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Effective and Organ Specific Radiation Doses from Videourodynamics in Children

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Abstract

Purpose—Effective and organ specific doses of ionizing radiation during videourodynamics are unknown. We estimated radiation exposure in children undergoing videourodynamics, and identified patient and examination factors that contribute to higher dosing.

Materials and Methods—Fluoroscopy data were collected from consecutive patients undergoing videourodynamics. Documented dose metrics were used to calculate entrance skin dose after applying a series of correction factors. Effective doses and organ specific doses (ovaries/testes) were estimated from entrance skin dose using Monte Carlo methods on a mathematical anthropomorphic phantom (ages 0, 1, 5, 10 and 15 years). Regression analysis was performed to determine patient and procedural factors associated with higher dosing.

Results—A total of 100 children (45% male, mean $\pm$ SD age 9.3 ± 5.7 years) were studied. Diagnoses included neurogenic bladder (73%), anatomical abnormality (14%) and functional/nonneurogenic disorder (13%). Mean fluoroscopy time was 0.17 ± 0.12 minutes. Mean age adjusted entrance skin dose, effective dose, and testis and ovary doses were 2.18 ± 2.00 mGy, 0.07 ± 0.05 mSv, 0.09 ± 0.10 mGy and 0.20 ± 0.13 mGy, respectively. On univariate analysis age, height, weight, body mass index, bladder capacity and fluoroscopy time were associated with effective dose. On multivariate adjusted analysis, body mass index, bladder capacity and fluoroscopy time were independently associated with effective dose.

Conclusions—The average effective dose of ionizing radiation from videourodynamics was less compared to voiding cystourethrogram dose reported in the literature. Greater fluoroscopy time, body mass index and bladder capacity are independently associated with higher dosing.

Keywords

fluoroscopy; pediatrics; radiation dosage; urodynamics

There has been increasing concern regarding the use of ionizing radiation during diagnostic medical imaging due to the risk of direct tissue injury and potential for secondary

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malignancies.¹ It is known that certain radiation effects, including risk of malignancy, accumulate with time, which is of particular interest in children.^{2,3} Recent attention has been drawn to the risk of radiation exposure in pediatric urology patients.⁴

Fluoroscopy during videourodynamics is an application of ionizing radiation in pediatric urology. Currently it is unknown how much radiation these patients are exposed to. A prior study of pediatric videourodynamics showed radiation dose from the displayed air kerma on the fluoroscopy unit but did not provide absorbed organ specific doses or effective doses.⁵ Gonadal doses are of interest because reproductive organs are sensitive to radiation. ED can be used to compare the risk of radiation effects across different diagnostic modalities and relates the stochastic risk of individual organs to the risk of a uniform whole body dose.⁶ ED is a calculated value that describes the absorbed dose accounting for the differences in biological sensitivity of different organs. We studied estimated entrance skin dose, effective dose and organ dose (testes/ovaries) in children undergoing videourodynamics, and determined patient and examination factors that contribute to higher radiation dosing.

MATERIALS AND METHODS

Consecutive patients undergoing videourodynamics at a single pediatric hospital between February 2012 and December 2012 were entered into an institutional database with local institutional review board approval. Beginning in August 2012 data were entered prospectively. Patients in the retrospective cohort were excluded if radiation data were missing. Demographic information recorded included age, height, weight and primary diagnosis, which was categorized into anatomical anomaly (posterior urethral valves, strictures, bladder exstrophy), neurogenic bladder (myelomeningocele, spinal cord injury, VATER association) and functional disorders (dysfunctional voiding, primary bladder neck dysfunction, vesicoureteral reflux, nonneurogenic). Procedural data recorded included number of fill cycles, bladder capacity, fluoroscopy time, and radiation dose information in the form of displayed AK (mGy) and/or dose area product.

