Published in final edited form as:

Urology. 2013 October ; 82(4): 780–785. doi:10.1016/j.urology.2013.06.030.

Severe Obesity is Associated With 3-Fold Higher Radiation Dose Rate During Ureteroscopy

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Abstract

OBJECTIVE—To investigate and characterize the association between fluoroscopy radiation dose rate and various patient size metrics during ureteroscopy.

MATERIALS AND METHODS—Fluoroscopy data were collected from 100 patients undergoing ureteroscopy for stone disease. Radiation dose rates were determined from fluoroscopy dose and time. Estimated entrance skin dose was calculated from air kerma (AK) by applying correction factors. Effective dose (ED) was estimated with Monte Carlo–based simulation software. Patient size metrics included body mass index (BMI), anterior-posterior (AP) midline distance, AP transrenal thickness, and region of interest (ROI) pixel value magnitude on computed tomography scout. Univariate and multivariate regression analyses were performed to determine the association between AK dose rate and patient size metrics, adjusting for laterality and stone location.

RESULTS—Obese patients ($>30 \text{ kg/m}^2$) comprised 46% of the cohort. Mean fluoroscopy time, displayed AK, entrance skin dose, and ED were 4.2 ± 6.0 second, $1.2 \pm 2.1 \text{ mGy}$, $1.2 \pm 2.2 \text{ mGy}$, and $0.08 \pm 0.15 \text{ mSv}$, respectively. Mean AK dose rate and ED dose rates were $0.30 \pm 0.23 \text{ mGy/second}$ and $0.021 \pm 0.016 \text{ mSv/second}$, respectively. Compared with the nonobese category, the highest BMI category ($\geq 35 \text{ kg/m}^2$) had over a 3-fold higher mean AK rate (0.50 vs 0.16 mGy/second). On univariate and multivariate analysis, BMI, AP midline distance, AP transrenal thickness, and computed tomography scout region of interest pixel value magnitude were each significantly associated with dose rate.

CONCLUSION—Larger patients experience higher radiation dose rates under fluoroscopy. Severely obese patients receive 3-fold higher dose rates compared with nonobese patients. Given the higher incidence of stone disease in obese patients, all attempts should be made to minimize radiation exposure during ureteroscopy.

There is increasing awareness that ionizing radiation associated with diagnostic imaging has the potential to increase the risk of secondary malignancy.¹ Patients with nephrolithiasis often receive radiation exposure from radiation used in the diagnosis, treatment, and follow-up of their disease.^{2,3} All current surgical approaches for kidney stone treatment, including

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Financial Disclosure: The authors declare that they have no relevant financial interests.

shockwave lithotripsy, percutaneous nephrostolithotomy, and ureteroscopy, may use fluoroscopy.

With the prevalence of obesity now over one-third of the United States population⁴ and estimated to reach similar levels in Europe soon,⁵ it is prudent to investigate potential radiation concerns in fluoroscopy in this population. It is expected that larger patients will experience a higher dose rate than smaller patients because of the availability and usage of automatic exposure rate control (AERC) in fluoroscopy to maintain acceptable image quality. Furthermore, there may be particular concern in the obese population, because obesity is a strong risk factor for kidney stone formation.^{6,7}

A recent study reported that stone protocol computed tomographies (CTs) produce radiation doses more than 3-fold higher than in a nonobese patient.⁸ However, during urologic procedures using fluoroscopy, it is unknown whether or to what extent patient size imparts additional risk, beyond known factors such as fluoroscopy unit settings and fluoroscopy time.⁹ To our knowledge, no one has quantified the magnitude of this increased risk. With the variation in ureteroscopy technique, there are a wide range of reported fluoroscopy times and doses during ureteroscopy.^{2,10–14} However, evaluation of dose rate, rather than fluoroscopy dose or time, accounts for variation of user technique and allows for the determination of any associations between radiation exposure and patient factors. Therefore, the purpose of this study was to characterize the association between fluoroscopy dose rate and various patient size metrics during ureteroscopy.

