Original article

Urethrographic examinations: Patient and staff exposures and associated radiobiological risks

M. Alkhorayef [a,*], A. Sulieman [b], H. Barakat [c], H.I. Al-Mohammed [d], K. Theodorou [e], C. Kappas [e], D. Bradley [f,g]

[a] Department of Radiological Sciences, College of Applied Medical Sciences, King Saud University, P.O. Box 10219, Riyadh 11433, Saudi Arabia
[b] Prince Sattam Bin Abdulaziz University, College of Applied Medical Sciences, Radiology and Medical Imaging Department, P.O. Box 422, Alkharj 11942, Saudi Arabia
[c] Medical Physics Department, Faculty of Science and Technology, Al-Neelain University, Khartoum, Sudan
[d] Department of Radiological Sciences, College of Health and Rehabilitation Sciences, Princess Nourah Bint Abdulrahman University, P.O. Box 84428, Riyadh 11671, Saudi Arabia
[e] Department of Medical Physics, Medical School, University of Thessaly, Larissa, Greece
[f] Centre for Nuclear and Radiation Physics, Department of Physics, University of Surrey, Guildford, Surrey GU2 7XH, UK
[g] Sunway University, Centre for Biomedical Physics, Jalan Universiti, 46150 PJ, Malaysia

ARTICLE INFO

ABSTRACT

Medical exposure of the general population due to radiological investigations is the foremost source of all artificial ionising radiation. Here, we focus on a particular diagnostic radiological procedure, as only limited data are published with regard to radiation measurements during urethrograpic imaging. Specifically, this work seeks to estimate patient and occupational effective doses during urethrographic procedures at three radiology hospitals. Both staff and patient X-ray exposure levels were calculated in terms of entrance surface air kerma (ESAK), obtained by means of lithium fluoride thermoluminescent dosimeters (TLD-100(LiF:Mg:Cu.P)) for 243 urethrographic examinations. Patient radiation effective doses per procedure were estimated using conversion factors obtained from the use of Public Health England computer software. In units of mGy, the median and range of ESAK per examination were found to be 10.8 (3.6–26.2), 7.0 (0.2–32.3), and 24.3 (9.0–32.0) in Hospitals A, B, and C, respectively. The overall mean and range of staff doses (in μGy) were found to be 310 (4.0–1750) per procedure. With the exception of hospital C, the present evaluations of radiation dose have been found to be similar to those of previously published research. The wide range of patient and staff doses illustrate the need for radiation dose optimisation.

© 2020 Published by Elsevier B.V. on behalf of King Saud University. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

1. Introduction

Radiation doses from diagnostic and interventional procedures are one of the main sources of exposure from all anthropomorphic sources (NCRP 160, 2009). In recent years, the frequency of interventional radiology procedures has increased dramatically, reflecting the significant benefits that the various techniques offer compared to surgery or other invasive interventions (ICRP, 2010). The ascending urethrogram (ASU) procedure is carried out for the assessment of male urogenital system disorders (Martinez-Pineiro et al., 2010), with the duration of this dynamic study depending on the nature of the particular pathology (Dabela-Biketi et al., 2020). During ASU studies, radiographic and fluoroscopic images are acquired, with repetition arising from situations such as less co-operative patients, inopportune choice of urinary catheter for cannula insertion, and inadequate patient set-up. For patients, the ASU procedure can give rise to significant direct radiation exposure to the testicles, with the gonads being a particularly radiosensitive organ. Due to the increased use of ASU procedures, protecting personnel and patients from the added risk resulting from avoidable exposure is vital. Therefore, there is a need to adopt dose management techniques without compromising image quality and with a clinical purpose.