Videourodynamic procedures were performed with a supervising pediatric urologist, urodynamics registered nurse and radiation technologist using a mobile C-arm (Philips BV Pulsera, Andover, Massachusetts). Machine settings used included the automatic exposure rate control mode with the low dose and pulsed dose modes (12.5 pps). No collimation or lead shielding for the patient was used. Electronic magnification was not used, and the C-arm was positioned to ensure the organs being imaged remained in the field of view to avoid panning. The x-ray tube was located below the fixed height examination table, which decreases exposure of personnel to the x-ray field. All patients were positioned supine under the image intensifier.

Several techniques were used to promote patient cooperation with the study and avoid poor image acquisition. The urodynamics nurse and technologist were on opposite sides of the bed to continuously monitor patient positioning. The parents were allowed to be present but were not relied on to keep the child cooperative. In younger children bottle feeding was allowed, while older children were distracted with movies. When the need was anticipated,

child life specialists were recruited to help engage anxious children for a better examination environment.

The protocol for videourodynamics included a scout film followed by imaging during early bladder filling to verify catheter positioning and contrast material filling the bladder. The interval of imaging during bladder filling was typically every 30 to 50 ml and up to 100 ml for larger patients. Additional images were obtained if assessing for incontinence with Valsalva maneuvers and at the urge to void to assess for vesicoureteral reflux. Voiding and post-void images were obtained. The decision to perform additional fill cycles depended on whether the study was deemed adequate.

Accuracy of the system displayed AK was verified with an independent dosimetry system (Radcal Corp., Monrovia, California). Correction factors were applied to the documented AK values to account for clinical setup conditions and to estimate ESD, including 1) table attenuation, 2) mean energy absorption coefficient ratio, 3) back scatter factor, 4) dose display accuracy and 5) patient position with respect to AK reference point (inverse square factor).^{7,8} A generalized composite correction factor was calculated at 1.58 (combining table attenuation of 1.12, mean energy absorption coefficient ratio of 1.05, back scatter factor of 1.3, dose display accuracy of 0.89 and inverse square factor of 1.54) and was applied to the AK to estimate ESD.

ED was estimated using Monte Carlo based simulation software (X-Dose software, version 2.1 and NRPB-SR262, Public Health England, London, United Kingdom) referencing a mathematical anthropomorphic phantom (available ages 0, 1, 5, 10 and 15 years; hermaphroditic organs).⁹ In all cases the nearest aged phantom was selected for simulation purposes. The organs used to estimate ED in the simulation include the adrenals, brain, breasts, eye lens, gall bladder, heart, kidneys, liver, lower large intestine, lungs, esophagus, ovaries, pancreas, red bone marrow, residual tissues (muscle), skeleton (bone surfaces), skin (excluding eye lenses), small intestine, spleen, stomach, testicles, thymus, thyroid, upper large intestine, bladder and uterus. Organs within the posteroanterior bladder view were assumed to be within the primary beam. Other inputs to the simulation included documented kVp (60 kVp if undocumented), 2.5 mm Al filtration and estimated ESD. Numerical output included ED (mSv) and organ doses (mGy) for the ovaries and testes. Testis and ovary specific doses were determined according to respective gender.

Univariate linear regression models were used to determine the association between ED and patient and urodynamic study variables. Covariates that had a statistically significant association with ED on univariate analyses were entered into a multivariate linear regression model. In 2 separate multivariate analyses the association between testis and ovary specific doses and the same covariates were determined. All covariates were continuous variables. Statistical analyses were performed using Stata®, version 12.1, with $p < 0.05$ considered statistically significant.

RESULTS

Patient and study characteristics are outlined in table 1. During the study period 103 patients underwent videourodynamics, of whom 3 were excluded from the retrospective cohort due to missing radiation data. Of the remaining 100 patients 44 comprised the group with prospectively collected data. Males made up 45% of the cohort, and 7 of the patients were 18 years or older.

On univariate analysis age, height, weight, BMI, bladder capacity and fluoroscopy time were associated with overall ED, while gender, primary diagnosis category, vesicoureteral reflux and number of fill cycles were not (table 1). Compared to age, BMI and bladder capacity, fluoroscopy time was the most strongly correlated with ED (see figure). Each additional 10 seconds of fluoroscopy time was associated with an ED increase of 0.048 mSv.

