Computed Tomography Radiation Exposure Among Referred Kidney Stone Patients: Results from the Registry for Stones of the Kidney and Ureter

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Abstract

Purpose: Kidney stone patients routinely have CT scans during diagnostic work-up before being referred to a tertiary center. How often these patients exceed the recommended dose limits for occupational radiation exposure of >100 mSv for 5 years and >50 mSv in a single year from CT alone remains unknown. This study aimed to quantify radiation doses from CTs received by stone patients before their evaluation at a tertiary care stone clinic.

Methods: From November 2015 to March 2017, consecutive new patients enrolled into the Registry for Stones of the Kidney and Ureter (ReSKU™) had the dose-length product of every available CT abdomen/pelvis within 5 years of their initial visit recorded, allowing for an effective dose (EDose) calculation. Multivariate logistic regression analysis identified factors associated with exceeding recommended dose limits. Models were created to test radiation reducing effects of low-dose and phase-reduction CT protocols.

Results: Of 343 noncontrast CTs performed, only 29 (8%) were low-dose CTs (calculated EDose <4 mSv). Among 389 total patients, 101 (26%) and 25 (6%) had an EDose >20 mSv and >50 mSv/year, respectively. Increased body mass index, number of scans, and multiphase scans were associated with exceeding exposure thresholds ($p < 0.01$). The implementation of a low-dose CT protocol decreased the estimated number of scans contributing to overexposure by >50%.

Conclusions: Stone patients referred to a tertiary stone center may receive excessive radiation from CT scans alone. Unnecessary phases and underutilization of low-dose CT protocols continue to take place. Enacting new approaches to CT protocols may spare stone patients from exceeding recommended dose limits.

Keywords: kidney stones, CT, low-dose CT, ionizing radiation, effective dose, radiation dose limit

Introduction

ALTHOUGH NONCONTRAST CT is the gold-standard imaging modality for detecting urinary calculi,¹ its amplified usage in the 21st century has prompted concern for a higher risk of developing secondary malignancies.^{2–4} Pre-

vious studies have shown that effective dose (EDose) is proportional to total imparted radiation from an imaging study and represents an estimate that accounts for future cancer risk based on irradiated organ type.⁵

The recommended EDose limit for occupational exposure by the International Commission on Radiological Protection

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(ICRP) is <100 mSv in 5 years (i.e., average <20 mSv/year for 5 years) with the further provision that no annual exposure be >50 mSv.⁶ Although 50 mSv is the annual occupational exposure threshold, no such threshold has been established for medical imaging, with 20 and 50 mSv commonly cited as medical imaging exposure limits in previous studies.² Consistent with the ALARA (as low as reasonably achievable) principle, some centers have introduced low-dose and ultra-low-dose CT protocols to help reduce patient radiation exposure.⁷

Despite the introduction of lower dose CT scans, large radiologic series have shown considerable variability in the amount of ionizing radiation utilized per scan across multiple institutions.⁸ In addition, stone patients continue to receive contrast and multiphase CT scans, despite this being against recently published Choosing Wisely[®] American College of Radiology (ACR) recommendations for abdominal CTs.⁹ To date, the extent and contribution of these scans to stone patients' overall radiation exposure has been relatively overlooked.

We hypothesized that referred patients may have already exceeded ICRP radiation thresholds solely from diagnostic CT imaging before receiving care at our stone center. This study aimed to estimate the EDose stone patients received from CTs performed for renal colic/nephrolithiasis and stone-related indications before their visit to a tertiary care stone clinic. A hypothetical model was then created to demonstrate the potential radiation reduction achieved if a low-dose, phase-reduction, and a combination of these different imaging protocols was implemented.

Materials and Methods

Study participants

From November 2015 through March 2017, consecutive new patients presenting to the University of California San Francisco (UCSF) Urology clinic for urinary stone disease management were prospectively enrolled into the Registry for Stones of the Kidney and Ureter (ReSKUTM). The methodology and organization of this registry have been previously described.¹⁰ All enrolled subjects provide written consent and the study has been approved by the Institution's Committee on Human Research (Protocol 14-14533).

Inclusion criteria

ReSKU subjects >18 years of age with at least one CT abdomen/pelvis scan performed before being referred to UCSF for urinary stone care were included. All available CT scans performed within 5 years before the subject's first visit were retrospectively reviewed to determine the subject's maximum EDose for a single 12-month period. As kidney stone patients often present with a variety of signs/symptoms, CTs were considered to have stone-related indications if the listed indication was not only renal colic/nephrolithiasis but also abdominal pain, hematuria, and recurrent urinary tract infections (UTIs).

