Original Article

Radiation Dose Used in Pediatric Voiding Cystourethrography: Three-Year Data from King Chulalongkorn Memorial Hospital

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Objective: To quantify and evaluate radiation dose for pediatric patients from age of one day to 15 years that underwent VCUG according to the protocol used at King Chulalongkorn Memorial Hospital.

Materials and Methods: The data of 191 consecutive pediatric patients that underwent VCUG according to the protocol used at King Chulalongkorn Memorial Hospital, including demographic data, entrance skin dose (ESD), dose-area product (DAP), the fluoroscopy time, and the number of the radiographic acquisition for each patient between January 2014 and October 2016 was recorded. The data was classified into two groups according to positive or negative vesicoureteral reflux (VUR), and to four stratifications based on age.

Results: The mean ESD, DAP, and effective doses of 191 children were 6.44 mGy, 82.97 cGy·cm^2, and 0.17 mSv, respectively. The local third-quartile diagnostic reference levels (DRLs) levels in each age groups were calculated as 34.73, 54.87, 142.71, and 254.46 cGy.cm^2 in the age of 0 to 1, more than 1 to 5, more than 5 to 10, and more than 10 to 15 years, respectively. The median number of the radiographic acquisition was 2. The average fluoroscopic time during examination was 87.80 seconds. The DAPs of male and female patients were not significantly different. The patients with VUR had significantly higher DAP than the patients without VUR.

Conclusion: The means of DAP values in the present study and in each age stratification were lower than those reported by other authors, except in age group 0 to 1 year. The local DRL values in some age groups were higher than in another study in Thailand and ICRP 2011. Radiologists should be aware of radiation dose used and try to lower the radiation dose in the pediatric patients.

Keywords: Voiding cystourethrography, Fluoroscopy, Radiation dose, Effective dose, Children

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Urinary tract infection (UTI) is a common pediatric problem with an incidence of about 8% for girls and 2% for boys[1]. Vesicoureteral reflux (VUR), the backward flow of urine from the bladder into the kidneys, is the most important risk factor for the development of UTI[1]. The prevalence of VUR is about 18% to 40% of the child population investigated for their first episode of UTI[1]. Voiding cystourethrography (VCUG) together with ultrasonography is a part of the imaging examination of a febrile child with UTI[2]. The examination is the standard imaging study for detecting and grading VUR[3,4]. Moreover, VCUG is the study used to follow up on cases with treated VUR[4]. VCUG is the most frequent fluoroscopic examination performed in children, approximately 35% of fluoroscopy were done in pediatric patients[5].

It is widely known that children are more sensitive to ionizing radiation than adults. Young children are approximately three times more sensitive to radiation exposure than adults because of their longer life expectancy and more tissue sensitivity[6]. Radiation effect can manifest for years after the exposure. Radiation exposure rate during pediatric fluoroscopy needs to be based on 'as low as reasonably achievable' (ALARA) principle, which means reduction in exposure without loss of essential

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Table 1. DRLs for VCUG as recommended by National Radiation Protection Board (NRPB 2000, Public Health England) and International Commission on Radiological Protection (ICRP 2011)[13,14]

Age groups	DRLs of DAP for VCUG (cGy.cm^2)	
	NRPB 2000	ICRP 2011
0 to 1 year	90	81
>1 to 5 years	110	94
>5 to 10 years	210	164
>10 to 15 years	470	341

DAP=dose-area product; DRLs=diagnostic reference levels; VCUG=voiding cystourethrography

diagnostic information[6-8]. There are numerous factors contributing to radiation dose from fluoroscopy including patient physical parameters, patient cooperativeness, characteristic of the investigated region, fluoroscopy time, and a frequency of radiation exposures[1,9].

