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ORIGINAL ARTICLE

Clinical Audit of Radiation Dose Reduction in Micturating Cystourethrogram: an Initiative for Patient Safety and Quality Improvement

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ABSTRACT

Objectives: *To ensure that the radiation dose from micturating cystourethrograms (MCUs) performed in our centre is regularly and constantly reviewed, and to identify ways in which radiation dose can be reduced and maintained in line with international standards.*

Methods: *This was a clinical audit of the radiation dose and fluoroscopic screening time of MCU examination performed in 97 patients between April 2013 and June 2015 at a tertiary referral centre in Hong Kong before and after implementation of radiation reduction measures. Along with the general measures to reduce radiation dose, the three major measures taken were (1) minimising fluoroscopic screening time during the early-to-intermediate bladder filling phases during which time only limited diagnostic information was obtained; (2) bilateral fluoroscopic screening of the urinary tract in one voiding cycle to detect reflux, thus avoiding the need for two voiding cycles; and (3) using a mathematical formula to estimate the time when urinary bladder capacity was reached and the child might start to void. Statistical analysis was performed of dose area product (DAP) and fluoroscopic screening time during the MCU and compared with the diagnostic reference level (DRL) set by the UK's National Radiological Protection Board.*

Results: *The mean DAP of MCUs in our hospital before and after implementation of dose reduction measures was 49.3 uGym^2 and 38.1 uGym^2, respectively, with a statistically significant reduction in DAP of 22.7% ($p = 0.036$). A similar reduction of 20.6% was also observed in the fluoroscopic screening time that reduced from a mean of 115.3 seconds before to 91.6 seconds after dose reduction measures ($p = 0.002$). Overall, a reduction in radiation dose from our MCU examinations from 20.2% above the DRL to below the third quartile was observed.*

Conclusion: *A statistically significant 22.7% reduction in radiation dose from MCU examinations was achieved after the implementation of dose reduction measures in our hospital. This has also resulted in a mean radiation dose that is below the third quartile of the DRL of the UK's dose reference level.*

Key Words: *Cerebral hemorrhage; Cranial fossa, posterior; Hydrocephalus; Intracranial arteriovenous malformations; Varicose veins*

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中文摘要

有關排尿式尿道膀胱造影輻射劑量減少的臨床審計：病人安全和質量改進的倡議

區嘉殷、黃慧中、邱麗珊

目的：確保本院定期並不斷地評價排尿式尿道膀胱造影（MCU）時產生的輻射劑量，並找出能減少輻射劑量以及與國際標準保持一致的措施。

方法：本臨床審核研究於香港一所三級轉介中心內進行。在減少輻射劑量措施實施前後，比較輻射劑量和暴露在X光射源下的時間。研究對象為2013年4月至2015年6月期間的97名病人。除一般的減少輻射劑量措施外，還實施了以下三項主要措施：（1）由於早期至中期的膀胱充盈期間所獲得的診斷資料有限，應盡量減低病人暴露在X光射源下的時間。（2）在一個排尿周期內檢測膀胱兩側的回流，替代以往的兩個排尿周期，這樣可減低病人暴露在X光射源下的時間。（3）使用數學公式來估計膀胱脹滿尿液的時間而可以讓兒童可以開始排尿。利用統計學分析MCU期間的劑量面積乘積（DAP）和暴露在X光射源下的時間，並與英國國家輻射保護委員會設定的診斷參考水平（DRL）進行比較。

結果：本院在減少輻射劑量措施實施前後的DAP分別為49.3 uGym^{2}和38.1 uGym^2；下降幅度為22.7%，並統計顯著（p=0.036）。暴露在X光射源下的時間則由方法實施前的115.3秒減至實施後的91.6秒；下降幅度為20.6%（p=0.002）。總的來説，MCU檢測中輻射劑量的減少從實施前在英國DRL之上的20.2%減至實施後DRL第三四分位數以下。

結論：本院在減少輻射劑量措施實施後，MCU輻射劑量顯著下降了22.7%。平均輻射劑量亦減至按英國DRL標準的第三個四分位數以下。

INTRODUCTION

Compared with adults, children and neonates have a two to three times higher risk of developing radiation-induced cancer or other serious hereditary effects, related to their longer life expectancy and greater cell proliferation.[1-3] The risk coefficients for the average population are 5% and 1.3% Sv^{-1} respectively, as estimated by the International Commission on Radiological Protection.[2] For children, they are documented to be 13% for stochastic effects, and 4% Sv^{-1} for hereditary effects.[2] Radiation safety and protection has always been a focus of debate in the field of radiology. Adherence to the principle of 'as low as reasonably achievable' (ALARA) has been increasing over the last few years; publications studying the field of dose calculation and related risk are well established in the literature.[4-14]

The incidence of urinary tract infection (UTI) in paediatric patients is 2% in males and 8% in females.[15] An important underlying risk factor is vesicoureteral reflux (VUR) that allows retrograde flow of urine from the urinary bladder to the renal pelvis. Some studies have also documented the presence of VUR in approximately 18% to 40% of paediatric patients being investigated for a first episode of UTI.[10-15]