Exclusion criteria

Subject CTs missing radiation dose metric data such as CT dose index volume (CTDI_{vol}) and radiation dose-length product (DLP) were excluded. CTs without a listed indication

of renal colic/nephrolithiasis or one of the stone-related indications (abdominal pain, hematuria, or recurrent UTIs) were excluded. In addition, CTs with competing diagnoses found in the report were excluded from analysis (i.e., if the indication was "abdominal pain" and ruptured appendicitis was found, the CT was excluded from analysis).

Reporting CT characteristics

The following characteristics from each CT were recorded: study date, study location, indication for the study, use of intravenous contrast, phases of CT (single vs multiple), CTDI_{vol}, and DLP.

Calculating EDose

DLP is generally accepted as the total emitted radiation imparted to the patient.¹¹ Multiplying DLP by a standard conversion factor ($k=0.015$ mSv/mGy-cm for a CT abdomen/pelvis) yielded each scan's EDose.⁵ EDose measured in mSv allows for comparisons of CT doses with other types of radiologic studies and background exposures.¹¹ For each subject, the maximum EDose was based on the highest sum of all EDose values within any 12-month period during the 5 years preceding their initial visit. Based on previous studies, a low-dose CT scan was defined as having a calculated EDose <4 mSv.^{12,13}

Statistical analyses

Statistical analyses were performed using R 3.4.0 (R Foundation, Vienna, Austria). Analysis of variance was used to determine significant differences in continuous variables between radiation exposure groups, whereas Pearson's chi-square was used for categorical variables. Given the non-normal distribution of CT scan radiation doses, the use of logarithmic transformations of EDose was applied to improve the approximation of normality for regression models. A multivariate logistic regression analysis was performed to determine the subject and scan characteristics associated with exceeding 20 and 50 mSv annual threshold EDose levels. A p -value <0.05 was considered statistically significant. Finally, a dot plot for all CTs was generated using R to illustrate which scans contributed to a patient exceeding the 50 mSv EDose threshold during any 12-month period. This was then applied to a hypothetical model to demonstrate the effects of enacting a low-dose, phase-reduction, and combination imaging protocol—all aimed at reducing radiation exposure.

Results

A total of 389 subjects with 556 CT scans met inclusion and exclusion criteria for the study. Table 1 provides information on patient demographics and CT characteristics. CT scans were performed at 130 unique radiologic centers. Within the 5 years before their initial visit, 99 subjects (25%) had undergone two or more CT scans.

For 343 noncontrast CT scans among 232 subjects, only 29 (8%) CTs had a calculated EDose of <4 mSv and would be considered low dose. Of the remaining 314 noncontrast scans not considered low dose, the associated BMI was <30 in 188 (60%) of scans. On subanalysis, 300/343 (87%) of non-contrast CTs had an indication of nephrolithiasis. Of these 300 scans, 40 (13%) resulted in an EDose >20 mSv. Meanwhile of

TABLE 1. PATIENT DEMOGRAPHICS AND CT CHARACTERISTICS

Patient demographics: No. of patients = 389	
Mean age (years, mean $\pm$ SD)	55 $\pm$ 15
Mean BMI (kg/m ² $\pm$ SD)	29.2 $\pm$ 7.6
Gender, <i>n</i> (% total)	
Men	205 (53)
Women	184 (47)
Number of CT scans per patient (median [IQR]) (within 5 years before initial visit)	1 [1–2]
Min. No. of scans = 1, Max. No. of scans = 12	
No. of patients with two or more scans, <i>n</i> (% total)	99 (25)
No. of patients with additional imaging ordered before surgery	21 (5)
Radiologic facility, <i>n</i> (% total)	
UCSF only	162 (42)
Non-UCSF Radiology Institution*	221 (57)
Combination of UCSF and non-UCSF radiologic centers	6 (1)
*Unique outside radiology institutions	129
Characteristics of CT scans: No. of CT scans = 556	
Type of CT performed, <i>n</i> (% total)	
Single phase	460 (83)
Noncontrast	343 (62)
Contrast	117 (21)
Multiple phase (2-phase: noncontrast+contrast, 3-phase: CT urogram = noncontrast, contrast, delayed)	96 (17)
Low dose (<4 mSv) noncontrast CT scans, <i>n</i> (% total)	29 (8)
Indication for CT, <i>n</i> (% total)	
Stone (flank pain, nephrolithiasis, renal colic, stone)	340 (61)
Abdominal pain	144 (26)
Hematuria (gross or microscopic)	54 (10)
Recurrent UTI	18 (3)

UCSF=University of California San Francisco; UTI=urinary tract infection.

these 40 higher EDose CTs, 11 (27%) were in subjects with a BMI <30.

