# Evaluation of radiation dose in voiding cystourethrography in children*

*Avaliação das doses de radiação em uretrocistografia miccional de crianças*

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**Abstract** **OBJECTIVE: To evaluate dose-area product, skin entrance dose and doses from fluoroscopy and radiography in voiding cystourethrography studies of pediatric patients. MATERIALS AND METHODS: Procedures performed in 37 patients by four physicians of the institution were evaluated. Measurements were performed with an equipment including an ionization chamber directly coupled to the x-ray tube window and an electrometer (Diamentor) connected to a computer for data collection. RESULTS: Some procedures heterogeneity was observed and guidelines for good radiographic techniques were not followed. On average, 11 radiographies are performed for each study, with extended fluoroscopy time delivering a higher average final dose than those reported in the literature. CONCLUSION: The adoption of radiography with high kilovoltage technique and restricted utilization of fluoroscopy can result in a significant reduction of doses during this procedure, considering that the major contribution to the final dose comes from fluoroscopy.**

*Keywords:* X-rays; Dosimetry; Cystourethrography; Fluoroscopy; Pediatric radiology.

**Resumo** **OBJETIVO: Analisar o produto dose-área, a dose de entrada na pele do paciente e as doses relativas à fluoroscopia e às radiografias em exames de cistouretrografia miccional em crianças. MATERIAIS E MÉTODOS: Foram avaliados os procedimentos em 37 pacientes, realizados por quatro médicos do serviço. As medições foram realizadas com um equipamento composto de uma câmara de ionização acoplada diretamente à saída do tubo de raios X e um eletrômetro (Diamentor) ligado diretamente ao computador, para a coleta dos dados. RESULTADOS: Foi observada alguma heterogeneidade na realização do procedimento, que não segue padrão de técnica radiográfica. São realizadas em média 11 radiografias por exame, usando tempo longo de fluoroscopia, com dose média final mais alta que a encontrada em referências da literatura. CONCLUSÃO: A adoção da técnica de alta quilovoltagem nas radiografias e o uso restrito da fluoroscopia podem proporcionar importante redução das doses durante a realização deste procedimento, porque o maior contribuinte para as altas doses verificadas foi a utilização da fluoroscopia.**

*Unitermos:* Raios X; Dosimetria; Uretrocistografia; Fluoroscopia; Radiologia pediátrica.

Travassos LV, Boechat MCB, Santos EN, Oliveira SR, Silva MO, Carvalho ACP. Evaluation of radiation dose in voiding cystourethrography in children. Radiol Bras. 2009;42(1):21–25.

## INTRODUCTION

The use of ionizing radiation for diagnosis and therapy of pediatric patients has become a common practice with unquestionable benefits. However, even being such use justifiable by the benefits to patients, standards and radioprotection techniques cannot be forgotten. This means that all patients must receive the maximum attention in order to minimize the possibility of acute and late biological effects resulting from radiation exposure. Thus, if radioprotection of patients exposed to ionizing radiations is important, it is moreover so, with pediatric patients[1,2].

Cystourethrography also referred to as voiding cystourethrography, is a radiological contrast-enhanced study for evaluation of the urinary tract and, according to reports in the literature, represents 30% to 50% of fluoroscopy studies performed in children[3,4]. The main indications for this imaging method are: evaluation of repeated urinary infections, vesicoureteral reflux and congenital abnormalities of the bladder and of the urethra.

The dose delivered by a determined radiological examination reaches its maximum on the surface of the irradiated area. One can determine the radiation dose incident on the exposed areas by using the Diamentor, a device that is coupled to the x-ray tube that allows the monitoring of accumulative radiation emitted by the x-ray tube during the examination, and which will not interfere on the procedure performance. Based on the entrance-surface air

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Received October 31, 2008. Accepted after revision November 14, 2008.

kerma rate, one determines the dose-area product (DAP) in gray (Gy) and area unit, and the entrance-skin dose (ESD) in Gy. Variations in the fluoroscopy time during examination as a function of the equipment utilized, the radiologist´s skill, the degree of cooperation from the patient, characteristics of the region under investigation and dimensions of exposed areas, are factors influencing the total dose in the procedure.