The micturating cystourethrogram (MCU) is the most frequent examination in paediatric patients, representing about 30% to 50% of all fluoroscopic examinations performed in children. It is regarded as the gold standard for detection and grading of VUR, and for the demonstration of urethral and bladder abnormalities.[4-15]

Concern about the radiation exposure during an MCU is due to the many radiosensitive organs and tissues located in the field of radiation, that is, the abdomen. In accordance with the principle of ALARA, radiologists should always optimise the radiation dose when obtaining essential diagnostic information.[2,3] Improving operator-dependent factors such as the training of radiologists with skilful techniques, together with the use of an international reference, namely the diagnostic reference level (DRL), in keeping with the intended diagnostic purpose[10] can enable radiation dose optimisation. DRL is a good indicator of what is often referred to as 'best practice',[2,16] and should not be exceeded in everyday practice.

To illustrate our initiative for patient safety and quality improvement, we aimed to review the radiation dose of MCU examinations at our centre, identify the potential areas for improvement, implement modifications to reduce radiation dose, and re-audit to ensure that our radiation dose conforms with internationally accepted levels.

METHODS

Two phases of the study have been conducted and a prospective phase 3 is being planned. Approval has been being sought from the Ethics Committee of our institution with informed consent being waived.

Phase 1 included a retrospective review of the radiation dose of all consecutive MCUs performed in the fluoroscopic suite (Artis zee multi-purpose system; Siemens, Muenchen, Germany) at our centre from April 2013 to December 2013. Patient demographic data, reasons for referral for MCU, MCU procedural details, quality of fluoroscopic images, radiation dose, and screening time were independently reviewed by two radiologists. Statistical analysis was performed of the radiation dose, calculated using dose area product (DAP) in uGym^2, and compared with the third quartile of the DRL set by the National Radiological Protection Board (NRPB) in the UK. Statistical analyses were performed by Mann-Whitney *U* test using the Statistical Package for the Social Sciences (Windows version 19.0; SPSS Inc, Chicago [IL], US). A p value of <0.05 was considered statistically significant.

Literature was searched for the international recommendations on radiation dose from MCU. The NRPB is a public authority in the UK set up under the Radiological Protection Act 1970. Its statutory function is to conduct research on radiological protection and to provide advice and information. In consultation with the relevant professional bodies, it provides guidance on 'national reference doses' for common X-ray examinations, based on rounded third quartiles of patient doses observed in national surveys. Table 1 shows the analysis of paediatric data on radiation dose [DAP/examination (mGycm^2)] in MCU examinations published in *Doses to patients from medical X-ray examinations in the UK — 2000 review*.[17]

The mean and third quartile of radiation doses in MCU examinations as analysed by NRPB are 430 mGycm^2 and 410 mGycm^2, respectively for children younger than 1 year. These values were adopted as reference standards in our study in which we aimed to reduce the DAP in our MCU examinations to ≤410 mGycm^2, or ≤41 uGym^2 (the unit of measurement utilised in our department).

After retrospectively reviewing our results in phase 1 of the study, the mean DAP was determined to be above the third quartile of radiation dose as analysed by NRPB (≤41 uGym^2).[17] After reviewing international recommendations and guidelines,[18] we identified the major reasons for the relatively high radiation dosage of our MCU examinations in phase 1 as follows:

(1) Radiologists routinely performed fluoroscopic screening or image capturing of the early-to-intermediate filling phase of the urinary bladder where continuous imaging was not necessary.[19,20]
(2) There was no practice of using a mathematical formula to calculate the estimated bladder capacity; instead radiologists depended upon fluoroscopic screening of the urinary bladder to detect fullness in anticipation of possible reflux in the late-filling to early-filling phase.
(3) Routinely, at least two fill/void cycles were performed in all cases (filling to capacity followed by voiding and refilling 2-3 times with the catheter

Table 1. Analysis of paediatric data on radiation dose on 2209 patients.[17]

Standard age (years)	Normalised dose area product / MCU examination (mGycm^2)						
	No. of rooms	Minimum	1st quartile	Median	Mean	3rd quartile	Maximum
0	25	70	150	260	430	410	2100
1	29	70	350	640	810	900	3450
5	28	150	320	700	940	1140	4200

Abbreviation: MCU = micturating cystourethrogram.

in place), even in non-infants and those without high pretest probability.[18]

(4) Other minor weaknesses:
  (a) Explanation of the procedure to parents about the importance of immobilising their child during the examination was unclear, thus procedure time and subsequent radiation were often unnecessarily increased.
  (b) Inconsistent practice of using the 'last image hold' to review anatomy rather than using additional fluoroscopy.

Areas for improvement were identified that could optimise the radiation dose in MCU examinations. The MCU procedural protocol in our centre was also revised following a review of the literature. Along with general measures (such as preliminary assessment of urinary bladder capacity that was adequate for assessing reflux), three specific major dose reduction measures were recommended to our radiologists:

(1) To minimise fluoroscopy screening time during the early-to-intermediate filling phases of the urinary bladder as only limited diagnostic information would be obtained.[19,20]
(2) To screen using fluoroscopy for VUR on both sides of the urinary system during just one voiding cycle, thus obviate the need for two voiding cycles.
(3) To use a mathematical formula to estimate when urinary bladder capacity is reached so the child may start to void.

