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PATIENT ENTRANCE SURFACE DOSE MEASUREMENTS USING XR-QA2 GAFCHROMIC FILMS DURING MICTURATING CYSTOURETHROGRAPHY PROCEDURES

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The aim of this study was to test the feasibility of using Gafchromic XR-QA2 films in the measurements of patient entrance surface dose (ESD) during the micturating cystourethrogram (MCUG) examination in paediatric patients. Radiochromic films were used to map the entrance dose and to identify the location of peak surface dose (PSD). Direct *in vivo* measurements of entrance dose were conducted by placing a radiochromic film between the patient and the examination table. The measured ESD values for the commonly performed MCUG fluoroscopic examinations at the authors' institution was in the range of 1.2–7.8 mGy and the PSD in the range of 1.2–8.5 mGy per MCUG procedure for patients with age ranging from 1 to 12 y old. Gafchromic films (XR-QA2) were found to be an efficient and practical dosimetry method that can be easily used to measure clinical patient entrance doses during fluoroscopically guided procedures and potentially in other diagnostic investigations.

INTRODUCTION

The micturating cystourethrogram (MCUG) is one of the most commonly performed fluoroscopic investigations in paediatric radiology departments; at the authors' hospital, a minimum of 10 cases per week are performed. MCUG is a radiographic and fluoroscopic study of the lower urinary tract. It requires aseptic bladder catheterisation, injection of iodinated contrast media, fluoroscopic observation and recorded images of the opacified structures. The purpose of the examination was to assess the bladder, urethra, postoperative anatomy and micturition in order to determine the presence or absence of bladder and urethral abnormalities, including vesicoureteral reflux (VUR)[1].

There are some publications comparing the MCUG technique with others such as radionuclide cystograms, voiding urosonography, MR cystography, genetic screening and biomarker discovery. Most references seem to suggest the MCUG technique as the gold standard for investigating urethral abnormalities in children[2–4].

While the effects of various radiation dose-reduction techniques have been reported and described, there is limited information available concerning measured entrance radiation exposure during the performance of clinical paediatric MCUG with fluoroscopic equipment that enables multiple radiation dose-reduction techniques[5]. The use of pulsed fluoroscopy significantly reduces the radiation exposure to children undergoing conventional fluoroscopy. This reduction in exposure is achieved across all types of studies[6]. In children, MCUG examinations can be performed with grid pulsed fluoroscopy techniques that deliver much lower doses than conventional fluoroscopy[7]. The European Commission suggests 65–90 kV for paediatric MCUG examination[8]. Significant dose savings are achieved by using the pulsed low-dose fluoroscopy technique in MCUG examination compared with the continuous fluoroscopy technique[9].

The amount of patient radiation dose depends on the fluoroscope design and on how the radiologist conducts the examination. Radiation dose tracking is important from the patient safety point of view. Measuring peak surface dose (PSD) is currently considered the best predictor for skin injuries occurring as direct effect of radiation overdose. Cumulative dose records of current fluoroscopy correlate well with the PSD. However, sometimes they tend to overestimate the PSD values, simply because they are measured at one reference point which may not be the location of the PSD[10].

Dose area product (DAP) is known to be a good indicator of stochastic radiation-related risks but not for deterministic effects, and in the absence of widely available capability to measure the PSD value, cumulative dose has been identified as the best alternative parameter used to predict deterministic effects[11]. The DAP meter reading does not include the back scatter factor (BSF), resulting in the underestimation of the PSD value. For the study under investigation here and for the selected group of patients monitored, the entrance surface dose (ESD, in mGy) value must be multiplied by 1.08 in order to account for the BSF ($PSD = 1.08 \times ESD$)[12]. It is known that DAP is not

an adequate indicator of patient peak skin dose. The inaccuracy of the DAP meter readings in estimating the PSD value suggests the use of an alternate assessment method. One reference indicates that a direct measurement of ESD is recommended, since there is relatively weak correlation between both DAP and fluoroscopy time with peak skin dose; they have measured ESD using Gafchromic XR-type R films[13]. Radiochromic films change colour in direct proportion with the dose; such films can be examined visually immediately after being exposed to radiation, and quantitatively after being digitised using flatbed-type document scanner. Advantages of the films include and not limited to the following: high spatial resolution, capture peak dose from overlapping projections, large surface area, easy to place under the patient, self-developing and insensitive to visible light[14].

Based on radiation protection recommendations, there is a need to measure and document patient's skin doses accurately in diagnostic radiology departments. Periodically, patient radiation doses should be measured[15]. The aim of this study was to establish a simple, efficient and sufficiently accurate method for routine monitoring of patient ESD.

ESD distribution during MCUG examinations of paediatric patients was successfully measured using radiochromic films technology; specifically, the Gafchromic (XR-QA2) films were tested against the well-established standard ionisation chamber dosimetry.

