (i.e., EDose <4 mSv).[4,6] Study settings had been determined by each site's radiation physicist teams. Because the LD protocols were developed independently at each site in the years before this review, implementation and provider education were not standardized. Instead, these relied on each site's respective radiology and urology clinician champions' leveraging of available resources to implement the LD protocol in whatever way was possible within institutional and electronic health record (EHR) constraints.

Urology clinic records were retrospectively reviewed to identify consecutive patients who had undergone CT KUB between January and October 2019 and subsequently been referred for the management of nephrolithiasis, representing a convenience sample from each institution. Patient records were reviewed for age, sex, body mass index (BMI), and location at the time of imaging (inpatient, outpatient, ED). The EDose in mSv of each CT was calculated using a previously established conversion of multiplying reported dose length product by a *k*-factor of 0.015.[9] Imaging was considered LD when the EDose was ≤4 mSv, utilizing this less stringent AUA definition instead of the more stringent ≤3 mSv recommended by the ACR.[4,6]

Patients were excluded from the analysis if their CT was performed at outside institutions, or if the study protocol was not described as CT KUB (e.g., CT abdomen/pelvis with or without contrast). Because the AUA guidelines recommend LD CT KUB only for patients with a BMI <30, data were separately analyzed for this subset of patients. The Pearson chi-square test was used to evaluate the rates of LD CT across institutions at the univariate level. Logistic multivariate regression, with CT dichotomized into conventional and LD as the dependent variable, was used to investigate the relationship between BMI, institution, and imaging setting with radiation exposure (JMP 15, SAS, Cary, NC). Statistical significance was assigned when $p < 0.05$.

Results

Fifty consecutive patients meeting the above criteria were identified from each site, yielding an overall cohort of 200 patients with a mean age of 54 years (standard deviation [SD] 16). The cohort included 93 male (47%) and 107 female (53%) patients, with a mean BMI of 30.1 (SD 9.3). Most patients underwent imaging in an outpatient (132 patients, 66%) or ED (60 patients, 30%) setting (Table 1). Of these 200, 46 patients (23%) underwent CT KUB that qualified as LD based on an EDose of ≤4 mSv. The percentage of CTs qualifying as LD ranged from 10% to 48%, depending on the institution of imaging ($p < 0.001$, Table 2). The highest dose CT KUB at each institution resulted in an EDose of 33.8 to 44.6 mSv, exceeding the recommended exposure of an LD scan by 10-fold.

Table 1. Patient and Imaging Characteristics for the Multi-Institutional Cohort

	N (%)
Patients	200
Age, mean (SD)	54 (16)
Gender	
Male	93 (47%)
Female	107 (53%)
BMI	
<25	59 (30%)
25.1–30	51 (26%)
30.1–35	40 (20%)
>35	50 (25%)
Imaging setting	
Inpatient	8 (4%)
Outpatient	132 (66%)
Emergency department	60 (30%)

BMI = body mass index; SD = standard deviation.

On univariate analysis, BMI, imaging setting, and institution were all associated with higher rates of LD CT KUB ($p < 0.001$, Supplementary Table S1). On multiple logistic regression, BMI ($p < 0.001$) and institution ($p < 0.05$) maintained an association with LD CT KUB.

A subset of 116 patients with BMI <30 were identified among the 4 institutions. Within this nonobese cohort, only 37 patients (32%) underwent LD CT KUB (range 15%–53% between institutions, $p < 0.001$). The remaining 79 patients (68%) with BMI <30 underwent CT with a mean dose of 8.4 mSv (SD 3.5) or double the recommended radiation exposure. Linear regression demonstrated a Pearson's correlation coefficient of 0.718, with 52% of the variance in radiation exposure explained by BMI ($p < 0.001$, Fig. 1). The highest exposure CT among the nonobese patients was fivefold higher than recommended (14–20.3 mSv; Table 2).

Discussion

The present study demonstrates that at four high-volume academic medical centers with established LD CT KUB protocols, a minority of patients (23%) with suspected nephrolithiasis underwent cross-sectional imaging that meets the criteria for low radiation dose by the AUA/ACR guidelines. This finding cannot be explained by the patient BMI, as limiting the cohort to nonobese patients (BMI <30) improved the likelihood of EDose <4 mSv to only 32%. Wide variability existed in CT radiation exposure both within and between the four institutions.