After incorporating measures for radiation dose reduction as stated above, the new protocol recommended to our radiologists to optimise dosage is listed in Table 2,[18] with an example shown in Figure 1.

Before phase 2 re-audit of the study, radiologists were advised about the proposed radiation dose reduction measures and the importance of radiation protection was re-emphasised. Phase 2 of the study was conducted between January 2014 and June 2015, in a similar fashion to phase 1 with statistical analysis of the DAP and fluoroscopic screening time in all consecutive MCU examinations performed at our centre, after implantation of dose reduction measures. The results of phase 2 of the study were compared with those of phase 1 to ascertain any improvement in our performance in radiation reduction.

RESULTS

In phase 1, there were 58 patients with a mean age of 6.4 months. The majority (86%) of patients were referred by paediatricians because of UTI; the remainder (14%) were referred because of antenatal hydronephrosis (Table 3).

In phase 2, there were 39 patients with a mean age of 8.8 months. Once again, the majority (69%) of patients were referred for UTI; the remainder (31%) because of antenatal hydronephrosis (Table 3).

The radiation dose and fluoroscopic screening time measured in MCU examinations in the two phases are shown in Table 4.

The mean DAP for MCU at our hospital was 49.3 uGym^2 before implementation of dose reduction measures and 38.1 uGym^2 after, with a statistically significant reduction of 22.7% ($p = 0.036$). A similar reduction was also observed in fluoroscopic screening time that reduced from a mean of 115.3 seconds before to 91.6 seconds after implementation of dose reduction measures, with a 20.6% reduction ($p = 0.002$). Overall, a reduction from 20.2% above the DRL of the NRPB

Table 2. New protocol recommended to radiologists to optimise dosage.

New protocol	Details*
Preliminary assessment of bladder capacity	• Estimate bladder capacity that is adequate for assessing reflux[18]: bladder capacity (in ml) = (age [years] + 2) x 30
MCU procedure	• Explain procedure. Cleanse meatus. Catheterisation using a 5-Fr feeding tube • Early-filling image (several seconds after contrast instillation) {1} • Intermediate filling (little or no imaging is necessary) • Pre-voiding estimated bladder capacity (80%), oblique view of bilateral sides of urinary bladder covering VUJ {2} • Image during voiding: oblique view of both sides of the urinary bladder covering the VUJ, and the urethra in boys. Voiding around the catheter is recommended (as it allows repeat filling if the procedure is technically suboptimal, and avoids re-catheterisation if the child does not void after catheter removal) {2} • Post-voiding image: remove urinary catheter. Take a kidney/ureter/bladder radiography {1}

Abbreviations: MCU = micturating cystourethrogram; VUJ = vesicoureteric junctions.
* {1} and {2} indicate the ideal number of fluoro-captured images in an uncomplicated micturating cystourethrogram, giving a total of six.