Considering these factors and the following variables, (a) anatomic differentiation, (b) discrepancy among techniques utilized to obtain pediatric radiographic images and (c) different doses to which patients are exposed, the European Community has issued the European Guidelines on Quality Criteria for Diagnostic Radiographic Images in Paediatrics[5], defining the quality criteria of images for most of these procedures.

The Instituto Fernandes Figueira of Fundação Oswaldo Cruz (IFF/Fiocruz) is a third-level public maternal and child hospital, in which 90% of patients are children. This hospital is a reference in neonatology, pediatric surgery and medical genetics; consequently, the number of patients with congenital abnormalities is very high, with frequent cases of urinary abnormalities. In 2001, the implementation of a program for quality control assurance was initiated in the Division of Radiology with the approval of the Committee for Ethics in Research with Humans of IFF/Fiocruz (Report No. CAAE-000042/0008-02). Considering the predominantly pediatric profile of the institution, the present study is aimed at analyzing the radiation doses to which children are exposed during voiding cystourethrography.

## MATERIALS AND METHODS

The examinations were performed in the period between March 2008 and September 2008 in the Division of Radiology at IFF/Fiocruz, by four radiologists with at least eight years of experience with pediatric patients. The equipment utilized was Prestilix™ telecommanded unit with image intensifier (General Electric Medical Systems; Milwaukee, USA).

The dose values were obtained by coupling a Diamentor™ direct readout ionization chamber model M4-KDK (PTW; Freiburg, Germany), to the exit of the x-ray tube. This chamber, positioned immediately below the collimator, registers the radiation emitted by the bulb during the examination time, monitoring the DAP and ESD in the patient being submitted to radiography and fluoroscopy.

Thirty seven children, 16 (43%) girls and 21 (57%) boys, with ages ranging from one day to 16 years, were submitted to the examination. The patients were divided into four age groups: infants (less than one year), 1–4 years, 5–9 years and 10 or more years, and were evaluated for radiation doses to which they were exposed during the investigation with radioscopy and radiography.

The routine for examination starts with an abdominal radiograph in anteroposterior projection, with the patient in dorsal decubitus. The next step is a careful genital antisepsis and introduction of a catheter through the urethra to the interior of the bladder. Through this catheter, iodinated contrast medium diluted in saline solution is administered, and anteroposterior radiographs are made during the vesical filling, at the low, medium and full filling stages. These images will allow the evaluation of a possible vesicoureteral reflux, of the contents and of the bladder wall. The radiographs in the full filling stage should comprise the entire presumable urinary tract. After the bladder filling phase, the voiding study is performed with anteroposterior radiographs in the case of girls, and with lateral or oblique, in the case of boys. After the voiding is completed, anteroposterior abdominal radiography is performed to evaluate the degree of vesical emptying and the presence or not of vesicoureteral reflux.

## RESULTS

One half the children were one year old or less at the time the examinations were performed. Their weight ranged from 2.5 kg (two children) to 34 kg, and height ranged from 40 cm (two children) to 1.45 m. The body mass index (BMI) was calculated and ranged from 10.4 to 40.8. It is important to observe that the majority of the children were below the ideal weight (21 children with BMI < 18.5). Only one child presented obesity (BMI = 40.8), two were overweight (BMI = 29.1 and 26) and all the others presented BMI ≤ 24 (Table 1).

Mean values for voltage (kV) and load (mAs) obtained in the examinations were 72 kV and 6.1 mAs, respectively. The number of exposures ranged between 6 and 18, the average fluoroscopy time was 516 seconds, corresponding, on average, to 85% of total dose. Total DAP ranged from 154 to 1,865 cGy.cm$^2$ and total ESD ranged from 17 to 321 mGy (Table 2).

Mean total DAP for radiography and fluoroscopy was separately evaluated for each age group, noticing that in the highest age group, the utilization of larger films and fluoroscopy fields contributes for a larger irradiated area, and consequently, to an increase in the dose (Table 3).