At the outset, it needs to be strongly stated that this radiographic procedure brings about undoubted benefits in the diagnosis of the urogenital diseases. Although estimates of effective radiation dose per procedure for both patients and practitioners is endorsed, there are still few published studies on ASU proce-

* Corresponding author.
  E-mail address: malkhorayef@ksu.edu.sa (M. Alkhorayef).
Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

dures (Ngaile et al., 2018; Sulieman et al., 2015; Sandilos et al., 2006; Livingstone et al., 2004; Perisinakis et al., 2002). A varied assortment of effective doses has been quantified, ranging from 0.64 mSv to 1.8 mSv per ascending urethrography procedure (Sulieman et al., 2015; Wambani et al., 2014). With observations of patient dose values of up to two-fold or greater in previous studies, there is evidence of a need to monitor ASU procedure patient doses; it should also be acknowledged that imaging technology has improved substantially over the past several years. Livingstone et al. (2004) reported an average entrance surface air kerma (ESAK) during ASU procedures of up to 11.4 mGy, with a wide range from 1.32 to 31.3 mGy. Furthermore, while the diagnostic reference level (DRL) is seen to be a useful optimisation tool in medical imaging, its use has yet to be globally adopted. Staff and patients nevertheless need to be protected against unproductive radiation doses when seeking to mitigate against unnecessary exposure to X-rays and their projected risks. Notably, the magnitude of risk from radiation is a dose-related effect (ICRP, 2007). The International Commission on Radiological Protection (ICRP, 2010) has reported that, outside of imaging units, there is a lack of safety measures and radioprotection practice for medical staff (urologists, gastroenterologist, etc.) using fluorographic imaging guidance, leading to a potentially increased risk of radiation-induced effects for both staff and patients. The present research, conducted in three hospitals, has sought to investigate the effective radiation doses for urologists and patients during the ASU procedures, comparing values against international standards.

2. Materials and methods

2.1. ASU procedure

The procedure is performed for various clinical indications, including fistulae, urethra stricture, trauma prostatic or peri-urethral abscess. To ensure patient collaboration, the urologist explains the procedure to the patient before the start. The patient is then placed in a supine position, the assistance of an anaesthetic gel allowing the 8Fr Foley catheter to be gently advanced into the urethra to the bladder and secured in place by a small inflated balloon. Then, 30 ml of iodinated contrast medium is injected into the urethra to evaluate the pathological condition and cause of reduced flow of urine. A series of radiographic and fluoroscopic images are taken with the patient in an oblique position to evaluate and document the pathology. The team of urologists, nurses, and technologists usually carry out the procedure. During image acquisition, the urologist stands beside the patient to carry out the procedure, and is thus exposed to scattered X-rays from the patient.

2.2. Radiation measurement

The ESAK was measured using cylindrical thermoluminescence dosimeters (TLD), type GR200A (4.5 × 0.8 mm², comprising of doped lithium flouride (LiF) with Mg, Cu, and P) manufactured by FIMEL (Fontenay-aux-Roses, Paris, France). For the range of tube potential values used, in vivo measurement calibration was carried out to ensure the accuracy and reproducibility of the radiation dose measurements, with careful determinations made of the detector response to the radiation and to quantify their element correction factors (Sulieman et al., 2007; Martin et al., 1998). The exposed TLDs were post-annealed and then reported using an automatic PCL3 Reader (Automatic type), also from FIMEL. The dosimeter readout cycle is comprised of a 55 °C preheat temperature phase, with subsequent dosimetric peak signal acquisition over the temperature range 55 °C to 260 °C at a heating rate of 11 °C/s. Post-

readout and pre-irradiation annealing was carried out using an automatic controlled annealing oven (TLDO) manufactured by Physikalisch-Technische Werkstätten (PTW) (Freiburg GmbH, Germany) at a temperature of 240 °C for a time of 10 min. Fifty six TLDs were selected out of a total of 70, according to sensitivity. The selected detectors were then placed in 14 transparent plastic envelopes, and marked to prevent mix-up when used to obtain measurements at three numbered positions. The plastic envelopes containing the dosimeters were attached at the beam centre on the patient's skin. The TLD signal (measured in nC) was converted into absorbed dose D (in mGy) by the establishment of a signal to dose coefficient from a standard known dose, as illustrated in equation (1):

$$D(mGy) = \text{TLD signal (nC)} \times \frac{Dose(standard\ (mGy))}{\text{TLD signal (standard) (nC)}} \quad (1)$$