Table 2 exhibits the characteristics among different exposure groups. Higher BMI and multiphasic scans were

found among subjects in the >20 mSv/year and >50 mSv/year groups and were statistically significant ($p < 0.01$). In the >50 mSv/year group, there was a higher percentage of female subjects (68%) and scans performed at non-UCSF locations (76%); however, these differences were not statistically significant ($p = 0.68, 0.28$, respectively). Multivariate logistic regression evaluated factors associated with exceeding the 20 and 50 mSv levels (Table 3). BMI, number of scans, and multiphasic scans were all significantly associated with increased EDoses.

Figure 1 shows how the EDose associated with CTs in this study would hypothetically be affected if different approaches to utilizing imaging protocols were implemented. In changing all noncontrast CTs to low-dose scans (<4 mSv), the number of scans contributing to overexposure would be reduced by 51%. Meanwhile, replacing 99% of the multiphase CTs with an EDose of a noncontrast scan would result in removing many of the highest exposure scans, but a smaller (30%) reduction in the total number of scans exceeding the threshold. Finally, the biggest reduction was seen when these protocols were implemented concurrently, with an 85% reduction in scans contributing to an overexposure in this combined protocol.

Discussion

The results of this study demonstrate that a subset of subjects with kidney stones (6%) exceeded the 50 mSv/year ICRP limit of occupational exposure before being referred to a tertiary stone clinic. Overall, 26% of subjects exceeded 20 mSv/year, the average annual exposure of the 100 mSv/5-year ICRP threshold. Our simulated model demonstrated that both low-dose and phase-reduction protocols reduce the number of CT scans contributing to an overexposure.

There remains limited data on how much radiation exposure patients are receiving and even less on how this exposure is monitored.³ Our results reinforce previous findings that there is wide variability in the radiation doses patients are exposed to depending on where the CT is performed.¹⁴ To our knowledge this is the first study to approximate the radiation received by stone patients solely from CTs before their referral to a tertiary stone clinic. In 2006, Ferrandino et al. retrospectively examined the radiation received by 108 stone patients at two academic institutions within one

TABLE 2. CHARACTERISTICS OF SUBJECTS WHO RECEIVED AN EFFECTIVE DOSE <20, 20–50, AND >50 mSv IN A SINGLE 12-MONTH PERIOD

	≤ 20 mSv, <i>n</i> = 288	20–50 mSv, <i>n</i> = 76	≥ 50 mSv, <i>n</i> = 25	<i>p</i>
Mean age (years $\pm$ SD)	54 $\pm$ 16	58 $\pm$ 14	56 $\pm$ 12	0.21
Female gender, <i>n</i> (%)	133 (46)	34 (44)	17 (68)	0.68
Mean BMI (kg/m ² $\pm$ SD)	27.4 $\pm$ 6.0	33.6 $\pm$ 9.0	36.9 $\pm$ 8.5	<0.01
Non-UCSF location, <i>n</i> (%)	161 (56)	47 (62)	19 (76)	0.28
Single phase scans, <i>n</i> (%)	254 (88)	44 (58)	9 (36)	<0.01
Maximum 12-month effective dose (mSv)				
Median	10.5	29.2	64.1	
IQR	6.3–14.5	23.6–40.1	56.1–80.8	—
Range	2.6–19.9	20.2–49.8	51.4–210.5	
Number of CT scans corresponding to max effective dose (<i>n</i>)				
Median	1	1	2	
IQR	1–1	1–2	1–3	<0.01
Range	1–4	1–3	1–5	

TABLE 3. MULTIVARIATE REGRESSION ANALYSIS IDENTIFYING FACTORS ASSOCIATED WITH EXCEEDING RECOMMENDED 20 AND 50 mSv EFFECTIVE DOSE THRESHOLDS