There are many quantities used in assessing the radiation risk from diagnostic X-ray examinations. Dose-area product (DAP) value is a preferred indication by many investigators to assess radiation risk from fluoroscopic studies. It is a more useful indicator of overall patient exposure than measurements of entrance skin dose (ESD) at different locations, since DAP is defined as the absorbed dose multiplied by the irradiated area[10]. Estimation of effective dose is a product of measurement of DAP and dose conversion factors. The International Commission on Radiological Protection (ICRP) estimated that the risk coefficients for children for stochastic and hereditary effects are 13% per sievert (Sv) and 4% per Sv, respectively[1,11].

The diagnostic reference level (DRL) is a radiation dose level recommended by international authorities for radiation protection and optimization of patient imaging. They are typically defined as the seventy-fifth percentile of the dose distribution from a regional survey using a specified dose-measurement protocol[12]. The DRLs for VCUG as recommended by the National Radiation Protection Board (NRPB 2000, Public Health England) and the ICRP 2011 are classified patients in age groups as shown in Table 1[13,14].

Radiation dose data collection of pediatric patients undergoing radiologic examinations were started a couple years ago at some centers in Thailand[15,16]. To the authors knowledge, there are only a few studies that represented Asian population. DRLs for Thai and Asian population have not been established yet.

The aims of the present study were to quantify and evaluate radiation dose for pediatric patients from age of one day to 15 years that underwent VCUG according to the protocol used at King Chulalongkorn Memorial Hospital (KCMH).

Materials and Methods

The VCUG procedures were performed using digital pulsed fluoroscopic-radiographic system (Toshiba Kalare, Toshiba Medical Systems, Tustin, California, USA) equipped with DAP meter. The evaluation of radiation dose was done at fluoroscopy unit on the fourth story of Queen Sirikit building, KCMH.

The routine VCUG was carried out by training resident physicians under the supervision of the board-certified pediatric radiologists. The procedures started with sterile urethral catheterization with different sizes of catheter depending on patients' ages. A diluted water-soluble contrast material with sterile water with a concentration of 100-milligram iodine per milliliter was administered via a urethral catheter using gravity pressure. The predicted bladder capacity was calculated using the followings formulae, in children younger than 1 year, the estimated volume in milliliters is the child's weight in kilograms multiplied by 7, while in children older than 1 year, the estimated volume in milliliters is the child's age in years plus 2, multiplied by 30. The VCUG was performed by pulsed fluoroscopy unit set at four frames per second. Intermittent fluoroscopy was performed with automatically selected kV and mAs exposure parameters.

The supine scout fluoroscopic image was obtained before contrast media administration. The diluted iodinated contrast media was then filled retrogradely via the urethral catheter. Intermittent fluoroscopy was done in supine, lateral and oblique views during the early filling phase and a full bladder. Last image hold technique was used. Radiographic images were taken in cases of difficulty in detecting abnormality or grading of VUR. Fluoroscopic images were taken during voiding with a supine position in girls and oblique or lateral views in boys. An anteroposterior fluoroscopic image was performed after voiding.

Data were collected retrospectively on consecutive patients between January 2014 and October 2016. The patients were excluded if their essential data were not available. Technologists recorded demographic data, ESD, DAP, the fluoroscopy time, and the number of the radiographic acquisition for each patient. The

Table 2. The data parameter of patient information

	Mean	SD	Max	Min	Median
Height (cm)	88.75	28.38	157	47	84
Weight (kg)	14.12	10.22	67	2.3	11.5
Age	3.38 years	3.49 years	14 years	7 days	2.01 years

SD=standard deviation

Table 3. The radiation doses to the patients from VCUG procedures (n = 191)

	Mean	SD	Max	Min	Median	75th percentile
ESD (mGy)	6.44	13.12	92.01	0.06	1.56	6.61
DAP ($cGy.cm^2$)	82.97	128.31	957	1	43	87.00
Effective dose (mSv)	0.17	0.27	2.01	0.0021	0.09	0.18

DAP=dose-area product; ESD=entrance skin dose; SD=standard deviation; VCUG=voiding cystourethrography

Table 4. The mean radiation doses to the patients from VCUG procedures categorized into age groups and sexes