Computer software from a sector of Public Health England (PHE) that was previously known as the National Radiological Protection Board (NRPB) was used to assess the effective dose (Hart et al., 1994). The effective dose (E) is quoted in the SI unit Sieverts (Sv), a radiation protection quantity that allows for the estimation of radiogenic risk resulting from the radiation exposure, with partial. or uniform. exposure based on tissue weigting factor (w_T) multiplied by the radiation dose equivalent (H_T).

Effective dose (mSv) is calculated by the subsequent expression (ICRP, 2007).

$$E = \sum_T w_T \cdot H_T \quad (2)$$

2.3. X-ray Machine

The current work was conducted at three hospitals, A, B, and C. The ASU examination was carried out using radiographic X-ray units as detailed in Table 1. All of the units are of the form of an under-couch image intensifier and an over-couch X-ray tube. The machines were all ones which satisfied quality control (QC) tests, assuring adherence to national criteria, as defined by the regulatory authority.

2.4. The measurement of ESAK

Two hundred and forty three individual ASU examinations were carried out at three hospitals: A, B, and C. The examinations were performed according to ethical guidelines and the institutional review board (IRB) provided permission to conduct the examinations. During the procedures, it was ensured that the TLDs were maintained in the required locations at the centre of the X- ray beam, firmly positioned using medical adhesive tape. The urologists executed the examination according to departmental protocol. Patient and urologist demographic data were obtained, including Body Mass Index, (BMI, in kg.m⁻²) and age (in y). Image acquisition parameters (tube potential (kVp), time (s), and tube current (mA), in addition to exposure geometry data, were also collected.

2.5. Staff dose measurement

The procedures in each case were carried out by one of the three urologists, with radiation dose being monitored at the chest level outside of a frontal protective 0.5 mm thick lead equivalent apron (Rheix-srl, Milan, Italy). Protective eyeglasses and thyroid collars were not used by the urologists in any of the ASU procedures.

Table 1
X ray machines.

Hospital	Manufacturer	Year installed	Filtration (mm Al)	Focal spot (coarse and fine) (mm)
A	Toshiba	2011	2.5	1.2/0.6
B	Siemens	2004	3.5	1.0/0.6
C	Shimandzu	2008	2.5	1.2/0.6

3. Results

With regard to the two hundred and forty three examinations that were carried out, the average patient population age was 45.7 y, ranging from 15 to 86 years (see Table 2), while the average BMI (in kg.m^{-2}) was 22.2, ranging from 13.7 to 36.4. Table 3 details the image acquisition factors for the three department procedures. The number of films and fluoroscpoic time was observed to be greatest at hospital C, translating to a more significant radiation dose compared to the other two groups. Table 4 displays the calculated patient ESAK (in mGy) and effective dose (in mSv) per department, together with the overall averages. The ESAK (mGy) and effective dose (mSv) show widespread variation, the parameters of choice having central tendency. In addition to ESAK and efficacious doses, cancer risk resulting from radiation exposure is also shown in Table 5 for all procedures. The mean patient ESAK per procedure for all patient groups was found to be 12.3 ± 1.0 mGy. The wide variation in patient doses seen at each hospital is attributable to variation in patient BMI as well as the complexity of the lesion, image acquisition factors such as tube potential (kVp), time (s), and tube current (mA), and fluoroscopy mode (continuous or pulsed). The observation that patients in hospital C were exposed to more significant radiation doses, in the order of a factor of two or more compared to the other two hospitals attributed to the higher image acquisition factors, duration of fluoroscopic exposure time, and the number of films acquired, as illustrated in Table 3. The overall Urologist radiation dose per ASU examination are revealed in Table 7. The average dose and range per procedure (in μGy) were 310 (4–1750). Urologists at hospital C received up to 10 times greater doses compared to the other two hospitals.

