Radiation From Kidney-Ureter-Bladder Radiographs Is Not Trivial

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OBJECTIVE To estimate effective dose of kidney-ureter-bladder (KUB) radiographs in a contemporary population of patients with urolithiasis.

METHODS A retrospective review was performed to identify patients visiting a urology clinic for urolithiasis where a KUB was obtained and whom had a recent computed tomography (CT). Effective dose for KUBs was estimated using a Monte Carlo based simulation program and for CT utilizing the reported dose-length-product. Age, gender, body mass index, and abdominal diameter were analyzed for association with effective dose. KUBs performed at outside facilities in referred patient were compared to those obtained locally when available.

RESULTS Fifty-four patients were identified meeting criteria. The majority (92.6%) of KUBs contained multiple radiographs. Mean effective dose was 2.15 mSv ± 1.67 mSv. Only 26% of examinations effective dose was under 1 mSv. Body mass index, abdominal thickness, and image count were all associated with an increase in dose ($P < .01$ each). Similar to local KUBs, 88% of outside examinations contained multiple images.

CONCLUSION KUB examinations in this contemporary setting are associated with a 2-fold higher effective dose then is often referenced. Increased effective dose is associated with increased patient size and number of images acquired. Nearly 1 in 5 patient's KUB effective dose was similar to a low-dose CT. KUBs role should be re-examined given its limited sensitivity, specificity, associated radiation, and other available imaging options. UROLOGY 125: 46−49, 2019.

Patients with urolithiasis are at risk for high levels of radiation exposure given the recurrent nature of the disease which can result in frequent imaging.[1,2] As the risk of radiation exposure is thought to be stochastic, urologists often obtain kidney-ureter-bladder radiographs (KUBs) as an alternative to computed tomography (CT), albeit with lower sensitivity and specificity.

Professional societies' guide that KUB effective dose is generally 0.7-0.8 mSv; however, there are no recent estimations of KUB effective dose in contemporary patients using current techniques.[3-6] Given increasing patient size and the transition from plain film radiography to digital techniques, we sought to investigate KUB dose in a current population of stone formers using contemporary techniques.

MATERIALS AND METHODS

After Institutional Review Board (IRB) approval, a retrospective review was performed of all patients presenting to a single endourologist Nicole L. Miller (NLM) from January 1 to March 30, 2017. Records were examined to identify all patients seen for nephrolithiasis where a KUB was obtained in preparation for their office visit (within 30 days) and who had a CT scan of the abdomen within the preceding 3 years. Patient variables of age, sex, body mass index (BMI), and abdominal anterior-posterior (A-P) diameter were recorded along with the number of images acquired to assess for association with dose.

The effective dose for each KUB was obtained using PC Program for x ray Monte Carlo (PCXMC), a Monte Carlo based simulation program.[7] The height and weight for each patient was entered into PCXMC to simulate the patient size. The field of view was then determined using anatomical landmarks seen on each KUB image. PCXMC was set to simulate 200,000 photons for each patient. The peak kilovoltage and milliampere-seconds of each examination were also taken into account by the simulation. For all KUBs, the simulation assumed an anode angle of 17 mm and 3.5 mm of aluminum filtration in the beam, despite possible variations in manufacturers. PCXMC utilizes the tissue weighting factors from International Commission on Radiological Protection Report 103 to estimate effective dose for each image. The total effective dose for each KUB was calculated as the sum of doses from each image in the examination. Effective dose of subjects' CTs were calculated by multiplying the reported dose-length-product by an abdominal k-factor ($0.015 \frac{\text{mSv}}{\text{mGy cm}}$) as recommended by the American Association of Physicists in Medicine.[8] CT protocols were not controlled; therefore, patients were imaged on a variety of different scanners using different techniques. Only studies of the abdomen/pelvis were included in the analysis.

Age, BMI, abdominal A-P diameter, and the number of images/KUB examination were each assessed in the statistical software package "R" using a Pearson correlation to test for association with effective dose.[9] A Welch 2-sample t test was used to assess if the average effective dose was different between genders. A multivariable linear regression was performed including the

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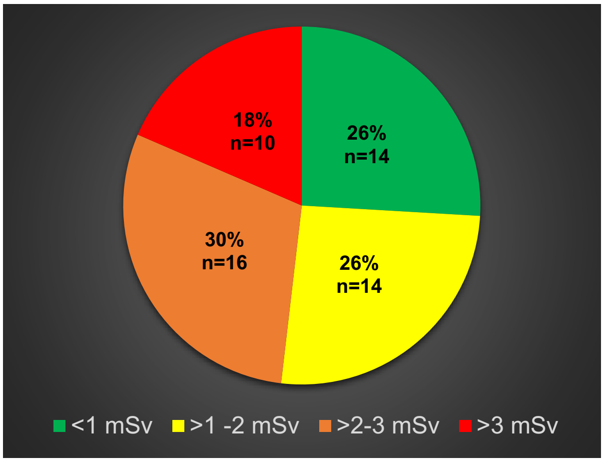

Figure 1. Effective dose categories. (Color version available online.)