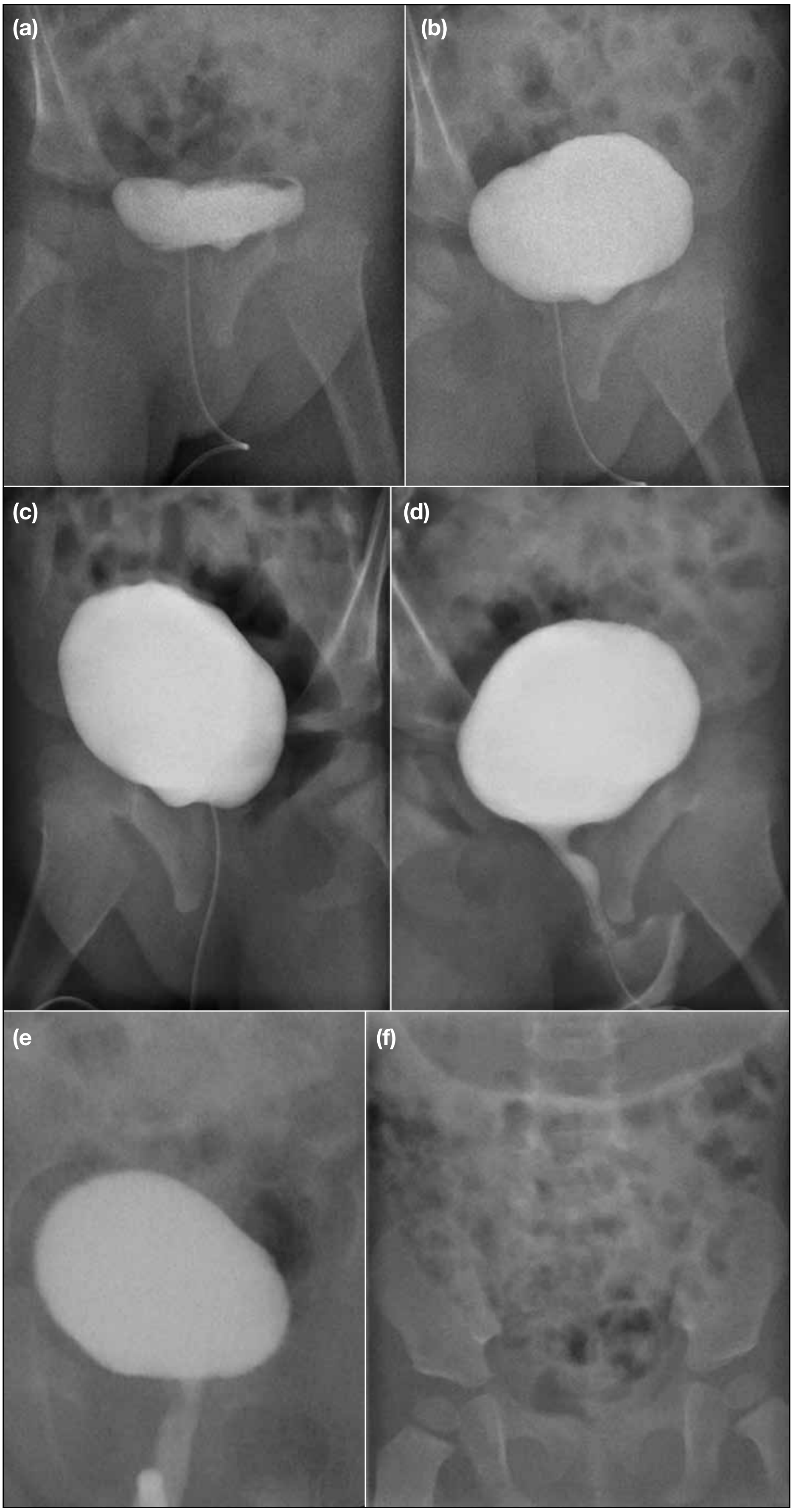

Figure 1. Micturating cystourethrogram examination of a 12-month-old boy; catheterisation using a 5-Fr feeding tube. (a) Early-filling image (several seconds after contrast instillation); intermediate filling (little or no imaging is necessary). (b, c) Pre-voiding images: when close to the estimated bladder capacity (80%), i.e. 72 ml, oblique view of bilateral sides of urinary bladder covering the vesicoureteric junctions (VUJ). (d, e) Images during voiding: oblique view of bilateral sides of urinary bladder covering the VUJ. (f) Post-voiding image: observing a kidney/ureter/bladder for any retained contrast in bilateral renal fossa that may signify the rare case of reflux that is occult during the earlier phases. If reflux is detected at this stage, radiologists can repeat the examination to to determine the grade of reflux and guide prognosis.

Table 3. Demographics of patients and their reasons of referral for micturating cystourethrogram.

	Phase 1 (n = 58)	Phase 2 (n = 39)
Demographics		
Mean (range) age (months)	6.4 (1-23)	8.8 (1-31)
Sex (male : female)	28 (48%) : 30 (52%)	26 (67%) : 13 (33%)
Reasons of referral		
Urinary tract infection	50 (86%)	27 (69%)
Antenatal hydronephrosis	8 (14%)	12 (31%)

Table 4. Radiation dose measured in dose area product and fluoroscopic screening time.

	Phase 1 (n = 58)	Phase 2 (n = 39)
Radiation dose (uGym^2)		
Range	3.1-458.9	3.1-320.3
Mean	49.3	38.1
Median	30.0	19.2
Standard deviation	65.4	54.0
Fluoroscopic screening time (seconds)		
Range	14-528	15-854
Mean	115.3	91.6
Median	95.5	65.5
Standard deviation	79.8	131.5

to below the mean and even the third quartile was observed (Figure 2).

We also reviewed our performance in both phases of the study (Table 5). There were seven (12.1%) cases of reflux detected in phase 1 and six (15.4%) cases in phase 2. There was one case of ureterocele found in phase 1. The rate of detection of VUR in both phases of the audit showed a similar percentage for each category of reflux severity. Short-term (1 month) and mid-term (1 year) follow-up of patients retrieved via the electronic patient record (ePR) system showed no suspected cases of delayed or missed diagnosis of VUR. All patients with no demonstrable VUR had no further episodes of UTI documented during their follow-up.

The compliance of radiologists with the new practice and number of fluoroscopic-captured images acquired in phase 2 revealed 100% compliance (i.e. six images captured in uncomplicated cases). There were 12 cases where more than six images were obtained (Table 6).

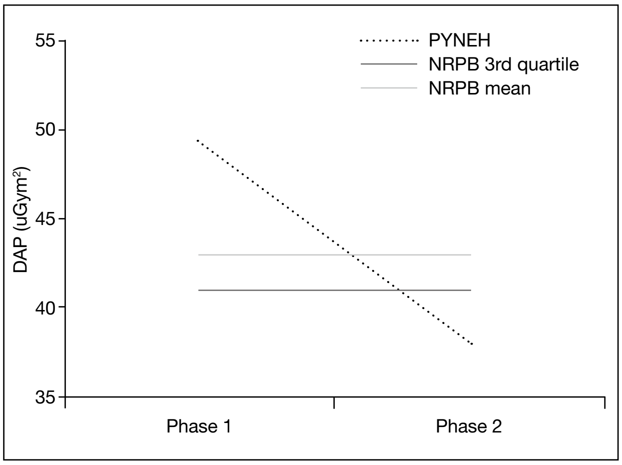

Figure 2. Reduction in dose area product (DAP) from above the diagnostic reference level to below the mean and third quartile in phase 2.
Abbreviations: NRPB = UK National Radiological Protection Board; PYNEH = Pamela Youde Nethersole Eastern Hospital.