4. Discussion

Patient ESAK during urethrography examinations is mainly affected by the image acquistion settings, radiation beam geometry (source to surface distance (SSD), X ray beam filtration, radiation beam restriction (collimation), clinical indication (pathology), and the weight distribution of the patient. Comparable values between the three hospitals were noticed in respect of patient characteristics (BMI) and fluoroscopic time (s). Providing the greater portion of patient dose, optimisation of screening time and reduction of the number of films will contribute significantly to patient and staff dose reduction (Sulieman et al., 2008). In addition, the use of proper fluoroscopic imaging unit settings by adoption of a normal fluoroscopic mode (ranging from 0.39 to 0.65 nC/kg) also reduces the radiation dose (Mahesh, 2001). As expected in interventional radiology procedures, no strong relationship was detected between image acquisition parameters, patient ESAK

Table 2
Patient body characteristics.

Hospital	No of patients	Age (year)	BMI (kg/m^2)
A	210	44.5(15–82)	22.4(13.7–36.4)
B	18	46.3(21–75)	21.7(16.1–27.6)
C	15	63.9(32–86)	19.8(16.6–24.9)
All	243	45.7(15–86)	22.2(13.7–36.4)

(mGy) and BMI (kg.m^{-2}). Patient doses depend on clinical indications and operator skills (ICRP, 2010). Although the mean dose values showed wide variation, the maximum doses for all groups are largely comparable. The maximum dose for all procedures is 32.3 mGy, with minimal radiation-induced effect expected even with multiple procedures (ICRP, 2007). It is important to underline that patient morphology factors (height, weight, and BMI) are among the various major contributory influences that need to be considered in understanding dose variations and elevated radiation doses, beam attenuation being related to BMI. The median and range of patient ESAK doses (in mGy) per examination were found to be 10.8 (3.6–26.2), 7.0 (0.2–32.3), and 24.3 (9.0–32.0) for hospitals A, B, and C, in that order. The average patient dose at department C has been seen to approach twice that observed at hospitals A and B, a further observation being that at all hospital patient doses showed wide variation. The Whisker chart of Fig. 1 illustrates the discrepancy seen in entrance surface air kerma (ESAK, mGy) per procedure during urethrographic procedures. The error bars plot display the quartiles values of ESAK. Extended fluoroscopic exposure durations and the excessive acquisition of radiographic images are the main causes of elevated patient doses, reflected in the order of two values seen in Table 4.

Care should be taken since cancer and genetic effects have no initiation threshold; the risk increases with the level of exposure, repeated exposures and the young age of the patient. Therefore, the results also suggest that there is a need to adopt a standard protocol for the urethrography examination for all hospitals, seeking to harmonise the practice towards establishing a diagnostic reference level (DRL). Medical irradiations exposes the patient to heterogeneous doses to the irradiated organs, which translates to an increase in the probability of radiogenic cancer risk and to tissue reactions at higher doses above 2.0 Gys (ICRP, 2007). The average and range of the patient effective doses at the three hospitals was estimated to be 1.4 (0.02–3.8) mSv. Sandilos et al. (2006) and Sulieman et al. (2015) have reported an average patient effective dose (in mSv) of 1.63 and 0.64 per ASU procedure, respectively. The results all compare well with international practice. Since there is a lack of previous studies regarding patient and staff dosimetry during ASU, further research is recommended to evaluate patient radiation risk during the entire procedure. The mean and range of doses to the testicles are 8.16 (0.01–21.4) mGy per procedure, which is far below the threshold of temporary infertility (ICRP, 2007). Special attention is required for children and young adults, as children are more radiosensitive than adults because of high cell multiplication; also, the longer life expectancy potentially leads to radiation late effects (cancer) manifesting, with a risk of lethal cancer/dose unit two to four times greater than for adults (ICRP, 2007). The average fluorographic films per ASU procedure were found to be 4.8 (2–8), 3.4 (3–5), and 7.3 (6–9), at hospitals A, B, and C, respectively. A greater number of films was reported by Livingstone et al. (2004), with mean, standard deviation and range values of 11.4 ± 0.8 (1.3–31.3) for the micturating cystourethrography (MCU) procedure. Table 6 shows patient effective doses during certain fluoroscopic examinations including MCU, Extracorporeal Shock Wave Lithotripsy (ESWL), hysterosalpingography (HSG), Endoscopic Retrograde Cholangiopancreatography (ERCP) and ASU procedures (Sulieman et al., 2020, 2015;

Table 3
Average exposure factors and other parameters in use of each of the x-ray machines.