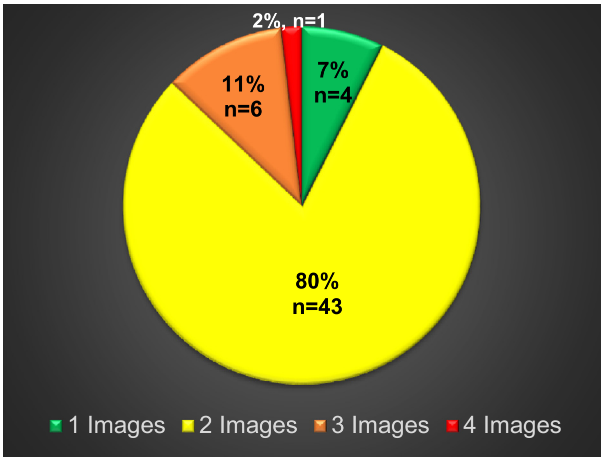

Figure 2. Images per kidney-ureter-bladder at Vanderbilt University Medical Center. (Color version available online.)

significant covariates from the univariate analysis. KUB examinations performed at other institutions and available in referred patients were also collected and assessed. The effective dose of these examinations could not be estimated without knowledge of technique factors; however, image count was recorded.

RESULTS

During the study period, 55 patients were identified who obtained a KUB at our institution and met all other criteria. Additionally, 41 KUB examinations from outside institutions were identified in referred patients for comparison. The mean age was 55 ± 14 years and the population was large in size with a mean BMI of 31.6 ± 6.7 kg/m^2. The range of effective dose was 0.14-13.2 mSv. The 13.2 mSv examination was an outlier and dropped from further analysis. Thereafter, the mean effective dose per KUB was 2.15 ± 1.67 mSv. Figure 1 shows frequency of effective dose categorically. Only 26% of examinations' effective dose was less than 1 mSv and 56% of patients were exposed to more than 2 mSv. Most local patients' KUB contained multiple images (93%) as shown in Figure 2 (range 1-4). Similarly, 90% of KUBs from outside institutions contained more than 1 image (Supplementary Figure 1). The mean CT effective dose observed was 11.3 mSv ± 5.1 mSv. Two patient's CTs included the chest and were excluded. Effective dose of both CT and KUB increased with BMI as shown in Table 1. On univariate analysis, patient BMI, A-P diameter, and images/KUB were associated with an effective dose >1 mSv (Table 2). On multivariate analysis, only A-P diameter and image count were significantly associated with increasing effective dose.

Table 1. KUB and CT effective dose by BMI category

BMI Category (*n*)	Mean KUB Dose (mSv)	Mean CT Dose (mSv)
<25 (9)	1.1	6.2
25-30 (14)	1.9	10.8
30-35 (15)	2.3	11.5
>35 (16)	2.9	14.8

BMI, body mass index; CT, computed tomography, KUB, kidney-ureter-bladder.

DISCUSSION

The introduction of CT has greatly enhanced the diagnostic yield of medical imaging but is also associated with a dramatic increase in medical radiation exposure.[10,11] CT has become the test of choice for the diagnosis of urolithiasis given its high sensitivity and rapid acquisition. The recurrent nature of urolithiasis often requires frequent imaging and stone formers in the CT era are at particular risk of exposure to high levels of ionizing radiation. Two North American studies have shown 17%-20% of stone formers will exceed the "safe" 1-year exposure limit for radiation workers in the 12 months following an acute episode.[1,2,12] While the risk of malignancy from radiation exposure associated with medical imaging remains highly controversial, the public and scientific community remain

Table 2. Association of patient variables with effective dose

	All	<1 mSv	>1 mSv	UVA *P* Value	MVA *P* Value
N	54	14	40		
Sex (female/male)	32/22	9/5	23/17	.1	
Age (y)	55 ± 14	55 ± 13	55 ± 14	.2	
BMI (kg/m^2)	31.6 ± 6.7	27 ± 4.9	33.2 ± 6.2	<.01	.65
A/P diameter (cm)	28.6 ± 4.4	26.2 ± 4.9	29.4 ± 4	<.01	.005
Images per KUB study	2.1 ± 0.5	1.9 ± 0.7	2.2 ± 0.4	<.01	.008
Mean effective dose	2.2 ± 1.7	0.5 ± 0.2	2.8 ± 1.5		

UVA, Univariate Analysis; MVA, Multivariate Analysis.

rightfully concerned, and efforts continue to lower exposure to "as low as reasonably achievable."