MATERIALS AND METHODS

With institutional review board approval, consecutive patients undergoing ureteroscopy by a single surgeon for stone disease between June 2011 and June 2012 were entered into an institutional database prospectively. Patients were excluded if no fluoroscopy was used or had missing fluoroscopy data. Demographic and perioperative data were recorded. The presence of associated hydronephrosis was determined according to the radiologist review of preoperative imaging. In addition to body mass index (BMI), 3 additional patient size metrics were determined from the preoperative CT scan by a blinded reviewer. First, the anterior-posterior (AP) midline skin-to-skin distance was determined at the level of the renal vein on the axial view. Second, the AP transrenal distance was measured through the hilum at the level of the renal vein to approximate the focus of the C-arm. Finally, a region of interest (ROI) measurement from the preoperative CT scout was investigated as an estimation of average tissue density. Because CT scouts on modern scanners are used to modulate tube current, it was expected that the scout film would provide a potential surrogate to a planar attenuation map, similar to what is presented to the C-arm. The ROI pixel value (PV) magnitude was determined from an ROI measurement over the approximate anatomic location of the C-arm X-ray field and a second ROI measurement in the background. PV magnitude was calculated as the C-arm field of view PV minus the background PV. For bilateral procedures, the PV was averaged between both kidneys. ROI measurements were excluded ($n = 22$) if the CT was performed at an outside institution because of varying system manufacturers and acquisition parameters.

During ureteroscopy, the fluoroscopic C-arm was set in the low dose and pulsed modes with last image hold option. The settings were not verified in 3 cases before start, and they were switched to these modes during the procedure. AERC was used at all times. The X-ray tube was positioned below the operating room table (Steris Amsco 3080 SP or 3085 SP; Mentor, OH) with the field collimated to limit exposure to surrounding organs. No electronic magnification was used. Radiation data, including fluoroscopy time and air kerma (AK), were recorded for a collection of digital mobile C-arms (GE OEC 9900 Elite GE Healthcare; Waukesha, WI) with a 12-inch image intensifier. Medical physics staff verifies the accuracy of displayed AK on all systems annually.

Estimated entrance skin dose (ESD) was calculated from AK by applying correction factors for skin entry location (inverse square factor), backscatter (BSF), mean energy absorption coefficient ratio, and table attenuation (TA).¹⁵ Correction factors were determined on the basis of a detailed analysis of a subset of 5 randomly selected patients in this study. In this subset, X-ray tube focal spot to skin entry distance and the radiographic technique were documented. A qualified medical physicist, using empirical and measured data, performed individual ESD calculations for each patient. According to these results, conservative generalized correction factors were applied to the entire cohort of patients (inverse square factor = 1.73, TA = 2.49, mean energy absorption coefficient ratio = 1.06, and BSF = 1.4).

Effective dose (ED) was estimated according to ESD using Monte Carlo-based simulation software (X-Dose v2.1 using NRPB-SR262) that references a mathematical anthropomorphic adult phantom.¹⁶ The simulation was performed assuming a posterior-anterior kidney view, 100 kVp, 5-mm Al filtration, and the estimated ESD. Dose rates were determined from the measured or calculated dose divided by fluoroscopy time.

Univariate linear regression models were used to determine the association between log-transformed AK dose rate (mGy/second) and the patient size metrics, including BMI, AP midline distance, AP transrenal distance, and ROI PV. Multivariate regression analyses were used to determine the association between log-transformed AK dose rate and each of the patient size metrics modeled separately, adjusting for stone location and laterality. The untransformed AK dose rate was not normally distributed and therefore transformed logarithmically. AK rate was chosen for modeling instead of ED rate because in the clinical setting it can be readily calculated by displayed AK and fluoroscopy time. Statistical analysis was performed using Stata 12.1 (StataCorp LP, College Station, TX) with $P < .05$ considered statistically significant.

RESULTS

Over the study period, 119 patients underwent ureteroscopic treatment of stone disease, of which 19 were excluded because of no fluoroscopy used. Of the remaining 100 patients, demographic and perioperative data are listed in Table 1. CT studies were performed within a mean $\pm$ SD 1.3 ± 1.3 months from the surgery date (range, 0.1–5.2).