Hospital	Tube voltage [kVp]	Tube current–time product [mAs]	Source-skin distance [SSD]	No of films	Fluorsocopic time [min]
A	91.2 (80–99)	15.6 (10–32)	91.1 (78–100)	4.8 (2–8)	1.1 (0.1–2.7)
B	73.8 (69–77.3)	34.7 (26–45)	95 (80–100)	3.4 (3–5)	1.4 (0.4–2.5)
C	76.6 (67.9–80)	51.2 (36.9–69)	87.6 (80–95)	7.3 (6–9)	1.8 (1.0–2.7)
All	89 (67.9–99)	19.3 (10–69)	91.9 (78–100)	4.8 (2–9)	1.1 (0.1–2.7)

Table 4
Mean, median, 3rd quartile and range of patients ESAK (mGy) and effective dose (mSv) per procedure.

Hospital	Mean ± Sd	Minimum	1st quartile	Median	3rd quartile	Maximum	Effective dose (mSv)
A	10.1 ± 1.5	3.6	6.1	10.8	18.4	26.2	1.2 ± 0.2 (0.4–3.0)
B	7.8 ± 1.0	0.2	3.6	7.0	23.9	32.3	0.9 ± 0.1 (0.02–3.8)
C	19.1 ± 0.6	9.0	14.5	24.3	28.1	32.0	2.2 ± 0.1 (1.0–3.7)
All	12.3 ± 1.0	0.2	7.4	14.0	23.5	32.3	1.4 ± 0.1 (0.02–3.8)

Table 5
Mean entrance surface dose (in mGy) and effective dose (in mSv), and cancer probability, hospital by hospital.

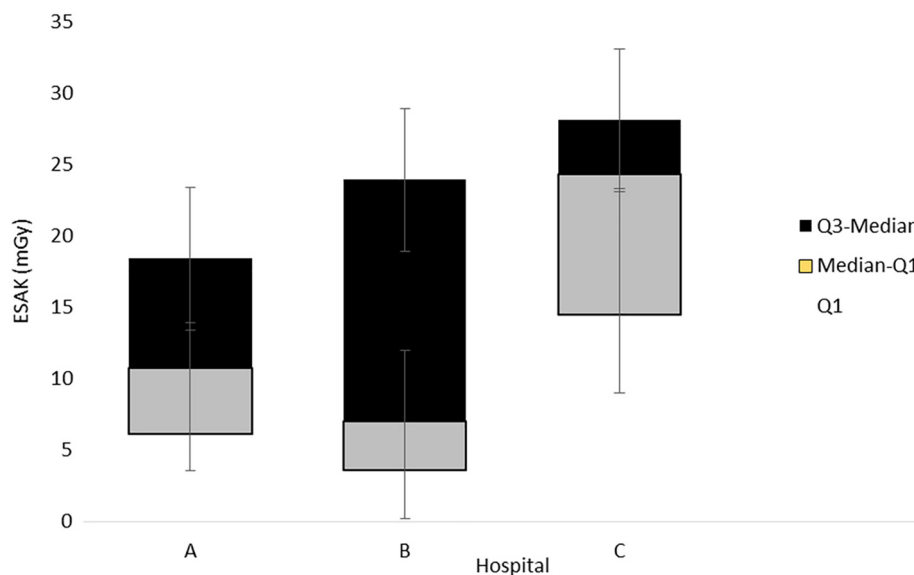| Hospital	A	B	C	All
Mean ± Std dev (mGy)	10.1 ± 1.5	7.8 ± 1.0	19.1 ± 0.6	12.3 ± 1.0
Effective dose (mSv)	1.2	0.9	2.2	1.4
cancer probability × 10^{-6}	1.5	1.2	2.9	1.9

Std dev: standard deviation.