	>20 mSv		>50 mSv	
	OR (95% CI)	p	OR (95% CI)	p
Age (per year of age)	1.0 (0.98–1.05)	0.35	1.0 (0.93–1.07)	0.10
Female gender	0.8 (0.34–1.72)	0.52	1.5 (0.29–8.40)	0.61
BMI (per point of BMI)	1.2 (1.16–1.32)	<0.01	1.4 (1.16–1.61)	<0.01
No. of scans	22.1 (7.56–57.2)	<0.01	27.1 (6.06–127)	<0.01
Multiphase scans	63.0 (21.0–188)	<0.01	799 (29.6–21,604)	<0.01
Non-UCSF location	1.9 (0.86–4.21)	0.11	1.5 (0.34–6.77)	0.59

CI=confidence interval; OR=odds ratio.

calendar year, finding 20% of patients received an EDose >50 mSv from not only CTs but also all sources of radiation.¹⁵ Katz et al. retrospectively examined the number of CTs among 4562 patients with renal colic for a 6-year period, finding 176 patients (4%) had ≥ 3 unenhanced CT scans, 19 had ≥ 6 scans, and 1 patient alarmingly underwent 18 scans.¹⁶ In our study a patient received 12 CTs before their initial visit

to our clinic, whereas two patients received an EDose >100 mSv from a single scan. More than a decade after these previous studies, some stone patients continue to receive extreme doses of radiation.

Low-dose and ultra-low-dose CT scans have been shown to have comparable sensitivity and specificity with little impact on diagnostic accuracy.¹⁷ Although perhaps less effective in

FIG. 1. In this dot plot, each *dot* depicts a CT scan performed during the study period. For any given subject, each *black dot* represents a scan that either by itself or in combination with other scans, contributed to that subject's maximum effective dose exceeding the 50 mSv threshold within a 12-month period.

Current dosing reflects the associated effective doses from each CT scan performed in this study.

Low-dosing protocol represents a model where all noncontrast CT scans were ordered as low-dose scans (<4 mSv). A shift is seen resulting in a 51% reduction in the number of scans exceeding the recommended 50 mSv in 1-year threshold.

Phase-reduction protocol represents a model where all multiphase CT scans are replaced with an effective dose of a randomized noncontrast CT scan. Applying a 1% chance of detecting a genitourinary malignancy requiring a multiphase scan,¹⁸ a randomized 1% of these scans were then modeled as being repeated as multiphase to simulate a staged approach in imaging for providers. This resulted in removing many of the highest exposure scans, but a smaller (30%) relative decrease in the number of scans exceeding the threshold.

Combined protocol demonstrates the effect of combining the low-dosing and phase-reduction protocols together. This resulted in the largest decrease (85%) in scans contributing to overexposure.

detecting stones <3 mm in size or in patients with a BMI >30 kg/m²,¹⁸ recent EAU guidelines state that ultra-low-dose CT be the new standard of care when ordering imaging for a patient with suspected renal colic.¹⁹ Despite these recommendations, studies have demonstrated relatively few institutions performing low-dose CT scans. In 2014, Lukasiewicz and colleagues found ~80% of institutions participating in the ACR CT Dose Index Registry did not contribute any reduced-dose CT scans.²⁰ Meanwhile, in 2017, Weisenthal et al. demonstrated that >80% of scans labeled “low dose” actually were associated with EDoses ~10 mSv.²¹ Consistent with previous definitions,^{12,13} our study utilized the higher threshold of low-dose equal to 4 mSv and yet only 8% of noncontrast scans were below this level. Moreover, 60% of the non-low-dose noncontrast CT scans in this study took place in patients with a BMI <30, providing further support that low-dose CT scans are being underutilized in the medical community when otherwise appropriate. These results helped prompt many of the authors’ radiology departments to begin implementing low-dose stone protocols.

The first goal of our simulated model was to illustrate how a low-dose protocol could reduce the number of CTs contributing to a patient exceeding the ICRP dose limit. Based on CT abdomen data from five University of California centers in 2013, Smith-Bindman and colleagues found the median EDose for single phase standard dose abdominal CT scan was 10 mSv.⁸ Our model shows that although a low-dose protocol would not eliminate those high-dose scans that by themselves exceeded 50 mSv, it would reduce the number of scans exceeding the dose limit by >50%. This potentially would spare patients already at risk and who otherwise would exceed the threshold had they received a standard (10 mSv) CT scan.