For nearly a decade, guidelines from the AUA and ACR have recommended that patients with suspected nephrolithiasis undergo LD CT KUB as opposed to higher dose

Table 2. Radiation Exposure Stratified by Patient Body Mass Index

	Institution 1	*Institution 2*	*Institution 3*	*Institution 4*	*All*	
CT KUB exposure, all patients						
Patients	50	50	50	50	200	$p < 0.01$
Mean (SD), mSv	8.9 (6.7)	10.0 (8.1)	6.0 (6.1)	10.9 (9.8)	10.1 (8.3)	
Range, mSv	1.2–33.8	1.9–44.6	0.7–35.8	1.0–42.6	0.7–44.6	
≤4 mSv: ''low dose''	11 (22%)	5 (10%)	24 (48%)	6 (12%)	46 (23%)	
CT KUB exposure, BMI <30						
Patients	24	26	38	28	116	$p < 0.001$
Mean (SD), mSv	5.7 (3.3)	7.2 (4.3)	5.1 (4.1)	7.7 (3.9)	6.4 (4.1)	
Range, mSv	1.2–14.8	1.9–20.3	0.7–18.4	1.0–15.4	0.7–20.3	
≤4 mSv: ''low dose''	7 (29%)	4 (15%)	20 (53%)	6 (21%)	37 (32%)	

CT KUB = CT of kidney, ureter, and bladder; mSv = millisieverts; SD = standard deviation.

conventional CT.[4,6] These guidelines are based on a meta-analysis of seven randomized trials that demonstrated greater than 95% sensitivity and specificity of LD CT KUB for nephrolithiasis.[10] While LD CT KUB is often discussed at academic meetings, adherence to these recommendations is poor, with prior research finding that LD studies are performed only 8% of the time in community practice.[7]

Reports from national imaging registries show LD CT KUB to represent only 2% of all the CT KUBs performed between 2011 and 2012,[8] improving to 8% from 2015 to 2016.[11] This modest improvement in adherence to CT guidelines does not appear to be explained by a shift toward ultrasound-first imaging. Despite prior work suggesting that such an approach is safe,[12] only 7% of ED patients diagnosed with nephrolithiasis undergo an initial ultrasound.[3] The present study suggests that imaging at academic medical centers with established LD protocols does not assure appropriately low radiation exposure for patients.

Multiple potential barriers exist to the widespread implementation of LD CT KUB. First, health care systems are neither incentivized to perform LD CT, nor penalized when it is not. The Merit-based Incentive Payment System (MIPS) requires that one or more of ''automated exposure control, adjustment of the mA and/or kV according to patient size, [or] use of iterative reconstruction technique'' be documented within each CT report.[13] While these are important strategies for dose reduction, they fail to achieve the desired EDose when they are merely applied to the incorrect CT KUB protocol. This MIPS documentation requirement may even result in the paradoxical effect of reassuring clinicians that CTs are LD when no such protocol exists at their institutions.

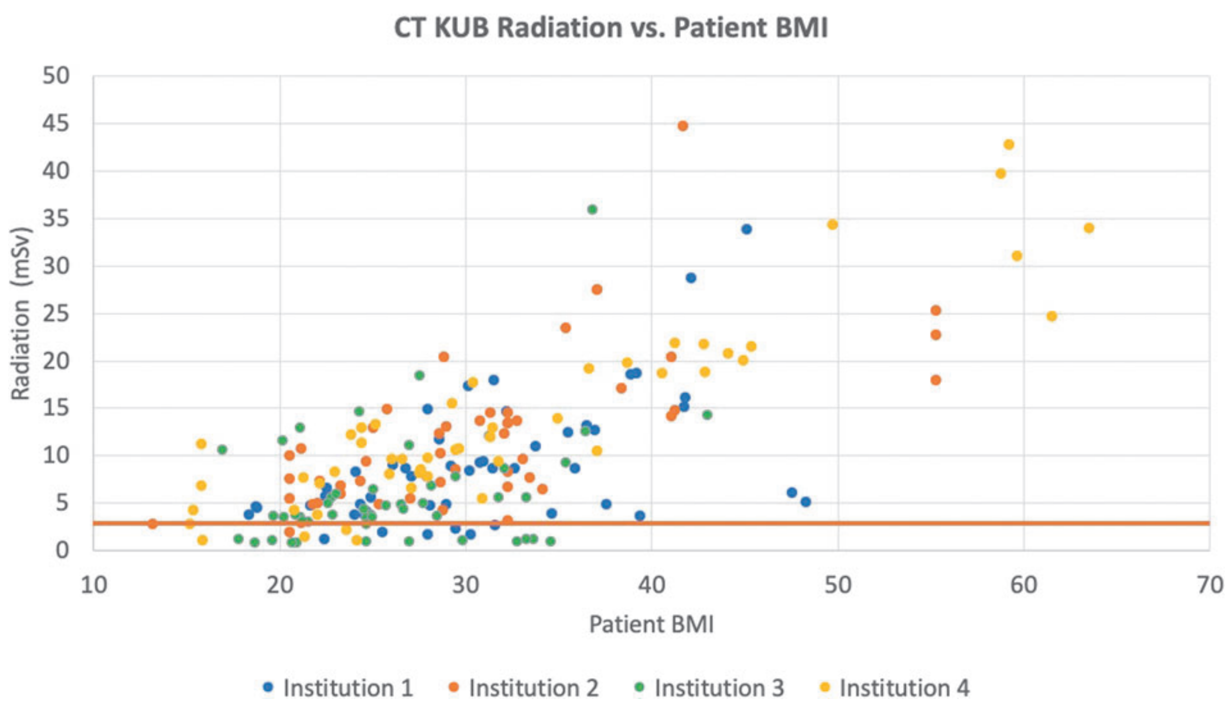

FIG. 1. Relationship between BMI and radiation exposure stratified by institution (Marker: AUA EDose threshold for LD CT KUB, 4 mSv). AUA = American Urological Association; BMI = body mass index; CT KUB = CT of kidney, ureter, and bladder; EDose = effective dose; LD = low dose; mSv = millisieverts. Color graphics are available online.