Fig. 1. The Whisker plot illustrates the discrepancy in entrance surface air kerma (ESAK, mGy) per procedure during urethrographic procedure. The error bars plot display the minimum, quartiles, and maximum values of ESAK.

Wambani et al., 2014; Yousef et al., 2014; Sandilos et al., 2006). For all of the procedures listed in Table 6, the patients incurred an average dose ≤ 6.3 mSv, which is considered to be below the onset of deterministic effects and offering insignificant cancer risk.

The variation between patient doses arises from differences in X-ray machine technology, settings, type of procedure and operator skills in exposure parameter adjustment. The mean and range

of dose value for the staff at the chest level over the apron were found to be 310 (4–1750) μGy per procedure (Table 7). Based on the present annual workload at the hospitals of interest, the mean annual dose for medical physicists, technologists and nurses were found to be 604, 680 and 1000 μSv, respectively. Even though the staff doses are below the annual dose limits for radiation workers (20 mSv/year) (ICRP, 1991), dose values could be significant in high

Table 6
Comparison of patients effective doses (mSv) for adult fluoroscopic procedures.

Procedure	Effective dose (mSv)	Reference
Micturating cystourethrography (MCU)	1.8	Wambani et al., 2014
Extracorporeal Shock Wave Lithotripsy (ESWL)	1.63	Sandilos et al., 2006
Hysterosalpingography (HSG)	1.94	Yousef et al., 2014
Endoscopic Retrograde Cholangiopancreatography (ERCP)	6.3	Sulieman et al., 2020
Ascending urethrography (ASU)	0.64	Sulieman et al., 2015
ASU	1.4	Current study

Table 7
Radiation exposure to the clinicians (in μGy) in ascending urethrography examinations.

Hospital	Mean Dose (μGy)
A	80 (4–390)
B	60 (18–90)
C	790 50–1750
All	310 (4–1750)

workload circumstances. In comparison with previous studies, staff dose at chest level is higher compared to the hysterosalpingography average dose of 175 μGy per procedure reported by Sulieman et al. (2008). The ICRP have stated that there is insufficient training on radiation protection aspects for medical doctors (non-radiologists) performing medical interventions. Thus, there are concerns about the radiation dose and its related risk to patients (skin erythema) and staff (eye lens opacities). Thus said, all reported effects, including cancer and tissue reactions, have been to patients and cardiologists during cardiac and complicated interventional procedure (ICRP, 2010). The occupational dose per urologist requires special concern since they tend to lean toward the patients during conduct of the procedures. In present studies it has been noted that none of the staff used leaded glass eye protection or thyroid shields. It is important to emphasize that the application of the principle of optimization (of image quality with radiation doses) and the basics of radiation protection (shielding, distance, and time) will provide additional reduction in occupational and patient radiation doses without affecting the clinical outcome.

5. Conclusions

ESAK and effective doses were assessed for ASU examination. Patient doses showed wide variation even, within the same department. The results also suggest that there is a need to adopt a standard protocol for urethrography procedures in each hospital as a preliminary step towards establishing DRL for the urethrographic examination. While the staff doses were found to be below the annual dose limits, careful monitoring and protection measures are recommended to eliminate unnecessary radiation exposure. Since there is a lack of previous studies regarding patients and staff dosimetry during ASU, further research is recommended to evaluate patient radiation risks during the entire procedure.

Declaration of Competing Interest

All authors declare that there is no conflict of Interest.

Acknowledgement

References

Dabela-Biketi, A., Mawad, K., et al., 2020. Urethrographic evaluation of anatomic findings and complications after perineal masculinization and phalloplasty in transgender patients. Radiographics. 40 (2), 393–402.