To this end, urologists often obtain KUB examinations to follow known stones or surveil for new calculi. The decreased sensitivity of the examination is broadly viewed as tolerable based on the presumed low radiation dose associated with the examination. This is despite research which demonstrates KUB is highly unreliable at detecting urinary tract calculi. An American Urological Association (AUA) pooled analysis reports KUB's median sensitivity for the detection of urinary calculi is 57%.[6] More recently, Kanno et al found a sensitivity of only 49% in a series of 994 kidneys with at least 1 stone identified on CT.[13] In this same study the addition of KUB to ultrasound alone only increased the sensitivity by 2%.

Our study shows that in a contemporary population of stone formers, mean KUB effective dose is over twice that which is typically referenced.[3-6] In fact, 18% of patients who had a KUB were exposed to a dose similar or greater than that of a low-dose CT (>3 mSv) and 3 patients had effective doses comparable to a standard stone protocol CT. Unsurprisingly, large patients and those who had multiple images obtained were more likely to have a KUB which exceeded 1 mSv. In fact, for patients with a BMI > 35 kg/m^2, mean effective dose was similar to low-dose CT at 2.9 mSv (Table 1). While we were unable to calculate the effective dose from outside KUBs, we feel our findings are likely generalizable as obesity is widespread and image counts were similar between local KUBs and those from outside institutions. While the effective dose of CTs in our study may appear high in an era where low-dose CT is often recommended, it is comparable to a recent report on dose from stone protocol examinations in the American College of Radiology CT dose registry.[14]

There are several possible explanations for the discrepancy between the high-KUB dose observed in our study and the often-referenced values. The most obvious is the majority of examinations contained multiple images, while most reference sources assume a single image acquisition. This may be driven by the ease of obtaining multiple images with digital radiography or increasing patient size making it challenging to obtain the optimal field of view with just 1 radiograph. Also, obesity is a known risk factor for nephrolithiasis, and thus our inclusion of stone formers only is inherently biased. Obese patients require a higher energy technique to obtain optimal exposure which drives up effective dose.

Given KUB's unreliability and associated radiation, we feel its role should be reexamined. KUB is recommended to follow patients with radiopaque ureteral stones, but it is often difficult to confirm passage of ureteral stones due to bowel gas, surrounding boney structures, and frequent pelvic vascular calcifications.[6] To make up for KUBs poor performance, many combine it with ultrasound. Confounding this strategy is that 35% of patients with asymptomatic ureteral stones do not display hydronephrosis.[15] Regardless of whether KUB is combined with ultrasound, if a stone or hydronephrosis is demonstrated, then a CT is potentially avoidable. Our findings however suggest this strategy may do less to mitigate radiation exposure then is currently perceived. AUA guidelines also recommend "periodic" follow-up imaging to assess for new stones or stone growth with either KUB, ultrasound or CT.[16] Given KUB's low sensitivity in detecting renal stones and its associated radiation, we feel that for most it is a poor surveillance modality. Ultrasound is much more sensitive without any associated ionizing radiation. If a more specific test is required, then reduced dose CT techniques are probably more appropriate as the desired information is much more likely to be determined with a potentially comparable dose to KUB.

Advances in imaging technology and software continue to provide potential for significant dose reduction in stone protocol CT scans. Two recent systematic reviews demonstrate that low-dose (<3.5 mSv) and ultralow-dose (<1.9 mSv) studies can provide sensitivity in excess of 90% for detecting urinary tract calculi.[17,18] Unfortunately, despite strong evidence and guidelines recommending these techniques, in the US they are still infrequently used.[14] One potential barrier to employing these examinations is patient size. This is in large part due to an early study which suggested low-dose CT was less sensitive in patients with BMI > 30 mg/m^2.[19] However, subsequent series using modulated tube current have shown similar or better sensitivity in overweight compared to normal or underweight patients.[20,21] Given the performance of reduced dose CT and low radiation exposure which is achievable, it is a good alternative to KUB where accessible.