Fluoroscopy and radiation exposure data are listed in Table 1. Compared with the lowest BMI category ($<25 \text{ kg/m}^2$), the highest BMI category ($\geq 35 \text{ kg/m}^2$) had over a 3-fold higher mean AK rate (0.50 vs 0.16 mGy/second).

Table 2 lists results from univariate linear regression analyses. As continuous variables, BMI, AP midline distance, AP transrenal distance, and CT scout ROI measurements were each significantly associated with log dose rate (all $P < .001$). Using multivariate regression adjusting for laterality and stone location did not appreciably alter the associations observed. Figure 1 shows positive correlations between AK rate and patient size metrics. Figure 2 shows the association between AK dose rate and patient size metrics by category. The ROI PV showed statistically significant positive associations with BMI, AP midline, and AP transrenal distance (all $P < .001$).

COMMENT

There are several important findings from this study of patients undergoing ureteroscopy for stone disease. First, obesity as measured by BMI was associated with significantly higher radiation dose rates during ureteroscopy, independent of fluoroscopy time. The severely obese group with BMI $\geq 35 \text{ kg/m}^2$ had a mean AK rate and corresponding ED rate of more than 3-fold higher than the nonobese group. Second, in addition to BMI, AP midline and AP transrenal distance were also associated with higher dose. Of these metrics, AP transrenal distance was most strongly correlated with dose rate. This is an expected finding because the C-arm is targeted near the kidney during ureteroscopy. Finally, the ROI PV from the CT scout film was found to have the strongest correlation with dose rate.

Modern C-arm systems typically report 3 potential dose metrics, including fluoroscopy time, dose area product, and AK. AK (in mGy) represents the system estimate of the radiation exposure at a designated distance from the source. In practice, the radiation beam passes through the table, patient, and any additional objects before the image intensifier. In AERC mode, the settings are adjusted to maintain an adequate image depending on the elements within the beam, of which AK accounts for these differences unlike time. In this study, AK rate was examined because it is a required starting point for calculating ESD and ED, and therefore similar trends would be expected with those measures.

ED (in mSv) is a calculated value that describes the absorbed dose accounting for the nonuniform differences in biologic sensitivity of different organs and relates stochastic risk. It can be used to compare the risk of radiation effects across different diagnostic modalities. For instance, the average adult ED for a posterior-anterior chest X-ray, kidney–ureter–bladder (KUB) X-ray, and single-phase CT abdomen and pelvis are 0.02 mSv, 0.7 mSv, and 14 mSv, respectively.¹⁷ One interpretation of the data presented is that the radiation detriment from a single case is approximately equal to one-tenth of a KUB, which is a finding specific to this patient cohort under a minimal-use fluoroscopy protocol¹⁴ and should not be generalized. Therefore, in this study, dose rate rather than overall dose was chosen as the outcome of interest to account for variation in user technique and patient factors affecting fluoroscopy time among cases (eg stone burden, composition, presence of impaction). It normalizes the total AK by the total beam-on time, and represents the average

dose per second over the course of the study. In other words, the dose rate measurement allows for any associations to be made between patient factors and the radiation source.

There is significant variation in how radiation dose is measured and reported during ureteroscopy.^{2,10–14} Rebeck et al¹⁰ reported their experience in 103 patients using AERC with mean fluoroscopy time and ED of 314 seconds and 6.0 mSv, respectively. ED was determined by conversion of dose area product from the C-arm dose report using ED per unit energy imparted and conversion factors.¹⁸ Although this conversion is reasonable, it is limited to calculating ED and cannot estimate skin dose. Lipkin et al¹¹ determined dose rates using a validated anthropomorphic male phantom and simulated ureteroscopy with three 5-minute runs of fluoroscopy using the AERC setting (80 kVp and 3.0 mA). The X-ray emitter for the fluoroscopy unit was located above the patient. Organ dose rates were converted to ED rates by the tissue weighting factors,¹⁹ yielding an ED rate of 0.024 mSv/second, which compares closely with our finding of 0.021 ± 0.016 mSv/second. Their ED rate was applied to fluoroscopy times from 30 nonobese males (mean BMI of 27.5 kg/m², median fluoroscopy time 47 second) to generate a median ED of 1.13 mSv. Kokorowski et al¹² calculated absorbed dose in mGy and ESD in a pediatric cohort from AK. Similar to our study, AK was adjusted for BSF, TA, and source-to-skin distance. In 37 procedures, mean fluoroscopy time, ESD, and midline absorbed dose were 2.68 minutes, 46.4 mGy, and 6.2 mGy, respectively. ED in their study was not determined. A follow-up study of 23 procedures from the same investigators reported that using a preprocedure checklist reduced mean fluoroscopy time by 66%, ESD by 87%, and midline absorbed dose by 86%. The checklist addressed patient and C-arm positioning, fluoroscopy settings, and established communication between the surgeon and technologist.²⁰