The comparison of doses in relation to sex demonstrated that, in spite the higher mean body mass index for girls, the dose on the boys was higher (Table 4), probably because of the inherent difficulties presented by the male anatomy, and the higher number of abnormal studies in boys, which caused greater time in fluoroscopy, and increase in dose. A little over half of the studies, 21 (57%), were considered abnormal, with a subtle predominance (13) among boys.

The comparison by examiner (radiologist) showed small differences in the way the examinations were conducted, and highlights the extension of the fluoroscopy time by all the examiners as per Table 5. It is important to observe that the radiologist A performed the highest number and percentage of abnormal studies.

**Table 1** Biophysical profile of patients.

| | Minimum | Mean | Maximum | Median |
|---|---|---|---|---|
| Weight (kg) | 2.5 | 13.6 | 34 | 13 |
| Height (cm) | 40 | 82.6 | 145 | 85 |
| Body mass index | 10.4 | 18.8 | 40.8 | 17.3 |
| Age | 1 day | 3 years | 16 years | 1 year |

## DISCUSSION

Costa et al.[6–8] have introduced videofluoroscopy to evaluate the swallowing dynamics which requires constant fluoroscopy for detail observation, and dosed the radiation utilized in such procedure in adults, with a mean fluoroscopy time of seven minutes in two similar radiological units, and have observed that, although the doses were within the acceptable range of values in one of them, there was a significant difference between the values in each equipment. One of these units produced a DAP five times higher than the other (804 and 4,101 cGy.cm$^2$), in spite of similar selected parameters for mAs and kV. These authors have considered that a DAP/minute around 100–120 cGy. cm$^2$ was appropriate, and have concluded that there was a problem in the second equipment, which coincidentally, was deactivated few months later. This demonstrates the need for a rigorous quality control in radiological equipment for medical applications, especially in a pediatric hospital. Lacerda et al.[9] have observed that in Brazilian hospitals with older equipment and perhaps inappropriate operational conditions, sometimes the irradiated field was larger than the selected film because of error in the manual collimation, a fact also observed by Azevedo et al.[10].

Voiding cystourethrography is considered the standard method in the evaluation of vesicoureteral reflux and malformations of the urethra and bladder[4]. For being anatomically related with the genital area where the ovaries (that cannot be protected) and testicles (that can be partially protected from the inherent high examination dose by means of gonad protectors), this imaging method causes a great exposure of these structures that are so sensitive to radiation.

Quantifying the radiation exposure determined by an imaging method is a relevant task, especially when this method has such a clarifying meaning as observed in voiding cystourethrography, considering that there is the opportunity to define the actual level of exposure caused by the method and, within the acceptable values to produce a good radiographic image, to

**Table 2** Fluoroscopy time, number of exposures, and observed dose values.

| | Minimum | Mean | Maximum | Median |
|---|---|---|---|---|
| Fluoroscopy time (seconds) | 82 | 516 | 1,240 | 429 |
| DAP fluoroscopy (cGy.cm$^2$) | 141.3 | 704.8 | 1,720.3 | 571.5 |
| ESD fluoroscopy (mGy) | 11.2 | 99 | 298.3 | 73.7 |
| Exposures (*n*) | 6 | 10.8 | 18 | 11 |
| DAP radiographs (cGy.cm$^2$) | 12.5 | 89.4 | 391.5 | 66.4 |
| ESD radiographs (mGy) | 2.3 | 14.7 | 54 | 12 |
| DAP total (cGy.cm$^2$) | 154.4 | 794.2 | 1,865.8 | 804.4 |
| ESD total (mGy) | 17 | 113.5 | 321.2 | 83.3 |

DAP, dose-area product; ESD, entrance skin dose.

**Table 3** Values observed by age group.

| Age group | Patients (*n*) | Average exposures (*n*) | DAP radiographs (cGy.cm$^2$) | % Total DAP | Mean fluoroscopy time (seconds) | DAP fluoroscopy (cGy.cm$^2$) | % Total DAP |
|---|---|---|---|---|---|---|---|
| < 1 year | 12 | 10 | 34.8 | 7% | 461 | 463 | 93% |
| 1–4 | 16 | 9 | 98.4 | 11% | 486 | 809 | 89% |
| 5–9 | 6 | 11 | 95.5 | 12% | 531 | 731 | 88% |
| ≥ 10 | 3 | 9 | 247.8 | 19% | 929 | 1,065 | 81% |

DAP, dose-area product.