Table 5. Detection of vesicoureteral reflux.

	Phase 1 (n = 58)	Phase 2 (n = 39)
Grade 1	3 (5.2%)	2 (5.1%)
Grade 2	2 (3.4%)	2 (5.1%)
Grade 3	1 (1.7%)	1 (2.6%)
Grade 4	1 (1.7%)	1 (2.6%)

Table 6. Number of fluoro-captured images and micturating cystourethrogram results in phase 2.

No. of images	Positive reflux	Negative reflux
6	0	27
>6	6	6

Table 7. Number of fluoro-captured images and the reasons for acquiring more than six images.

	No. of images				
	6	7	8	9	>9
No. of cases	27	5	4	1	2
MCU findings	Uncomplicated cases	2 Reflux	2 Reflux	1 Reflux	1 Reflux
No. of cases having unremarkable findings (i.e. no reflux) but extra fluoro-captured images (i.e. >6) taken	0	3	2	0	1
Reasons for extra fluoro-captured images in unremarkable findings*	N/A	a, b, c*	2 cases of c*	N/A	d

Abbreviations: MCU = micturating cystourethrogram; N/A = not available.

* Reasons for extra fluoro-captured images in cases with unremarkable findings:

a. Scout view was taken at the beginning of the examination as there was clinical suspicion of a renal stone.
b. Follow-up of the patient with a history of bilateral grade 1 reflux. First voiding cycle demonstrated no evidence of reflux. The radiologist studied an additional voiding cycle to confirm the recovery of bilateral reflux, and to exclude missing the diagnosis.
c. Equivocal reflux thus warranting another voiding cycle to confirm the findings.
d. Irritable and struggling patient voiding prematurely before the urinary bladder reached 80% of its calculated capacity.

Table 8. Radiation dose in positive-reflux and negative-reflux cases in two phases.

Radiation dose (uGym^2)	Positive reflux	Negative reflux
Phase 1	(n = 7)	(n = 51)
Range	24.2-458.9	3.1-115.9
Mean	106.8	36.4
Median	43.8	30.0
Standard deviation	157.2	23.4
Phase 2	(n = 6)	(n = 33)
Range	19.1-63.3	3.1-320.3
Mean	37.1	26.7
Median	37.0	26.5
Standard deviation	15.7	53.6

Reasons for acquiring more than six fluoro-captured images were reviewed by the authors and considered acceptable (Table 7).

We also determined the radiation doses for positive-reflux and negative-reflux MCU in both phases (Table 8). The mean DAP (uGym^2) was higher in cases of positive-reflux than in those of negative-reflux in both phases. Despite the observation that a higher radiation dose was imposed in positive-reflux cases, the mean DAP of positive cases and negative cases in phase 2 was lower than those in phase 1. In addition, there was less increase in dose in positive cases versus negative cases in phase 2 compared with phase 1; being 10.4 uGym^2 (37.1-26.7 uGym^2) in phase 2 and 70.4 uGym^2 (106.8-36.4 uGym^2) in phase 1. This may suggest that although radiologists might perform more fluoroscopic screening to demonstrate reflux and anatomical details of the urinary system in positive-reflux cases, they were compliant with the radiation dose reduction measures. This resulted in lower radiation doses incurred in phase 2 than in phase 1.

DISCUSSION

It is established that radiologists can control the overall amount of real-time fluoroscopy and the number of actual recorded images that comprise the examination and consequent total radiation exposure.[18-20] Investigators have tailored MCU examination protocols to exclude preliminary images, utilise the fluoroscopy capture mode, and optimise digital fluoroscopy video techniques all in an attempt to reduce radiation exposure.[6,11,18-21]

The radiologist can also reduce radiation exposure by using pulsed fluoroscopy rather than conventional, continuous fluoroscopy.[22] Unlike continuous fluoroscopy, pulsed fluoroscopy has multiple available pulse rates (number of radiation beam pulses per second) and pulse widths (duration of each pulse).[23,24] If the radiologist selects a lower pulse rate, the radiation exposure of the patient is reduced. Pulsed fluoroscopy has been shown to decrease radiation exposure in an adult study and in a paediatric phantom study.[22,23,25,26] Other radiation reduction techniques include increasing the source-to-skin distance (i.e. maximise the distance between the child and the X-ray source), and removing the anti-scatter grid between the patient (source of scattered radiation) and the detector.[27]

It has been recommended in the local literature that MCU examinations be performed with low-dose digital fluoroscopy using low-frequency pulsed fluoroscopy.[28] Using this technique the radiation dose can be reduced without compromising image quality.[6,11,18-21,28] The reduction in skin dose can be as high as 87% without any appreciable deterioration in spatial or contrast resolution.[26]

Revision of the Micturating Cystourethrogram Protocol

In phase 1 of the study, the mean radiation dose of our MCU was 49.3 uGym^2, which is higher than the international reference of third quartile of the DRL as documented by NRBP in the UK. Following a review of the literature, our MCU procedural protocol was revised, and radiation dose reduction measures were recommended to our radiologists to optimise radiation dose in order to avoid unnecessary radiation exposure to paediatric patients during MCU. Some specific measures to reduction radiation dose were implemented:

(1) In phase 1 of the audit, we discovered that radiologists would routinely perform fluoroscopic screening or image capturing of the urinary bladder during the intermediate filling phase when studies have already shown there is only limited diagnostic value in fluoroscopic imaging of the bladder during this part of the examination.[19,20] Thus in phase 2 of the re-audit, we recommended radiologists to minimise fluoroscopic screening during this part of the examination.