MATERIALS AND METHODS

Gafchromic XR-QA2 radiochromic films were scanned using the reflective mode as described in Lederman *et al.*[9] An Epson 10000XL flatbed RGB scanner in conjunction with the in-house Matlab computer program was used to read and analyse the irradiated films.

The film dose calibration was done against the readings from a PTW (SFD-type 34060 ionisation chamber) with calibration for the relevant X-ray energies and traceable to German National Laboratory (PTB).

The radiochromic film calibration curve was obtained by exposing the films free in air as recommended by the film's manufacturer. Films were placed on the patient table and irradiated free in air using the under-couch configuration exactly as in the clinical set-up.

A calibration curve was obtained linking the red channel net reflectance optical density to the corresponding dose as shown in Figure 1, as recommended by the film manufacturer, and as described in works such as Alnawaf *et al.*[16] and Niroomand-Rad *et al.*[17] The analytical form of the relationship between radiation dose and the net optical density are as follows:

$$\mathrm{RD} = \log\left(\frac{65535}{\mathrm{PV}}\right) \quad (1)$$

$$\mathrm{RD_{BG}} = \log\left(\frac{65535}{\mathrm{PV_{BG}}}\right) \quad (2)$$

$$\mathrm{NRD} = \mathrm{RD} - \mathrm{RD_{BG}} \quad (3)$$

$$\mathrm{ESD} = a(\mathrm{NRD})^2 + b(\mathrm{NRD}) + c \quad (4)$$

where, RD is the Reflectance Density, PV is the Pixel Value, BG is the Background, NRD is the net reflectance density and ESD is the entrance surface dose.

Once the calibration process was established and dose data were cross-checked, the radiochromic films were used *in vivo* and placed over the examination table, and under the patient's body, the irradiated films captured all the radiation fields used during the procedure in size and in value. The obtained results were then analysed and presented in Table 1.

The fluoroscopy system used in this study was the digital fluoroscopy machine (Philips, Diagnost) with under-table X-ray tube configuration. The MCUG examination consists of mainly PA projection pulsed fluoroscopy, and for most cases additional two symmetric oblique projections are commonly used by radiologists. The film response was proved to be independent of irradiation angle except when the beam is parallel to the film surface[18].

RESULTS

The maximum error in the film readings was 16 %, and the average error was 8 %. Uncertainties were estimated using the method described in Devic *et al.*[19] Doses were measured *in vivo* with Gafchromic films on 33 patients. The obtained exposed film, as in Figure 2, was digitised using Matlab tools for image mapping, histogram and contours functions (Figure 3). Radiation dose distribution can be easily calculated and displayed, which enables the physicist to determine the magnitude and location of the PSD for the fluoroscopic examination under investigation. The results are presented in Table 1.

DISCUSSION

The ESD range measured in this study was found to be in agreement with other published studies. Fotakis *et al.*[20] reported a mean ESD per examination of 5.76 mGy for a 5-y-old child. Ward *et al.*[21] reported an ESD of 5.7 mGy using the continuous fluoroscopy technique and 0.58 mGy using the pulsed fluoroscopy technique. Sulieman *et al.*[22] reported an ESD range of 0.37–2.36 mGy.

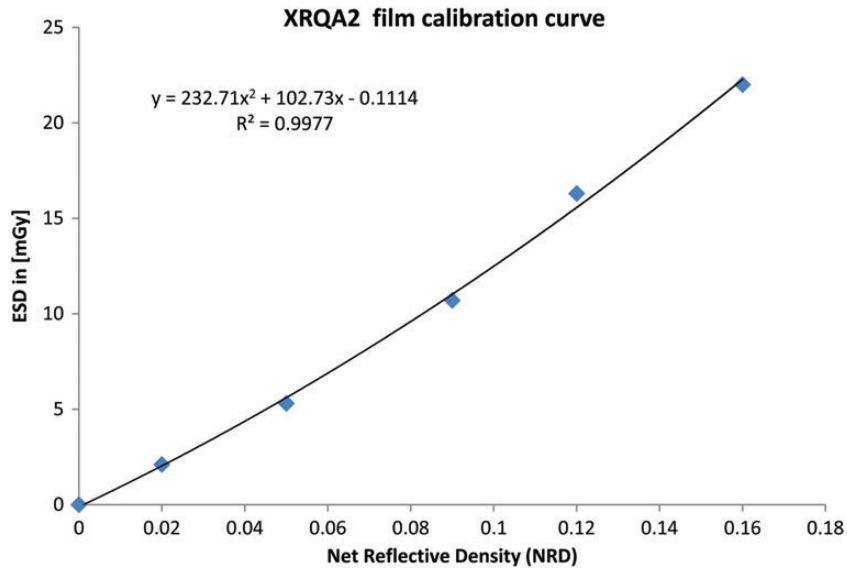

Figure 1. ESD (in mGy) versus the net reflective density of the calibration films exposed free in air.