CONCLUSION

Effective dose from KUBs in a contemporary population of stone formers is associated with a 2-fold higher effective dose then what is commonly referenced. Contributing factors appear to be patient size and number of images acquired in the examination. Given KUBs limited sensitivity and associated radiation exposure, alternative imaging such as ultrasound, and reduced dose CT techniques should be considered in lieu of KUB when available.

SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.1016/j.urology.2018.11.035.

REFERENCES

1. Ferrandino MN, Bagrodia A, Pierre SA, et al. Radiation exposure in the acute and short-term management of urolithiasis at 2 academic centers. *J Urol*. 2009;181:668–672. discussion 73.
2. Fahmy NM, Elkoushy MA, Andonian S. Effective radiation exposure in evaluation and follow-up of patients with urolithiasis. *Urology*. 2012;79:43–47.
3. Mettler Jr. FA, Huda W, Yoshizumi TT, Mahesh M. Effective doses in radiology and diagnostic nuclear medicine: a catalog. *Radiology*. 2008;248:254–263.

4. Turk C, Petrik A, Sarica K, et al. EAU guidelines on diagnosis and conservative management of urolithiasis. *Eur Urol*. 2016;69: 468–474.
5. EAU Guidelines on Urolithiasis, 2016 ed. European association of urology, 2016. 2017. Available at: https://uroweb.org/wp-content/uploads/EAU-Guidelines-Urolithiasis-2016-1.pdf.
6. Americal Urological Association. Clinical effectiveness protocols for imaging in the management of ureteral calculous disease: AUA technology assessment, 2012. 2017. Available at: https://auanet.org/guidelines/imaging-for-ureteral-calculous-disease.
7. Tapiovarra M, Siiskonen T. *PCXMC. A Monte Carlo Program for Calculating Patient Doses in Medical X-Ray Examinations*. 2nd ed. 2008; STUK-A231.
8. 23 AAoPiMTG. *The measurement, reporting, and management of radiation dose in CT*. 2008.
9. R Development Core Team. *R: A Language for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing; 2016.
10. Mettler FA. Jr, Thomadsen BR, Bhargavan M, et al. Medical radiation exposure in the U.S. in 2006: preliminary results. *Health Phys*. 2008;95:502–507.
11. Brenner DJ, Hall EJ. Computed tomography—an increasing source of radiation exposure. *N Engl J Med*. 2007;357:2277–2284.
12. The 2007 recommendations of the International Commission on Radiological Protection. ICRP publication 103. *Ann ICRP*. 2007;37:1–332.
13. Kanno T, Kubota M, Funada S, Okada T, Higashi Y, Yamada H. The utility of the kidneys-ureters-bladder radiograph as the sole imaging modality and its combination with ultrasonography for the detection of renal stones. *Urology*. 2017;104:40–44.
14. Weisenthal K, Karthik P, Shaw M, et al. Evaluation of kidney stones with reduced-radiation dose CT: progress from 2011-2012 to 2015-2016-not there yet. *Radiology*. 2018;286:581–589.
15. Wimpissinger F, Turk C, Kheyfets O, Stackl W. The silence of the stones: asymptomatic ureteral calculi. *J Urol*. 2007;178:1341–1344; discussion 4.
16. Pearle MS, Goldfarb DS, Assimos DG, et al. Medical management of kidney stones: AUA guideline. *J Urol*. 2014;192:316–324.
17. Rob S, Bryant T, Wilson I, Somani BK. Ultra-low-dose, low-dose, and standard-dose CT of the kidney, ureters, and bladder: is there a difference? Results from a systematic review of the literature. *Clin Radiol*. 2017;72:11–15.
18. Rodger F, Roditi G, Aboumarzouk OM. Diagnostic accuracy of low and ultra-low dose CT for identification of urinary tract stones: a systematic review. *Urol Int*. 2018;100(4):375–385.
19. Poletti PA, Platon A, Rutschmann OT, Schmidlin FR, Iselin CE, Becker CD. Low-dose versus standard-dose CT protocol in patients with clinically suspected renal colic. *AJR Am J Roentgenol*. 2007;188:927–933.
20. Mulkens TH, Daineffe S, De Wijngaert R, et al. Urinary stone disease: comparison of standard-dose and low-dose with 4D MDCT tube current modulation. *AJR Am J Roentgenol*. 2007;188:553–562.
21. Moore CL, Daniels B, Ghita M, et al. Accuracy of reduced-dose computed tomography for ureteral stones in emergency department patients. *Ann Emerg Med*. 2015;65. 189 e2-198 e2.