(2) Instead of performing fluoroscopic screening of each side of the urinary collecting system separately in two voiding cycles to assess reflux (i.e. one voiding cycle for each side), the new implementation comprised screening both sides during just one voiding cycle. This required the radiologist to turn the patient to a steep oblique position during voiding so that both sides could be assessed during one voiding cycle. This would reduce the time by one voiding cycle and the accompanying dose of radiation.

    We also alerted our radiologists that the measures to reduce radiation dose should not jeopardise the diagnostic accuracy and value of the examination. According to the literature, cyclical filling of the urinary bladder could still be carried out to increase detection of reflux at the discretion of the performing radiologist, such as in infants who have a high pretest probability (prior history of reflux, Hutch diverticulum, evidence of pyelonephritis etc.) but void at lower volumes, and patients with suspected ectopic ureter inserting below the bladder base.[18]

    In phase 2 re-audit after the introduction of the dose reduction measures, the mean DAP of our MCU examinations was 38.1 uGym^2 (absolute reduction of 11.2 uGym^2 and 22.7% relative reduction), which is below the international accepted level of 41.0 uGym^2 (third quartile of the DRL as documented in NRPB). This showed the success of measures implemented to reduce radiation dose in our MCU examinations.

(3) To estimate the time when the urinary bladder is reaching its capacity where the child may start to void using the following formula[18]: bladder capacity (in ml) = (age [years] + 2) x 30.

    In phase 1 of the audit, we found that radiologists would routinely intermittently screen the filling urinary bladder using fluoroscopy for an estimation of the fullness of the bladder and thus anticipation of the initiation of voiding in order to catch reflux in the late-filling to early-voiding phase. This practice would expose the child to unnecessary radiation. We advised our radiologists to use the above formula to calculate the estimated bladder capacity that would enable them to commence screening of the bladder when around 80% capacity was reached.

General Measures to Reduce Radiation Dose

General methods were suggested to optimise radiation exposure during MCU with reference to local international guidelines such as those recommended by 'Image gently' under the 'Alliance for Radiation Safety in Pediatric Imaging'.[29] Their mission is, through advocacy, to improve safe and effective imaging care of children worldwide.[28,29]

Prior to the MCU examination, the radiologist should obtain a clear clinical history from the child's parents or guardians and referring paediatrician to confirm and justify the clinical indication for MCU, an examination that utilises ionising radiation. All radiologists should review the clinical information of the child to ensure that the indication warrants this ionising examination. In nuclear medicine, direct radionuclide cystography (RNC) is technically a similar study that involves bladder catheterisation and intravesical administration of radiopharmaceuticals. In our institution, 0.7 mCi (25.9 MBq) of Tc-99m sulphur colloid is prescribed and two cycles are performed if there is no bilateral VUR seen in the first trial. RNC has the advantages of lower gonadal radiation dose and continuous examination of the kidneys and the urinary bladder during the filling phase.[30] It has been estimated that the radiation dose to the ovary is 0.005 to 0.01 mGy and even smaller doses to the testis have been found,[31] compared with 0.4 to 0.9 mSv of standard mean effective dose in MCU.[32] The diagnostic performance of RNC is comparable with MCU in terms of the detection of reflux,[30] however there is lower spatial resolution in RNC and therefore anatomical delineation may be impaired. Thus RNC is not recommended as the first diagnostic test in suspected VUR, especially in boys where detailed examination for urethral abnormality is limited. Furthermore, RNC also involves ionising radiation to both the parents and the child. MCU would still be the investigation of choice to evaluate for VUR in our institution. In adherence to the ALARA principle, we have shown that our radiation reduction measures effectively decreased the DAP to within NRPB's recommendations.

In the course of preparation, the radiologist should explain the procedure and risks to the parents as well as the need for the child to lie still since this can greatly shorten the study time and thus lower the radiation dose / exposure. Overhead exposure scout views are not routinely needed. Radiologists should also pause and consider the indications before obtaining additional views, and should collimate off the body parts that are not required for inclusion.

During the MCU procedure, radiologists should adopt the 'Pause and Pulse' technique. Pause refers to pausing to consider ways to minimise radiation exposure to the patient before executing the next step of the procedure; for example consider whether a scout view is needed and whether it can be performed using fluoro-captured instead of full exposure. In our centre, radiologists were strongly encouraged to use fluoro-captured instead of full exposure in MCU examinations to minimise the radiation dose to the child. Radiologists should also use pulsed fluoroscopy rather than continuous fluoroscopy where possible,[22] and pulse at the lowest possible rate. The frame rate adopted in MCU examinations in our centre was 10 films/sec. Radiologists should minimise the number of actual recorded images, and use the last image hold to review anatomy rather than using additional fluoroscopy. Apart from collimating the field of view to the anatomy of interest, for example the vesicoureteric junction (VUJ) or urethra, radiologists should also use their eyes rather than applying fluoroscopy to detect the initiation of micturation.