In the multivariate models height and weight were omitted due to collinearity with body mass index. BMI, bladder capacity and fluoroscopy time were independently associated with ED, while there was no significant association between ED and age. In a separate multivariate model age and fluoroscopy time were independently associated with testis specific dose, while BMI and bladder capacity were not. Finally, BMI and fluoroscopy time were associated with ovary specific dose, while age and bladder capacity were not (table 2).

DISCUSSION

There are several important findings from this study. First, mean $\pm$ SD effective radiation dose in this pediatric cohort undergoing videourodynamics was 0.07 ± 0.05 mSv. This dose is comparable to that from a single x-ray of the kidneys, ureters and bladder in a 5-year-old child,¹⁰ and less than that from a voiding cystourethrogram study across all age groups.^{11,12} By comparison, the reported ED from a voiding cystourethrogram is 0.11 to 0.47 mSv in male newborns and 0.12 to 0.42 mSv in female newborns, and 0.28 to 0.93 mSv in 10-year-old males and 0.55 to 0.82 mSv in 10-year-old females. In addition, on multivariate analysis greater BMI, bladder capacity and fluoroscopy time were independently associated with higher ED. Age was not associated with ED on multivariate analysis. Furthermore, testes and ovary specific doses were determined.

Our findings suggest that while mean EDs from videourodynamics are comparable to other radiographic studies, measurable amounts of radiation are produced. The additional information gained from fluoroscopy use during urodynamics must be weighed against the potential stochastic and deterministic effects of radiation.

Many national and international standards assume that stochastic effects such as radiation induced malignancy do not require a threshold dose for effects to occur, since any amount of radiation could theoretically injure DNA and contribute to the risk of malignancy.^{13,14} Children are more sensitive to radiation induced malignancy than adults due to their higher susceptibility to radiation and longer lifespan.^{2,3}

To our knowledge this is the first study to describe ED from videourodynamics. Ngo et al reported a mean fluoroscopy time of 1.8 minutes and a radiation dose of 10 mGy in 64

videourodynamic studies.⁵ A limitation of that series was that radiation dose was reported as AK, which is related to the exposure the C-arm produces at a defined point in the air. Since the table, patient and other materials are introduced into the beam, the AK might not accurately reflect the dose the patient receives. While the AK serves as a good comparative measure of radiation output, various factors affect the patient dose.

Direct comparison between the series of Ngo et al⁵ and the present study should be done with caution. In that multivariate model patient weight and bladder capacity were independent predictors of radiation dose, while there was no independent association with age. These findings are similar to ours, considering BMI and weight are interrelated. In both studies patient demographic data, including age, gender, height and weight, were similar. Also C-arm machine type and protocol were similar, except for the use of continuous mode fluoroscopy by Ngo et al.

In contrast, deterministic effects such as skin burns, erythema and cataracts require a threshold dose before effects appear, with increased severity at higher doses. None of these effects was observed in this patient cohort. There are no specific deterministic thresholds established for children. Mean ESD in this study was approximately 10^3 times less than the 2 Gy threshold for skin erythema,¹⁵ although the pediatric threshold is likely below this limit. Furthermore, testis and ovary specific doses in this study were comparable to doses from pediatric voiding cystourethrograms.^{11,12} Therefore, deterministic effects would not be expected at this dose range and they remain a theoretical risk.

In adults there is evidence that high testicular doses (0.1 to 6 Gy) are associated with potential temporary and permanent sterility.¹⁶ However, the long-term significance of dose to the testes and ovaries at these observed levels in children is unknown. In this study longer fluoroscopy time was associated with gonadal specific doses in both genders, as expected. Interestingly younger age was independently associated with higher testis specific dose but not ovary specific dose, while BMI was independently associated with higher ovary specific dose but not testis specific dose. These differences may be explained by the anatomical location of the sexual organs relative to the imaging focus during videourodynamics. Females with greater BMI may require higher radiation doses to penetrate tissue, delivering higher doses to the ovaries since they are located in an intra-abdominal position. In older male patients the position of the testes is likely farther away from the imaging focus.