Second, urologists are poorly educated about imaging standards, with only 36% correctly identifying the EDose of LD CT KUB on a recent survey of the Endourology Society.[14] This limited understanding suggests that clinicians are not only unlikely to advocate for LD CT within their institutions but may not even be able to recognize when this safety need exists. Such recognition is made even more difficult by the absence of reporting of EDose on most imaging reports; clinicians instead must manually review dose reports and mathematically convert dose length product to EDose. Third, the AUA guideline that calls for LD CT only in patients with BMI <30 is unnecessarily restrictive.[6] By 2030, nearly one in two adults in the United States will have obesity, and contemporary CT scanners can safely reduce their radiation exposure without sacrificing image quality.[15,16] Example LD protocols are freely available online.[17] Lastly, there is no consensus in the literature regarding terminology around ''low-dose'' CT KUB. While the ACR and AUA use cut-points of 3 and 4 mSv, respectively, to designate LD CT KUB, some authors have independently created new categories such as ''ultra-low dose'' (≤1.9 mSv)[18,19] and ''very low-dose'' (<1.5 mSv).[20] Such terms may further confuse urologists in the absence of broad consensus on their definitions. This consensus is likely a prerequisite before urologists can effectively advocate for appropriate imaging with primary care and emergency medicine colleagues, who are the actual source of care for most patients with nephrolithiasis.[21]

The present study has strengths that improve its generalizability. As a multi-institutional review, it provides a realistic snapshot of contemporary imaging practices at four centers that have independently implemented LD CT KUB protocols. While other institutions may have achieved greater success with implementation, national registry data suggest that higher dose imaging remains the norm.[11] The study also draws attention to an area with broad impact. Reducing the radiation exposure from a CT imaging study that is recommended to evaluate a condition affecting 8.8% of the population is an important goal considering the risk of secondary malignancy.[1,5] Furthermore, the prevalence of recurrent stone disease increases the likelihood of additional radiation exposure in the future.

The relatively small sample size of 50 patients from each site is one limitation of this study. However, there is little reason to suspect that a larger sample would have demonstrated LD CT KUB to be utilized more appropriately. Second, the results fail to explain the potential causes of variation in EDose within and between institutions. Rather than identifying these specific barriers, we hope that the present study will motivate urologists to explore their own institutions' CT practices and avoid the risk of assuming that their studies are LD—even if they have been told that such a protocol is in place. It is certainly possible that efforts at integration within the EHR and provider education could have improved adherence to recommendations for LD CT.

Third, the inclusion of CTs performed in the emergency setting may have resulted in confounding because of a need for higher resolution imaging in undifferentiated patients. However, it is the practice at our institutions that such patients undergo CT abdomen/pelvis with or without contrast, rather than CT KUB. Because we excluded those protocols from our analysis, all patients with CT KUB by definition should have been worked up for stones and thus would be expected to have LD imaging. Further investigation into specific barriers to safer imaging is urgently needed.

Lastly, this study likely underestimates the degree of the problem, given that it excludes patients who underwent unindicated contrast and multiphase examinations, which remain common.[22] The inclusion of CTs by review of those patients who ultimately presented to a urology clinic may have also introduced bias. However, these patients are among those who should be most likely to have undergone CT KUB that was LD, making our findings even more concerning. Addressing these gaps in appropriate imaging selection with clinical decision support may pose an additional opportunity for safer imaging practices.

Conclusion

This multicenter study demonstrates that the utilization of LD CT KUB for nephrolithiasis is poor, even at four academic centers with established LD protocols. The finding is not explained by high patient BMI, as even those with BMI <30 underwent CT that exceeded AUA and ACR guidelines for EDose in 78% of cases. Interdisciplinary collaboration and strategies to improve the implementation of LD CT KUB for nephrolithiasis patients are urgently needed at local and national levels.

Authors' Contributions

D.R.: conceptualization, formal analysis, investigation, data curation, and writing—original draft, review, and editing. D.T.T.: investigation and writing—review and editing. J.S.A.: investigation and writing—review and editing. S.K.B.: investigation and writing—review and editing. T.L.C.: conceptualization and writing—review and editing. M.D.S.: conceptualization and writing—review and editing. M.L.S.: conceptualization and writing—review and editing. J.D.H.: conceptualization, supervision, and writing—review and editing.

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Author Disclosure Statement

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Supplementary Material

Supplementary Table S1

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Abbreviations Used

ACR = American College of Radiology
AUA = American Urological Association
BMI = body mass index
CT KUB = computed tomography of the kidney, ureter, and bladder
ED = emergency department
EDose = effective dose
LD = low dose
mSv = millisieverts
SD = standard deviation