For systematic and easier adoption of the new protocol by our radiologists, we recommended they approach the protocol according to the 'filling phases' of the examination as shown below.

Pre-filling Phase

In our centre, radiologists should not routinely perform preliminary scout image. The patients scheduled for MCU in our centre usually undergo ultrasound of the urinary system to exclude any structural abnormality or hydronephrosis before the MCU. A scout view is performed at the discretion of the radiologist and only if there is a strong clinical suspicion of, for example, an intra-abdominal calcification, foreign body, or other disease process. It has been suggested that if an abdominal radiograph or other stored image taken within the last 3 to 6 months is available at the time of the MCU examination, it may serve as a guide to direct the remaining MCU examination, eliminating the need for a preliminary scout image.[33]

Early-filling Phase

Radiologists should image the minimally filled urinary bladder in the anteroposterior (AP) projection several seconds after the instillation of contrast material. In most children, this will be the only direct AP image of the urinary bladder. This image is important as it may provide information that is not optimally detected in later parts of the examination. For instance, bladder tumour or ureterocele can be well visualised during the early-filling phase, but may become obscured later on with more contrast entering the bladder due to increased background density.[34]

Intermediate-filling Phase

Little or no imaging is necessary during the intermediate bladder-filling phase. This message was reinforced to all radiologists during the implementation of radiation dose reduction measures. Nuclear cystography can be considered in cases where additional information is required such as at which bladder volume ureteric reflux occurs.[35,36] The reduction of radiation dose in this part of the MCU examination had an important effect in the overall radiation dose reduction in MCU examinations performed in phase 2 of the study.

Pre-voiding Imaging Phase

VUR can be seen in oblique projections obtained just before voiding and should be graded after voiding using the International Reflux System since each grade has prognostic significance.[37,38] Literature has shown that more frequent improvement and shorter time taken for improvement or resolution of VUR have been observed in low-grade categories.[39-41] To aid estimation of the time when the urinary bladder is reaching its capacity and the child may start to void,[18,42,43] we advised our radiologists to calculate the bladder capacity. Fluoroscopic screening for VUR should start when bladder capacity approaches 80% based on the aforementioned formula.

Attention should be paid to the flow of contrast material into the urinary bladder. When there is an abrupt increase in the intravesical pressure with complete bladder filling, as evidenced by the halt of contrast flow into the urinary bladder, radiologists should immediately capture steep oblique images of the urinary bladder centred on the VUJ. This positioning is advantageous[33] in that it allows detection of therapeutically significant abnormalities, for instance a bladder diverticulum situated over the posterolaterally located VUJ, and also allows a reduction in contralateral gonadal radiation exposure in girls.

This positioning should also increase the detection of therapeutically significant abnormalities such as bladder diverticula over the laterally and posteriorly located VUJ.[33]

We advise our radiologists to avoid obtaining AP images when the urinary bladder is contrast-filled as this might cause excessive gonadal exposure, and VUR and perivesical anomalies might become difficult to visualise.[33] This message has also been reinforced to all radiologists to avoid AP imaging of the pelvis when looking at the VUJ.

In the late bladder-filling phase, radiologists were advised to image the ipsilateral renal fossa in the AP projection prior to voiding if VUR was detected, to allow better delineation of the grade of reflux while reducing unnecessary radiation. To further decrease radiation to female patients, radiologists were reminded to ensure that spot radiographs of the renal fossa should only be centred on the fossa, and exclude the region of the gonads or the urine-filled urinary bladder.

Image during Voiding

In our radiation dose reduction techniques, one major implementation was to advise our radiologists to obtain steep oblique images of bilateral VUJs in one voiding cycle instead of two cycles as in phase 1. By the time the filling urinary bladder reached 80% of the calculated volume capacity, steep oblique images of the urinary bladder that were centred on each ipsilateral VUJ should be obtained to catch the potential VUR at this late-filling phase. When the patient voided, radiologists observed for VUR in the ipsilateral VUJ; and when optimal assessment had been made at the discretion of the performing radiologist, the radiologist could position the patient to obtain a steep oblique projection over the contralateral VUJ in one voiding cycle.

In cases of active bladder infection or neurological disorder with spastic bladder where smaller-than-expected voiding volume was encountered, radiologists were advised to refill the urinary bladder while paying special attention to the bladder volume in order to denote the reproducibility of this observation.[33] Although it is known that radiologists might choose to perform multiple cycles of bladder filling and emptying (i.e. cyclic MCU) to increase the diagnostic yield of detecting VUR,[44,45] they must remain aware that each cycle incrementally increases the radiation exposure of a child. Cyclic MCU should only be performed after the pretest probability of VUR has been considered and in selected patient populations.[44,45] Ultimately, the reduction in radiation dose in our MCU examinations should not compromise the image quality or the diagnostic accuracy. Thus, the decision to repeat a second voiding cycle to obtain more image acquisition for better radiological evaluation was at the discretion of the performing radiologist should the first attempt be suboptimal.