Groups	ESD (mGy)		DAP ($cGy.cm^2$)		Effective dose (mSv)	
	Mean	SD	Mean	SD	Mean	SD
0 to 1 year (n = 63)	4.59	11.28	34.73	36.88	0.07	0.08
>1 to 5 years (n = 69)	4.80	8.94	54.87	47.58	0.12	0.01
>5 to 10 years (n = 46)	9.79	18.07	142.71	181.31	0.30	0.38
>10 to 15 years (n = 13)	11.81	16.33	254.46	235.01	0.53	0.49
Male (n = 114)	7.21	14.30	95.97	151.81	0.20	0.32
Female (n = 77)	5.27	11.08	63.71	79.15	0.13	0.17

DAP=dose-area product; ESD=entrance skin dose; SD=standard deviation; VCUG=voiding cystourethrography

data were classified into two groups according to positive or negative VUR; and to four stratifications based on age (0 to 1, older than 1 to 5, older than 5 to 10, and older than 10 to 15 years old). Effective dose was calculated from DAP value multiplied by the conversion coefficient of 0.21 mSv/Gy·cm² for VCUG procedure[9,10]. The Institutional Review Board approval was obtained (IRB No. 192/59).

Statistical analysis

Mean and standard deviation (SD) were calculated for fluoroscopy time, ESD, DAP, and effective dose. Mean and median was calculated for number of radiographic acquisition. The seventy-fifth percentile of doses were obtained as the local DRL. Wilcoxon rank-sum test was used for comparing DAP between two groups. A p-value of less than 0.05 was considered statistically significant. All statistics in this study were done using IBM SPSS Statistics version 22 for Windows.

Results

One hundred ninety-one children (114 boys and 77 girls) underwent VCUG at KCMH between January 2014 and October 2016 and were included in this study. The median age of the study population was 2.01 years. The patients were stratified into four age groups, 0 to 1 year (63 patients), older than 1 to 5 years (69 patients), older than 5 to 10 years (46 patients), and older than 10 to 15 years (13 patients). The data of patient information is shown in Table 2.

The data of radiation doses to the patients from VCUG procedures are shown in Table 3. The number of radiographic acquisitions ranged from 0 to 12 (median 2). The average fluoroscopic time during examination was 87.80 seconds (range 6 to 480 seconds).

In the present study, the DAPs of male and female patients were not significantly different (p=0.36). Table 4 shows the radiation doses classified by age groups and sexes. The patients with VUR had

Table 5. The data parameters in positive and negative VUR groups

Groups	Mean number of radiographic acquisition	Mean fluoroscopic time (seconds)	Mean ESD (mGy)	Mean DAP (cGy.cm²)	Mean effective dose (mSv)
Positive VUR (n = 66)	3.03	98.18	6.33	84.44	0.18
Negative VUR (n = 125)	1.85	82.20	6.50	82.19	0.17

DAP=dose-area product; ESD=entrance skin dose; VUR=vesicoureteral reflux

Table 6. Comparison of the mean DAP value from this study with those reported by other authors

Age groups	Mean DAP (cGy.cm²)		
	This study	Siriwiladluk et al. (2012)[16]	Rongviriyapanich et al. (2016)[15]
0 to 1 years	34.73	46.58	27.85
>1 to 5 years	54.87	115.48	103.10
>5 to 10 years	142.71	292.28	116.42
>10 to 15 years	254.46	575.98	388.03

DAP=dose-area product

Table 7. Comparison of the DRLs of DAP value from this study with those reported by other authors, NRPB, and ICRP

Age groups	DRLs of DAP (cGy.cm²)				
	This study	NRPB 2000	ICRP 2011	Siriwiladluk et al. (2012)[16]	Rongviriyapanich et al. (2016)[15]
0 to 1 years	50.5	90	81	52	37
>1 to 5 years	83	110	94	182	77
>5 to 10 years	192.5	210	164	401	105
>10 to 15 years	352	470	341	754	595

DAP=dose-area product; DRLs=diagnostic reference levels; ICRP=International Commission on Radiological Protection; NRPB=National Radiation Protection Board

significantly higher DAP than the patients without VUR (p=0.03). The data parameter comparing between positive and negative VUR groups are shown in Table 5.