**Table 4** Values observed by sex.

| Sex | Exposures (*n*) | Weight (kg) | DAP (cGy.cm$^2$) | DAP fluoroscopy (cGy.cm$^2$) | Mean fluoroscopy time (seconds) | ESD (mGy) |
|---|---|---|---|---|---|---|
| Female | 10 | 15.6 | 776 | 680 | 463 | 92 |
| Male | 11 | 12.1 | 808 | 747 | 554 | 130 |

DAP, dose-area product; ESD, entrance skin dose.

**Table 5** Values observed by examiner (radiologist).

| Examiner | Studies | | Exposures (*n*) | Average (*n*) | Fluoroscopy time (seconds) | | | DAP (cGy.cm$^2$) | ESD (mGy) |
|---|---|---|---|---|---|---|---|---|---|
| | *n* | Abnormals | | | Mean | Minimum | Maximum | | |
| A | 10 | 8 | 8 to 18 | 13.5 | 470 | 218 | 1,240 | 939 | 104 |
| B | 6 | 4 | 6 to 15 | 9.5 | 362 | 82 | 1,080 | 471 | 95 |
| C | 9 | 4 | 8 to 11 | 9 | 471 | 190 | 777 | 712 | 95 |
| D | 12 | 5 | 7 to 16 | 11 | 525 | 245 | 1,180 | 896 | 144 |

DAP, dose-area product; ESD, entrance skin dose.

correct the application of eventually high doses which many times are caused by the radiologist habit of trying to produce a diagnosis by means of fluoroscopy, forgetting the radiation dose delivered to the patient. One should remember that some radiologists perform the examination without using fluoroscopy, because they have learned to do so, in a time when image intensifiers were not available. Nicholson et al.[11] have described dose reduction with the utilization of additional filters, and emphasized that the removal of the anti-scattering grid and the use of an additional 0.7 mm steel filter alone will reduce the fluoroscopy dose by 75% to 80%.

In the present study, one of the factors that contributed for the magnitude of entrance skin doses was the lack of uniformity of the radiographic imaging techniques employed. Some radiologists/examiners leave the technical factors in the automatic mode, while others set kV and mA of fluoroscopy and mAs at the radiography mode. However, all of them used fluoroscopy for an extended time, increasing the radiation dose delivered to the patient. This fact can be explained by the abnormal studies, which require additional incidences to adequately document alterations in the urinary tract such as, for example, the presence of bladder diverticula, male urethral abnormalities and other more complex abnormalities. Considering that the fluoroscopy time ranged from 82 to 1,240 seconds (mean, 516 seconds), the authors can suggest a radical reduction of this time. The utilization of high-kilovoltage and low-milliampere techniques, as well as fluoroscopy only for positioning the patient and observing the most remarkable alterations, will certainly result in an important dose reduction. The observation of total ESD ranging from 17 to 321.2 mGy (the fraction relative to fluoroscopy ranged from 11.2 to 298.3 mGy), of total DAP ranging from 154 to 1,865 cGy.cm$^2$ (with fluoroscopy accounting for 141.4 to 1,720.3 cGy.cm$^2$) and the number of exposures ranging from 6 to 18, suggests that changes in the habits of the radiologists/examiners will result in dose reduction.

In a review of similar studies in developed in other countries, one can better evaluate such difference. Livingstone et al.[12] have evaluated cystourethrography studies of an adult Indian population, with a thickness of up to 25 cm, and have observed that the mean fluoroscopy time was 2.7 minutes, ranging up to 6.5. The average number of radiographs/exposures was 8.6, mean total DAP was 376 cGy.cm$^2$ (ranging from 43 to 926 cGy.cm$^2$) and ESD, between 1.32 and 32.5 mGy, with an average of 11 mGy.