Table 1. Examination parameters, ESD and PSD as measured using Gafchromic XR-QA2 films

kV	mA	Average fluoroscopy output	Fluoroscopy time	Source image distance	ESD	PSD
60–63	0.3–0.5	1.23 mGy min^{-1}	0.4–5.3 min	95–125 cm	1.2–7.8 mGy	1.2–8.5 mGy

Figure 2. Digitised patient film.

The number of prolonged fluoroscopic procedures performed in diagnostic radiology has increased dramatically over the past 10 y. This phenomenon is partially driven by the preference of managed care to use methods that are less invasive and less costly than surgery[23]. The potential for skin injury due to excessive exposure to radiation has been highlighted by regulatory organisations such as FDA. Such organisations had recommended that constant monitoring of patient doses should be performed on a regular basis.

MCUG is considered to be the gold standard method used to detect and grade the VUR and show urethral and bladder abnormalities. It accounts for 30–50 % of all fluoroscopic examinations in children. Therefore, it is crucial to define and optimise the radiation dose received by a child during MCUG examination, taking into account that children have a higher risk of developing radiation-induced cancer than adults.

One limitation of the use of the films is the fact that the film response is under-optimised when it is placed parallel to the beam axis[24].

The method presented in this study is easy to use, relatively new and reproducible. The simple method described in this work using radiochromatic film dosimetry (Gafchromic XR-QA2) is found to be

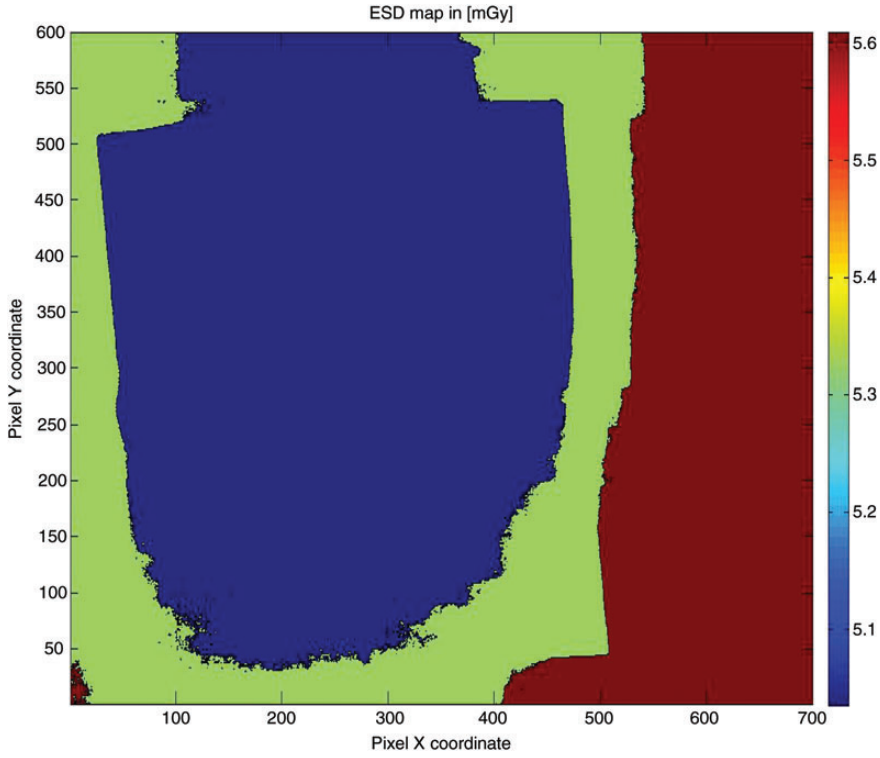

Figure 3. Dose value contours calculated using the Matlab software; the colour code is the dose range as indicated in the right-side colour bar.

appropriate for patient's dose monitoring especially for low-dose procedures such as MCUG.

CONCLUSION

A new radiochromic film dosimetry system can be used in clinical dosimetry with confidence to measure the patient's ESD and PSD in location and magnitude. The dosimetry method described in this study can be used in a wide variety of radiographic and fluoroscopic examinations; it is a simple, non-invasive and retrospective.

The radiochromic films (XR-QA2) used proved their efficiency in measuring and mapping patient skin dose during fluoroscopically guided procedures. The described film dosimetry will help institutions to comply with patient exposure measurements and documentation requirements. The films show the location of the maximum dose measured and how the skin dose was distributed. It can also be used to check the imaging system-recorded DAP values. Finally, it provides quantitative records for patient dose file and improves the fluoroscopic technique and patient safety.

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