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Monte Carlo based estimation of organ and effective doses to patients undergoing hysterosalpingography and retrograde urethrography fluoroscopy procedures

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ABSTRACT

Contrast investigations of hysterosalpingography (HSG) and retrograde urethrography (RUG) fluoroscopy procedures remain the dominant diagnostic tools for the investigation of infertility in females and urethral strictures in males, respectively, owing to the scarcity and high cost of services of alternative diagnostic technologies. In light of the radiological risks associated with contrast based investigations of the genitourinary tract systems, there is a need to assess the magnitude of radiation burden imparted to patients undergoing HSG and RUG fluoroscopy procedures in Tanzania. The air kerma area product (KAP), fluoroscopy time, number of images, organ dose and effective dose to patients undergoing HSG and RUG procedures were obtained from four hospitals. The KAP was measured using a flat transmission ionization chamber, while the organ and effective doses were estimated using the knowledge of the patient characteristics, patient related exposure parameters, geometry of examination, KAP and Monte Carlo calculations (PCXMC). The median values of KAP for the HSG and RUG were 2.2 Gy cm^2 and 3.3 Gy cm^2, respectively. The median organ doses in the present study for the ovaries, urinary bladder and uterus for the HSG procedures, were 1.0 mGy, 4.0 mGy and 1.6 mGy, respectively, while for urinary bladder and testes of the RUG were 3.4 mGy and 5.9 mGy, respectively. The median values of effective doses for the HSG and RUG procedures were 0.65 mSv and 0.59 mSv, respectively. The median values of effective dose per hospital for the HSG and RUG procedures had a range of 1.6–2.8 mSv and 1.9–5.6 mSv, respectively, while the overall differences between individual effective doses across the four hospitals varied by factors of up to 22.0 and 46.7, respectively for the HSG and RUG procedures. The proposed diagnostic reference levels (DRLs) for the HSG and RUG were for KAP 2.8 Gy cm^2 and 3.9 Gy cm^2, for fluoroscopy time 0.8 min and 0.9 min, and for number of images 5 and 4, respectively. The suggested DRLs for the HSG and RUG procedures may be used by the radiology departments in Tanzania for management of attained dose levels until the national DRLs are established.

1. Introduction

Contrast investigations of hysterosalpingography (HSG) and retrograde urethrography (RUG) procedures studied under fluoroscopy imaging have been important and most frequently radiological procedures for evaluation of the genitourinary tract diseases and abnormalities (Merkle et al., 1996; Efstathopoulos et al., 2013; Maciejewski and Rourke, 2015). In spite of promising clinical results, the conventional HSG and RUG procedures continued to suffer from unavoidable radiation exposure to patients as a result of the use of a combination of fluoroscopy and a large series of radiographic images of different projections (Calicchias et al., 1998; Kramer et al., 2006). In an effort to minimize patient dose associated with these procedures or/and improve image quality, alternative diagnostic technologies (including magnetic resonance imaging, hysteroscopy, and laparoscopy) have continued to replace a sizeable fraction of conventional fluoroscopy procedures of the genitourinary tract system (Merkle et al., 1996; Maciejewski and Rourke, 2015; Yoder and Papanicolaou, 1992; Philips et al., 2010). However, due to high capital and service cost associated with some of alternative diagnostic technologies, the conventional HSG and RUG fluoroscopic procedures are still the standard radiological procedures in many countries for the investigations of infertility in young women and urethral strictures in males, respectively (Efstathopoulos et al., 2013; Maciejewski and Rourke, 2015; Perisinakis

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Table 1
Details of the patient demographic data and patient-exposure related parameters collected for each patient enrolled in this study.

Patient demographic data	Patient related exposure parameters for each radiological projection		
	Radiographic exposure parameters	Fluoroscopy exposure parameters	Geometric factors
Gender (Female/Male)	Applied potential (kV)	Applied potential (kV)	Image field size (cm^2)
Patient age (years)	Exposure setting (mA s)	Tube current (mA)	Patient exit to image distance (cm)
Patient thickness (cm)	Exposure time (s)	Fluoroscopy time (min)	Tube focus-to-skin distance (cm)
Patient weight (kg) and height (cm)	Kerma area product (Gy cm^2)	Kerma area product (Gy cm^2)	Tube focus to table top distance (cm)

et al., 2003). In many developing countries like Tanzania alternative technologies being scarce and high diagnostic service cost, the conventional HSG and RUG procedures are still the dominant diagnostic tools for investigations of these diseases and disorders.