Dosimetry is not an exact science, and there are limitations in all techniques to measure dose. Relying on the cumulative displayed AK assumes all dose is deposited into a single region of the skin and does not account for any translation of the X-ray beam. In addition, the correction factors that were used to calculate ESD were generalized on the basis of a subset of patients. Variance in individual ESD calculations would be expected for large departures from the population. Confirmation of the findings of this study is needed from other centers.

As an alternative to using system-generated dose metrics, point dosimeters (eg thermoluminescent dosimeters or optically stimulated dosimeters) on different areas of the patient may measure ESD directly. A previous study reported organ-specific doses using thermoluminescent dosimeters during simulated ureteroscopy in 8 cadavers.²¹ Some organs received higher doses with BMI >30 kg/m², but these differences were not statistically significant likely owing to the small sample size. Limitations of this method include cost, and because measurement is only made at discrete points, special considerations would need to be made to capture the site of maximum skin dose.

Under the AERC setting, higher dose rates were observed with increasing BMI and AP thicknesses. Larger AP thickness measured at the midline and transrenal locations are expected to influence AERC, which adjusts X-ray tube voltage and current according to tissue attenuation to maintain signal-to-noise in the resultant images. The AERC responds to

the presented tissue thickness and composition (eg bone, soft tissue, air) that is introduced into the X-ray beam.

To estimate the average tissue density of the anatomy around the kidney, an ROI measurement on a CT scout was investigated. After accounting for background signal, the correlation between AK rate and CT scout ROI PV was stronger than with BMI and AP measurements. Although patients undergoing treatment of stones may be expected to have a preoperative CT scan available for ROI PV measurements, the clinical use of the ROI measurement is unclear and may be useful as a research tool.

Not surprisingly, there has been more interest to determine the association between radiation dose and obesity in the field of interventional radiology. In this type of clinical setting, one must consider the deterministic risks from radiation dose with longer fluoroscopy times. Kuon et al²² examined radiation dose during invasive cardiac procedures and found increasing dose parameters with higher BMI and body surface area. Ector et al²³ found that BMI was a more important determinant of overall radiation dose than total fluoroscopy time (adjusted partial correlation coefficient of 0.74 vs 0.22, $P = .04$). When comparing ED rate, obese patients received more than twice the rate of normal-weight patients during atrial fibrillation ablation procedures. The investigators attributed the findings to the AERC setting.

Limiting radiation exposure in patients undergoing ureteroscopy, especially in obese patients, should therefore be attempted whenever possible. We previously reported our technique for minimizing fluoroscopy use during ureteroscopy.¹⁴ The technique relies on C-arm positioning using a laser-guided C-arm, surgeon-controlled foot pedal, and visual and tactile cues to access the ureter. Adjustments in C-arm settings include low-dose settings, pulsed fluoroscopy, last image hold, narrow beam collimation, maximizing source-to-patient distance, minimizing patient-to-image intensifier distance, and keeping beam-on time to a minimum.⁹ Pulsed fluoroscopy has been shown to significantly reduce fluoroscopy time and radiation dose compared with continuous fluoroscopy without significant effect on image quality or stone-free rates.^{13,24} In obese patients, pulsed and low-dose settings in our experience are adequate because the typical rationale for using fluoroscopy is to visualize the stent or wire position. If finer definition is required, for example, trying to visualize a stone or the radiopaque line of a balloon dilation catheter, the C-arm can be switched off of the pulsed or low-dose setting.