Whether because of concerns of missing an incidental diagnosis or the lack of a financial incentive to image with lower dosing, adoption of low-dose CT has been limited despite years of availability.²¹ Therefore, the secondary goal of our model was to propose another solution to reduce patient radiation exposure besides simply implementing low-dose CTs. The inclusion of multiphase and contrast CTs in our analysis was intentional and reflects the reality of a urologist’s practice. Although CTs with a listed indication of gross hematuria, abdominal pain, or UTIs are often ordered for alternative differential diagnoses, they commonly result in the diagnosis of urolithiasis. Despite recent Choosing Wisely ACR recommendations against contrast and multiphase abdominal CT for kidney stones,⁹ our study found 17% of subjects had a multiphase scan performed before their referral to our stone clinic. Among the 25 subjects who exceeded the 50 mSv threshold, 16 (64%) received multiphase scans. The fact that “renal colic/nephrolithiasis” was listed as the primary indication for these multiphase scans was alarming and served as the motivation behind the phase-reduction and combined protocols of our simulated model.

As Loo and colleagues demonstrated only a 1% chance of upper tract malignancy being detected with multiphase CT scans,²² our model was run to keep a randomized 1% of the scans multiphase, replacing the remaining 99% with the EDose of a randomized noncontrast CT scan. The phase-reduction protocol demonstrates that if providers imaged thoughtfully for stones, consistent with ACR recommendations, this would eliminate many scans associated with the highest EDoses. Furthermore, the combination protocol

provided a hypothetical reduction of 85% in scans contributing to exceeding the dose limit. With previous studies finding nearly 53% of patients undergoing CT abdomen/pelvis scans received inappropriate unnecessary phases per ACR appropriateness criteria,²³ our simulation model reinforces the importance of imaging thoughtfully to reduce radiation exposure in stone patients.

There are reasons to suspect that the results of this study underestimate the amount of radiation received by patients before their referral to a tertiary stone clinic. It is likely that not all CTs in the 5 years preceding each patient’s initial visit were accounted for at the time of their initial appointment, especially since 57% of patients had imaging performed across 129 outside imaging centers. Furthermore, this study focused solely on CT scans and the additional radiation exposure from kidney, ureter, and bladder radiographs (KUB) and other imaging tests was not included.

Several important limitations warrant further discussion. Given the nature of radiologic reports, the setting in which subject’s previous CT scans were performed (i.e., emergency department vs ambulatory imaging) was not readily available, limiting our understanding of the provider specialty and context in which these scans were ordered. Second, by the nature of these patients being referred to a tertiary stone clinic, perhaps they were more complex and required additional imaging compared with more straightforward stone patients who were managed locally. Third, subjects who received >20 mSv in a single year often did not have another 4-year’s worth of radiation exposure data available to determine whether they exceeded the ICRP 5-year dose limit. Therefore, to highlight patients who may not have exceeded the 50 mSv/year dose limit but still received higher radiation, we included this 20 to 50 mSv/year group for analysis, a designation that has been made in previous studies as well.³ Finally, this study focused only on EDoses from CT scans and not necessarily the diagnostic accuracy derived from these studies. Without fully knowing the clinical context to which these CTs were ordered, it is possible that many of these scans, especially the contrast and multiphase scans, required higher dosing to provide necessary accurate diagnostic information and rule out competing diagnoses.

This study has taken the first step of estimating the long-term radiation exposure these ReSKU patients receive. With considerable radiation reported from fluoroscopy imaging performed during ureteroscopy, percutaneous nephrolithotomy,²⁴ as well as from KUB and CT scans after these operations;^{25,26} future ReSKU studies will be able to demonstrate whether radiation exposure during subsequent treatment and follow-up results in a higher number of patients exceeding ICRP thresholds.

Conclusions

Before their referral to a tertiary stone clinic, a subset of kidney stone patients exceeded current ICRP radiation dose limits from CT scans alone. A large amount of variability exists with respect to the CT radiation doses received by stone patients, with low-dose CT scans underutilized and multiphase scans taking place. The implementation of low-dose and phase-reduction CT protocols could potentially reduce the number of stone patients receiving radiation that exceeds current dose limit recommendations.

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Author Disclosure Statement

The authors declare that no relevant or material financial interests are related to the research described in this paper.

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Abbreviations Used

ACR = American College of Radiology
 ALARA = as low as reasonably achievable
 CI = confidence interval
 CT = computed tomography
 CTDI_{vol} = computed tomography dose index volume
 DLP = dose-length product
 EDose = effective dose
 ICRP = International Commission on Radiological Protection
 OR = odds ratio
 ReSKU = Registry for Stones of the Kidney and Ureter
 UCSF = University of California San Francisco
 UTIs = urinary tract infections