The comparison of the mean and the DRLs of DAP value from the present study with those reported by other authors and international recommendation are presented in Table 6 and 7[13-16].

Discussion

Because children have greater risks from ionizing radiation, each institute must be responsible for minimizing and optimizing radiation dose. Record of radiation dose-related information and fluoroscopic exposure times in radiology practice is important as part of quality assurance program[7]. The use of dose audit and critical review certifies optimization of radiation dose. The local third-quartile DRL reflects 'good and normal practice' in the institute[17]. In Thailand, Siriwiladluk et al[16] and Rongviriyapanich et al[15] reported radiation dose used in VCUG and calculated local DRLs in university hospitals.

Pediatric radiation dose depends on many factors, including patient's physical parameter. In the present study, the mean DAP value increased with increasing age range. As the child size grows with age, application of larger fluoroscopy fields contributes to a larger irradiated area, and to an increase in the radiation dose.

The number of radiographs taken during an examination in the present study varies from 0 to 12, which is lower from the report of Rongviriyapanich et al[15]. In the present study, the fluoroscopic time ranged from 6 to 480 seconds (0.1 to 8.0 minutes). The time was not different from those reported by Siriwiladluk et al[16] and Rongviriyapanich et al[15], which was 0.73 to 7.70 minutes and 0.3 to 7.9 minutes, respectively.

The DAP values in males and females were not significantly different which against the report of Travassos et al[9]. The reasons might be due to the similar use of position and technique to manipulate patients during fluoroscopic images taking between two groups. Hence the complicated anatomy of the boys does not lead to longer fluoro-scopic time and ultimately does not increased in radiation dose.

There was significant difference in the DAP and fluoroscopic time between positive and negative VUR groups. The number of radiographs taken in positive VUR group was significantly higher. This implies that patients with VUR have more complicated anatomical structures, thus examiners use longer fluoroscopic time to diagnose abnormalities. Some patients with negative VUR may have other anomalies that also require longer examination time such as ureterocele, urethral diverticulum, posterior urethral valve, urogenital sinus, cloanal malformation, or Mullerian duct remnant.

The mean of DAP values in the present study was lower than those reported by Siriwiladluk et al[16] and Rongviriyapanich et al[15], except in age group 0 to 1 year, which was higher than of Rongviriyapanich et al. The DRL values in the present study obtained by the seventy-fifth percentile of the DAP were lower than those reported by Siriwiladluk et al and NRPB in all age groups. However, the DRL values in the present study showed higher than those reported by Rongviriyapanich et al in nearly all age groups except in older than 10 to 15 year. The relatively higher radiation dose in small children may result from difficulty to collimate the area of interest. Collimation and maintaining the position of a young patient is challenging. The authors needed to hold the small patients and manipulate them on the table during fluoroscopy. The distance between patient and image receptor is longer than the older children, so the dose can be comparatively higher.

The mean effective dose in the present study was calculated to be 0.17 mSv (range 0.0021 to 2.01 mSv). In the literature, Rongviriyapanich et al[15] reported the effective dose ranged from 0.003 to 3.16 mSv (average 0.2 mSv).

Conclusion

The authors present the local DRL levels of pediatric VCUG examination at KCMH. Some of the DRL values are higher than another study in Thailand and the ICRP 2011, so the radiologists should try to lower the radiation dose in the pediatric patient. Radiologists should be aware of radiation dose used in children due to a higher risk of developing radiation-induced cancer. The national DRL for Thai pediatric patient should be established to review doses, compare with other studies, and optimize radiation dose.

What is already known on this topic?

Radiation dose data collection of pediatric patients undergoing radiologic examinations was started a few years ago at some centers in Thailand.

What this study adds?

The authors studied a larger number of pediatric patient to reassure and emphasize the need for Thailand to set a national DRL.

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Conflicts of interest

The authors declare no conflict of interest.

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