Voiding with the catheter in-situ was recommended to all radiologists as this would allow repeat filling if the examination was suboptimal or if the patient voided prematurely. This was also helpful when the patient would or could not void despite gentle manoeuvres of running close-by tap water or dribbling lukewarm water over the perineum. The catheter also allowed cyclic voiding in neonates and bladder drainage in patients who were unable to completely empty their bladders.[44] For image acquisition, we reminded our radiologists that the entire urethra must be imaged in steep oblique positions in boys to avoid overlapping of urethral segments, thus aiding the detection of any disease from the base of the urinary bladder to the urethral meatus.[45-48]

Post-voiding Imaging

At the conclusion of voiding, each renal fossa should be imaged, and our radiologists were advised to take a fluoro-captured kidney/ureter/bladder image. The advantage is that still images might demonstrate reflux not appreciable during real-time fluoroscopy. Still images may also help demonstrate urinary system anomalies. In children with high-grade reflux, delayed abdominal imaging at 15 minutes could also be performed at the discretion of the performing radiologist as there is evidence that such images after voiding can help to differentiate simple reflux from reflux with obstruction at the ureteropelvic junction or VUJ.[49] This might have treatment implications as the latter is more apt to produce UTI and scarring and thus requires different treatment to simple reflux. This practice was nonetheless not observed in the two phases. This advice for radiologists should be reinforced in the future prospective study.

The degree of bladder emptying must be documented. If the child voided prior to catheterisation, the volume of residual urine in the bladder detected at the time of catheterisation may be a more precise reflection of the patient's voiding ability. Lastly, as part of the examination, the radiologist should also assess and report the presence of opaque calculi or mass lesion, the presence of VUR and severity, the contour and capacity of the urinary bladder, the emptying capability of the urinary bladder, the appearance of the urethra, the insertion site of a refluxing ureter, and the status of the skeleton where abnormality could be associated with neurogenic bladder.

There were seven (12%) cases of reflux detected in phase 1 and six (15%) cases in phase 2. The rate of detection of VUR in both phases of the audit showed a similar percentage for each category of reflux severity. Short-term (1 month) and mid-term (1 year) follow-up of patients retrieved via the ePR system showed no suspected cases of delayed or missed diagnosis of VUR. All patients with no demonstrable VUR had no further episode of UTI documented during their follow-up. These results might reflect the consistent and good diagnostic performance with our new MCU protocol.

Our findings showed that the mean DAP was higher in cases of positive reflux than in those of negative reflux in both phases, being 106.8 uGym^2 vs 36.4 uGym^2 (phase 1) and 37.1 uGym^2 vs 26.7 uGym^2 (phase 2); these are comparable with the findings in Sulieman et al's study,[50] which demonstrated that the mean entrance surface dose for MCU with positive reflux was higher (1.45 mGy) than that of negative reflux (1.05 mGy). Even though the radiation dose in positive-reflux cases was higher than in negative cases in both phases, the absolute mean DAP values were lower in phase 2, with less increase in doses in positive versus negative cases in phase 2 compared with phase 1; 10.4 uGym^2 in phase 2 and 70.4 uGym^2 in phase 1. This might suggest that although radiologists in general undertook more fluoroscopic screening for demonstration of reflux and anatomical details of the urinary system in positive cases, they were compliant with the radiation dose reduction measures that effectively lowered the radiation dose imposed in phase 2.

As a retrospective study, this study has inherent limitations. The small sample size from a single centre might limit the generalisability of our results. The lack of analysis of the patient's body thickness related to the unavailability of such data limited a full assessment of the radiation risk as different body thickness will require different levels of radiation to obtain adequate diagnostic information. Nonetheless the results of this pilot study have shown that we have successfully reduced the radiation dose of MCU examinations at our centre and adhered to international standard.

CONCLUSION

MCU utilises ionising radiation and provides anatomical details that are of utmost clinical and surgical importance to the paediatricians and paediatric urologists. With increasing public concern about radiation risks, it is important to optimise the radiation dose delivered to a child during an MCU examination, and to adhere to the ALARA principle to minimise the possibility of acute and late biological effects of radiation exposure. A regular structured audit of the radiation dose and fluoroscopic screening time is an essential component when ensuring patient safety and quality assurance of the MCU examination service at our centre. A statistically significant reduction of 22.7% in radiation dose from an MCU has been achieved after implementation of dose reduction measures in our hospital. These measures included (1) minimising fluoroscopic screening during the early-to-intermediate filling phase of the urinary bladder when only limited diagnostic information could be yielded; (2) using fluoroscopic screening for VUR on both sides of the urinary system during just one voiding cycle instead of alternate sides in two voiding cycles; and (3) using a mathematical formula to estimate when the bladder is approaching capacity and the child may start to void. The new measures have led to successful reduction in mean radiation dose that is now below the third quartile of the UK's DRL. A third phase of this study is planned to further monitor the radiation dose in our MCU examinations.

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