Considering the risks of ionizing radiation, the necessity of fluoroscopy in the urodynamic evaluation of certain pediatric populations has been the subject of debate. The role of videourodynamics in evaluating neurogenic bladder is established. However, some authors recommend against routine videourodynamic testing in all children with non-neurogenic voiding dysfunction, as it might not change management or treatment.^{17,18} Others have proposed that this method is useful to evaluate dysfunctional voiding in the context of urinary tract infections.^{19–21} The findings from the present study may be helpful in counseling families regarding the amount of radiation dose expected from a video-urodynamic study.

Recent American Urological Association guidelines for adult urodynamics suggest that studies be performed “in a manner which provides the desired clinical information at the lowest possible radiation dose to the patient.”²² This recommendation is modeled after the ALARA (as low as reasonably achievable) principle. No guidelines for pediatric urodynamics exist.

We propose several recommendations to minimize fluoroscopy dose (see Appendix). Several factors have been known to be associated with higher dosing. Fluoroscopy time in this series was the most strongly correlated with ED, similar to other studies.^{5,23} Each additional 10 seconds of fluoroscopy time was associated with an ED increase of 0.048 mSv. Obesity and patient size as measured by weight or BMI are known to be associated with higher dosing.⁵ Larger bladder capacity is also associated with higher dosing, which may be due to the reliance on more fluoroscopy to determine the status of bladder filling.

Adjustments in C-arm settings and positioning can also decrease radiation exposure. Dose reduction techniques include low dose and pulsed fluoroscopy settings, and maximizing source to skin distance.^{23–25} Narrow collimation techniques and last image hold displaying the last frame can also decrease unnecessary exposure. Regardless of whether the radiation technologist or urologist controls the fluoroscopy unit, improved communication with all team members may also likely result in dose reduction. Finally, methods to decrease radiation dose to the patient also benefit the surgeon and staff.²⁶

Our findings must be interpreted within the context of the limitations of our observational study design. This is a single center study of radiation exposure during urodynamics. Patient characteristics, equipment and procedure technique likely differ from other centers, which may limit the generalizability of these findings. Direct comparisons using the estimated doses from this study to data from other centers should be done with caution. In addition, the calculation of ESD is based on generalized factors that were established based on reasonable setup assumptions. The calculations used to determine radiation dose are based on a mix of patient specific and population based information in this series. For the calculation of ED and organ dose only discreet, age specific computer models were available for simulation, which do not accurately represent the anatomy of any individual patient or body habitus. ESD may be a more robust measure of radiation exposure to the patient.

Other limitations include that there may have been unmeasured differences in the prospective cohort compared to the retrospective cohort (ie Hawthorne effect in the technologist, nurse and urologist). When comparing mean ED on exploratory analysis, there was no significant difference in the respective groups (0.07 vs 0.06 mSv, $p = 0.17$). Also the potential role of vesicoureteral reflux or history of vesicoureteral reflux was not examined in this series, which may be an unmeasured confounder. Finally, the fluoroscopy time recorded on the C-arm was displayed in units of minutes and not in seconds, limiting the precision of this measurement.

CONCLUSIONS

Greater BMI, bladder capacity and fluoroscopy time are independently associated with higher ED of radiation from videourodynamics. The additional information gained from fluoroscopy use during videourodynamics must be weighed against the potential long-term risks associated with radiation. Efforts should be made to use the lowest possible amount of ionizing radiation to obtain the necessary clinical information.