Persliden et al.[13] have evaluated cystourethrography studies in two pediatric hospitals in Sweden, and have found DAP values between 8 and 246 cGy.cm$^2$ in a hospital with conventional equipment, and between 4 and 254 cGy.cm$^2$ in a hospital with a digital equipment. In this latter hospital, the fluoroscopy time ranged from 0.1 to 1.6 minute, and in the other one, equipped with a conventional system, between 0.4 and 5.1 minutes. In the present study, in one study, the fluoroscopy time reached more than 20 minutes, perhaps justified by the problems of the patient affected by spine deformity, with severe scoliosis causing extreme difficulty in the manipulation of the region for images acquisition.

On the other hand, Ruiz et al.[14] and González et al.[15], in Spain, have found high dose values, up to 300% above those reported by other authors, and have suggested measures for dose reduction, observing that voiding cystourethrography correspond to 2.4% of studies performed in the pediatric population.

Osibote & Azevedo[16] and Azevedo et al.[17] had already observed the lack of standardization of radiographic techniques in Brazilian general and pediatric hospitals, certainly a contributing factor for dose variations in found in the present study. Azevedo et al.[17] have demonstrated that, although the doses calculated for chest radiography in the same institution are even lower than those reported in reference articles, they could be still lower, if an appropriate collimation were utilized, and if studies requisitions were more strict. Kyriou et al.[18] have compared the dose and the radiographic technique adopted by pediatric and general hospitals, observing increased doses in procedures performed by non-specialists.

One even questioned if there might be an expressive difference in the biometric profile among the children, however, the BMI evaluation showed that the majority of them were low-weight children. Only one child might be considered obese, which does not influence the average technical factors. However, considering what occurred in the fluoroscopy study, where similar equipment presented very different doses, leading to the finding of a serious problem in one of them which led to its deactivation, one may question if some technical non-conformity might be happening, and thus justify the high doses observed in the present study.

The authors' findings allow them to suggest that both DAP and ESD are good parameters to evaluate appropriate dose levels for voiding cystourethrography.

Higher patients or those in the higher age ranges require larger films to document the images, which in certain instances should include the whole collecting system from the bladder to the kidneys. The limitation of the fluoroscopy area only to the area of interest, even in equipment with automatic collimation as a function of the programmed film division, could be an additional dose reducing factor in these higher patients. It was found that the equipment makes divisions only "in the vertical sense", meaning that one 30 x 40 film will always have images with 30 or 40 cm in height, if the manual collimation is not made, which increases the exposed area. At the first years of life, the patients tend to be more active during the examination and, consequently, end up staying longer under fluoroscopy, which also contributes to the higher final dose. In one of the patients included in this age group, fluoroscopy accounted for 97.85% of total DAP.

If the fluoroscopy DAP value is divided by the time, the exposure level/time unit can be evaluated, which, one initially thought, should demonstrate similar values. However the values found were discrepant, ranging from 0.42 to 4.14 cGy.cm$^2$/s, suggesting that fluoroscopy with automatic exposure control may not be the best method to perform this phase of the study. Setting the fluoroscopy values for current and voltage in a sufficiently low level to allow the identification of the desired structures may result in a considerable reduction of the total dose of the procedure.

Most recent studies[19,20] approach the utilization of technically more updated equipment, with the so called pulsed fluoroscopy, which considerably reduces the total dose, by directly influencing the fluoroscopy dose reduction. Ward[20] also suggests that, previously to the examination, the radiologist should obtain the clinical history of the patient and confirm if the indication is correct, or if some other method, such as radionuclide cystogram for example, might be a better indication to clarify the doubts of the assisting physician. Persliden et al.[13] have observed that in the hospital with conventional imaging equipment, where the child undergoes ultrasonography before being submitted to voiding cystourethrography and the latter is indicated only when the first study is abnormal, the final dose and the number of radiographs are higher.

## CONCLUSIONS AND SUGGESTIONS

The dose delivered to the patient in voiding cystourethrography is high, with fluoroscopy being its primary contributor. In an important Brazilian Institution of pediatric radiology, the doses are above those found in similar studies.

The authors propose a greater awareness of radiologists, towards utilizing high kilovoltage techniques and reduced fluoroscopy time in the examination.

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