Hart, D., Jones, D.G., Wall, B.F., 1994. National Radiological Protection Board. Estimation of Effective Dose in Diagnostic Radiology from Entrance Surface Dose and Dose-Area Product Measurements. NRPB Report 262, Chilton, Oxon, U. K.

ICRP 1991. International commission on radiological protection, 1990 recommendations of the international commission on radiological protection. New York: Elsevier; Ann. ICRP 21(1––), 1–146.

ICRP, 2007. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann. ICRP 37 (2-4), 1–399.

ICRP, 2010. International Commission of Radiological Protection. 2010. Radiological Protection in Fluoroscopically Guided Procedures Performed Outside the Imaging Department. ICRP publication 117, Annals of ICRP 40(6), 1–133.

Livingstone, R.S., Koshy, C.G., Raj, D.V., 2004. Evaluation of work practices and radiation dose during adult micturating cystourethrography examinations performed using a digital imaging system. British J. Radiol. 77, 927–930.

Mahesh, M., 2001. Fluoroscopy: Patient Radiation Exposure Issues. RadioGraphics. 21 (4), 1033–1045.

Martin, C.J., Sutton, D.G., Workman, A., Shaw, A.J., Tempeton, D., 1998. Protocol for measurement of patient entrance surface dose rates for fluoroscopic X-ray equipment. Br. J. Radiol 71, 1283–1287.

Martinez-Pineiro, L., Djakovic N., Plas, E., et al., 2010. EAU guidelines on urethral trauma. Eur. Urol. 57, 791–803.

NCRP Report 160, 2009. National Council on Radiation Protection and Measurements. Ionizing Radiation Exposure of the Population of the United States.(2009). NCRP Report 160. National Council on Radiation Protection and Measurements, Bethesda, MD.

Ngaile, J.E., Msaki, P.K., Kazema, R.R., 2018. Monte Carlo based estimation of organ and effective doses to patients undergoing hysterosalpingography and retrograde urethrography fluoroscopy procedures. Radiat. Phys. Chem. 145, 148–159.

Perisinakis, K., Damilakis, J., Anezinis, P., Tzagaraki, I., Varveris, H., Cranidis, A., Gourtsoyiannis, N., 2002. Assessment of patient effective radiation dose and associated radiogenic risk from extracorporeal shock-wave lithotripsy. Health. Phys. 83 (6), 847–853.

Sandilos, P., Tsalafoutas, I., et al., 2006. Radiation doses to patients from extracorporeal shock wave lithotripsy. Health Phys. 90 (6), 583–587.

Sulieman, A., Barakat, H., Zailae, A., Abuderman, A., Theodorou, K., 2015. Measurement of patient radiation doses in certain urography procedures. Radiat. Prot. Dosim. 165 (1–4), 397–401.

Sulieman, A., Theodorou, K., Vlychou, Topaltzikis, T., Kanavou, D., Fezoulidis, I., Kappas, C., 2007. Radiation dose measurement and risk estimation for paediatric patients undergoing micturating cystourethrography. Br J Radiol 80, 731–737.

Sulieman, A., Theodorou, K., Vlychou, M., Topaltzikis, T., Roundas, C., Fezoulidis, I., Kappas, C., 2008. Radiation dose optimisation and risk estimation to patients and staff during hysterosalpingography. Radiat. Prot. Dosim. 128 (2), 217–226.

Sulieman, A., Tamam, N., Khandaker, M., Bradley, D., Padovani, R., 2020. Radiation exposure management techniques during endoscopic retrograde cholangio-pancreatography procedures. Radiat. Phys Chem. 108991, 1–9.

Wambani, J., Korir, G., Tries, M., Korir, I., Sakwa, J., 2014. Patient radiation exposure during general fluoroscopy examinations. J. Appl. Clin. Med. Phys. 15 (2), 262–270.

Yousef, M., Tamboul, J., Sulieman, A., 2014. Radiation dose measurements during hysterosalpingography. Sudan Med. Monitor. 9 (1), 15–18.