As a result of the relative high dose to patients associated with the HSG and RUG procedures, there have been great concerns of the possible undesired health effects such as stochastic cancer risk and genetic hereditary disorders following direct irradiation of pelvic region, in which some of the most radiosensitive organs including ovaries, uterus and testes are in the primary beam (Merkle et al., 1996; Efstathopoulos et al., 2013; Maciejewski and Rourke, 2015; Philips et al., 2010; Perisinakis et al., 2003). Of particular concern due to long life expectancy are the young male patients undergoing RUG and the young female patients undergoing HSG procedures, which in addition to radiation induced cancer they are susceptible to inherent risk of genetic hereditary disorders in males due to changes in the sperm and in females due to changes in oocyte; and descendants (Merkle et al., 1996; Efstathopoulos et al., 2013; Plecas et al., 2010; ICRP, 2007). Patient dose from the HSG and RUG procedures are also influenced by fluoroscopy personnel and institutional dependent factors such as the level of skills and experiences among fluoroscopy personnel, and the employment of different procedural protocols among technologists and institutions (Philips et al., 2010; Plecas et al., 2010; Sulieman et al., 2008; Tsapaki et al., 2009). These factors attribute significantly to the wide range of dose among patients observed within and across institutions and nations for the same type of fluoroscopy examination. The relative high dose to patients from these procedures are anticipated to be more pronounced in developing countries like Tanzania due to the general lack quality assurance programme, poor equipment maintenance, and inadequate skills on the use of existing dose reduction techniques (Tsapaki et al., 2009; Muhogora et al., 2008).

In view of these radiological concerns associated with the use of contrast based fluoroscopy procedures for the genitourinary track system with observation that radiation dose to patients is dependent on various factors that vary widely across fluoroscopy personnel, institutions and nations, there is a need to assess how these factors influence patient dose in Tanzania in general and its institutions in particular. Organ and effective dose are dosimetric quantities for estimation of radiation stochastic risk to patients (ICRP, 2007; Martin, 2008; UNSCEAR United Nations Scientific Committee on the Effects of Atomic Radiation, 2010). However, estimation of organ and effective dose to patients from complex fluoroscopic procedures has presented considerable difficulties and time consuming owing to the dynamic nature of the procedures and the wide diversity of examination procedures (Hart and Wall, 1994; Elbakri, 2014; Yakoumakis et al., 2015). A well-established method for estimation of organ and effective doses to patients is to use simple clinical measurements of air kerma area product (KAP) and Monte Carlo (MC) simulation techniques (Yakoumakis et al., 2015; Eckerman et al., 1996; Ruiz-Cruces et al., 2000). To our knowledge few studies have been conducted to assess the dose to the radiosensitive organs and effective doses to patients from HSG procedures; while for the RUG there are quite limited studies on patient dose compared with the importance and the frequency of the procedure. Thus, the aim of the present study were to (a) assess the magnitude of radiation burden imparted to individual patients during the HSG and RUG fluoroscopy procedures, (b) to evaluate the influence of existing patient related exposure parameters on radiation dose to patients from contrast based fluoroscopy procedures (c) propose local diagnostic reference levels (LDRLs) and (d) compare these doses to those reported in the literature.

2. Materials and methods

2.1. Description of data sources

The data used in the present study were collected between February 2014 and February 2015 from four consultant hospitals (i.e., H1, H2, H3, and H4), which experience larger percentage of patients undergoing HSG and RUG procedures in Tanzania. All four hospitals are equipped with 3 phase 12 pulse Philips fluoroscopic systems (Philips, Duo Diagnostic, Eindhoven, The Netherland) consisting of under coach image intensifier with three selectable input field diameters of 38, 31 and 23 cm. The focus-to-image distance was 110 cm and the equipment use a maximum tube voltage of 150 kV. The anode angle was 13°, whereas the total X-ray beams filtration including that by transmission ionization chamber amounts to 3.05 mm Al equivalent for the H2, H3, and H4 and 3.1 mm Al equivalent for the H1.

In order to investigate the influence of patient characteristics and patient related exposure parameters on patient dose, patient-exposure related parameters were collected using a patient dose survey form prepared for each patient participated in the present study. The patient–exposure related parameters extracted from the patient survey form are presented in Table 1. The selection of patient was random and included a minimum of ten adult patients per hospital for each selected fluoroscopy procedure. A total of 127 contrast based X-ray fluoroscopy procedures, for 127 patients were studied; of these 61 female patients followed HSG procedures and 66 male patients followed RUG procedures. The average age for patients who underwent HSG was 33 years with age range of 21–44 years, while for the RUG was 58 years with age range of 22–89 years. Moreover, details of the total fluoroscopy procedures (TFP) performed in 2014 were extracted from medical records of the four hospitals and then analysed.

For the contrast based fluoroscopy studies, the exposure parameters (i.e., kV and mA) for all units were selected automatically through the automatic brightness control mode. In case of conventional radiography, the exposure parameters (i.e., kV and mA s) were usually selected manually by technologists based on anatomical region of interest and patient size for all hospitals although at the H2 these exposure parameters were usually selected automatically. The preference for manual selection of radiographic exposure parameters was done in order to get clinical acceptable images. All hospitals under study did not have written standard protocols for the imaging procedure and hence, the technologists used their experiences and skills in the selection of exposure parameters.

To ensure proper function of the X-ray fluoroscopy units in compliance with the existing standards (IPEM Institute of Physics and Engineering in Medicine, 1997; IAEA International Atomic Energy Agency, 2007), dosimetric and image quality assessment were regularly performed during the study. The quality control tests such as kV reproducibility and accuracy, beam quality for each X-ray tube and the