APPENDIX

Recommended practices for videourodynamics to minimize radiation dose

Patient preparation

- Assess family for readiness of exam 1–2 weeks prior
- Determine need for child life therapy

C-arm and room setup

- Use lead shielding and thyroid shields for personnel in room
- Keep x-ray tube below the table if possible
- Keep patient far from the x-ray source and keep image intensifier as close to patient as possible
- Use pulsed mode and low dose settings (if image quality is acceptable)
- Avoid use of magnification modes or geometric magnification

Procedure

- Keep beam-on time to a minimum and interval of imaging appropriate with need for information
- Obtain voiding and post-void images
- Consider additional fill cycles if study inadequate

Other

- Perform regular maintenance, annual physics surveys, and inspection of C-arm equipment to ensure the radiation dose is within regulatory limits
-

Abbreviations and Acronyms

AK	air kerma
BMI	body mass index
ED	effective dose
ESD	entrance skin dose

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Figure.

Correlation between ED and fluoroscopy parameters during urodynamics. *A*, ED and age ($r = 0.32$). *B*, ED and bladder capacity ($r = 0.23$). *C*, ED and BMI (0.30). *D*, ED and fluoroscopy time ($r = 0.71$).

Table 1

Patient and study characteristics with univariate analysis of potential factors associated with effective dose

Characteristic	Value		p Value
Mean $\pm$ SD yrs age (range)	9.3 $\pm$ 5.7	(0.2–20.8)	<0.01
% Sex:			0.54
Male	45		
Female	55		
Mean $\pm$ SD cm ht (range)	124.4 $\pm$ 33.2	(55.6–181.9)	<0.01
Mean $\pm$ SD kg wt (range)	34.9 $\pm$ 23.0	(3.0–97.1)	<0.01
Mean $\pm$ SD kg/m ² BMI (range)	19.5 $\pm$ 5.4	(7.0–35.4)	<0.01
No. prior urodynamic study	42		0.25
% Primary diagnosis:			0.38
Anatomical abnormality	14		
Neurogenic bladder	73		
Functional disorder	13		
Mean $\pm$ SD fill cycles (range)	1.5 $\pm$ 0.7	(1–4)	0.27
No. vesicoureteral reflux	12		0.20
Mean $\pm$ SD ml bladder capacity (range)	262 $\pm$ 264	(13–1,550)	0.02
Mean $\pm$ SD mins fluoroscopy (range)	0.17 $\pm$ 0.12	(0.04–0.70)	<0.01
Mean $\pm$ SD mGy air kerma (range)	1.38 $\pm$ 1.26	(0.13–6.71)	
Mean $\pm$ SD mGy entrance skin dose (range)	2.18 $\pm$ 200	(0.21–10.61)	
Mean $\pm$ SD mSv effective dose (range)	0.07 $\pm$ 0.05	(0.004–0.23)	
Mean $\pm$ SD mGy testis specific dose (range)	0.09 $\pm$ 0.10	(0.01–0.46)	
Mean $\pm$ SD mGy ovary specific dose (range)	0.20 $\pm$ 0.13	(0.01–0.27)	

Table 2

Multivariate analysis of factors associated with radiation dose during urodynamics

	Coefficient (95% CI)		p Value
Effective dose (mSv):			
Age	0.00063	(−0.00068, 0.00194)	0.34
BMI	0.0023	(0.0010, 0.0037)	<0.01
Bladder capacity	0.000027	(0.000002, 0.000053)	0.04
Fluoroscopy time	0.30	(0.25, 0.35)	<0.01
Testis specific dose (mGy):			
Age	−0.00669	(−0.01121, −0.00217)	0.01
BMI	0.0015	(−0.0045, 0.0075)	0.61
Bladder capacity	0.000018	(−0.000063, 0.000100)	0.66
Fluoroscopy time	0.34	(0.16, 0.51)	<0.01
Ovary specific dose (mGy):			
Age	0.00336	(−0.00368, 0.01040)	0.34
BMI	0.0088	(0.0034, 0.0142)	<0.01
Bladder capacity	0.000170	(−0.000038, 0.000378)	0.11
Fluoroscopy time	0.73	(0.50, 0.95)	<0.01