CONCLUSION

During ureteroscopy, fluoroscopy use in obese patients, independent of time, is associated with higher radiation dose rates. The severely obese group had 3-fold higher dose rates compared with the nonobese group. The AERC with fluoroscopy adjusts settings according to tissue attenuation and is more strongly correlated with AP transrenal distance than BMI. Particularly for obese patients, a higher incidence of stone disease combined with exhibited higher fluoroscopy dose rates should lead to increased effort to minimize radiation exposure during ureteroscopy.

Acknowledgments

The authors thank Sarah Holt for assistance with the project.

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Figure 1.

Correlation between fluoroscopic radiation dose rate to patient size metrics in patients undergoing ureteroscopy. (top left) Air kerma (AK) rate and body mass index (BMI). (top right) AK rate and anterior-posterior (AP) midline distance. (bottom left) AK rate and anterior-posterior transrenal distance. (bottom right) AK rate and region of interest (ROI). (Color version available online.)

Figure 2.

Fluoroscopic radiation dose rate by body mass index (BMI; categorical), anterior-posterior (AP) measurements, and computed tomography (CT) scout pixel value (PV; quartiles). X indicates mean. Bars indicate interquartile range. Lines indicate minimum and maximum. AK, air kerma. (Color version available online.)

Table 1

Patient and operative characteristics

Variables	n = 100 Patients
Age, mean (range, SD), y	52.7 (19.9–82.4, 15.4)
Sex	
Male	59
Female	41
BMI, mean (range, SD), kg/m ²	30.8 (15.2–61.6, 8.9)
AP midline distance, mean (range, SD), cm	26.2 (17.5–44.6, 5.2)
AP transrenal distance, mean (range, SD), cm	25.8 (16.2–45.2, 5.1)
CT scout ROI, mean (range, SD), HU	615 (407–995, 107)
Laterality	
Left	60
Right	33
Bilateral	7
Presence of preoperative stent	40
Associated hydronephrosis	64
Stone impaction	33
Stone location (s)	
Renal	47
Proximal/mid ureter	18
Distal ureter	13
Multiple locations	17
No stone found	5
Use of ureteral access sheath	11
Ureteroscope type	
Flexible	66
Semirigid	15
Both	14
Operative time, mean (range, SD), min	62 (21–160, 29)
Fluoroscopy time, mean (range, SD), s	4.2 (0.4–34.5, 6.0)
Displayed AK, mean (range, SD), mGy	1.2 (0.1–17.5, 2.1)
AK rate, mean (range, SD), mGy/s	0.30 (0.07–1.14, 0.23)
BMI <25 kg/m ²	0.16 (0.07–0.34, 0.08)
25 to <30 kg/m ²	0.25 (0.08–1.00, 0.19)
30 to <35 kg/m ²	0.31 (0.11–0.72, 0.16)
35 kg/m ²	0.50 (0.13–1.14, 0.29)

Variables	n = 100 Patients
ESD, mean (range, SD), mGy	1.2 (0.1–18.0, 2.2)
ED, mean (range, SD), mSv	0.08 (0.01–1.20, 0.15)
ED rate, mean (range, SD), mSv/s	0.021 (0.005–0.078, 0.016)

AK, air kerma; AP, anterior-posterior; BMI, body mass index; CT, computed tomography; ED, effective dose; ESD, entrance skin dose; HU, hounsfield units; ROI, region of interest; SD, standard deviation.

Table 2

Association between log dose rate with patient size metrics in univariate analyses *

Patient Size Metrics	n	Correlation Coefficient (R)	P Value
AP midline distance	100	0.56	<.001
AP transrenal distance	100	0.57	<.001
BMI (continuous)	100	0.52	<.001
BMI (categorical)			
<25 kg/m ²	24		ref
25 to <30 kg/m ²	30		.030
30 to <35 kg/m ²	23		<.001
35 kg/m ²	23		<.001
CT scout ROI	78	0.65	<.001

Abbreviations as in Table 1.

* Multivariate regression adjusting for laterality and stone location for patient size metric modeled separately did not appreciably alter the associations observed (all $P < .001$, except BMI category 25 to <30 kg/m² $P = .011$).