Radiation Protection Dosimetry (2019), Vol. 187, No. 4, pp. 426–437
Advance Access publication 12 October 2019
doi:10.1093/rpd/ncz184

OCCUPATIONAL DOSE AND RADIATION PROTECTION PRACTICE IN UAE: A RETROSPECTIVE CROSS-SECTIONAL COHORT STUDY (2002–2016)

Wiam Elshami[1,†,*], Mohamed Abuzaid[1,†], Albert D. Piersson[2], Ola Mira[3], Mohamed AbdelHamid[3], Xiaoming Zheng[4] and MG. Kawooya[5]
[1]Assistant professor at Medical Diagnostic Imaging Department, University of Sharjah, 27272, Sharjah, United Arab Emirates
[2]Faculty, Department of Imaging Technology & Sonography, University of Cape Coast, Cape Coast, Ghana
[3]Ministry of Health and Prevention, Dubai 1853, United Arab Emirates
[4]Charles Sturt University, School of Dentistry and Health, Australia Sciences, Wagga Wagga NSW 2678, Australia
[5]Ernest cook Ultrasound Research and Education Institute (ECUREI) 7161, Kampala, Uganda

*Corresponding author: welshami@sharjah.ac.ae; wiamelshamihassan@gmail.com
†Wiam Elshami and Mohamed Abuzaid are co-first authors.

Received 16 February 2019; revised 4 July 2019; editorial decision 5 July 2019; accepted 5 July 2019

A two-phased retrospective cross-sectional study analysed the occupational dose and radiation protection practice among medical workers in two hospitals in the UAE. Phase 1 evaluated radiation protection practice using a questionnaire, whereas phase 2 assessed the occupational dose. Readings of 952 thermoluminescence dosimeters were analyzed. The result showed 52% of medical workers have a good level of radiation protection practice. Readings of 952 thermoluminescence dosimeters were analyzedAverage annual effective dose per worker ranged from 0.39 to 0.83 mSv. Cardiologists and nurses displayed a higher average of occupational radiation dose compared to other workers. There were no significant correlations between radiation protection practice and hospital, occupation or department. Finally, the occupational dose was within the international and national limits, but the reduction of radiation dose to cardiologist and nurses is essential. Moreover, training is essential to promote radiation safe practice among medical workers.

INTRODUCTION

Occupational radiation exposure refers to the dose of ionizing radiation received by workers due to operations within their workplace[1, 2]. Analysis of occupational radiation dose is vital to protect workers from unwanted effect of excessive radiation, estimate radiation risks and establish protective measures[3–8]. Chronological assessment of occupational radiation dose is essential to evaluate trends in occupational exposures and to compare the exposures among different countries. Results of occupational dose assessment can lead to changes in regulatory standards and modification in work practices[9].

Effective dose and equivalent dose are used to describe the radiation dose as recommended by the International Commission on Radiological Protection (ICRP)[10]. The equivalent dose Hp(10) is the absorbed dose received by tissue at a 10-mm depth from the skin surface and considered as whole-body dose. The Hp(0.07) is the dose received at a depth of 0.07 mm and considered as skin dose. The ICRP established the annual effective dose limits to the occupationally exposed workers, and this dose should not exceed 20 millisieverts (mSv) averaged over five consecutive years (100 mSv in 5-years), with a provision that the individual dose does not exceed 50 mSv in any single year[10]. The Federal Authority of Nuclear Regulation (FANR) in the United Arab Emirates (UAE) adopted the dose limits of occupational exposure for radiation workers as recommended by ICRP[11]. In addition to the national and international dose limits, FANR recommends a dose constraint of 3 mSv per year for diagnostic radiology[12].

The National Radiation Protection Center (NRPC) at the Ministry of Health and Prevention (MOHAP) provides dosimetry service for medical and non-medical facilities that employ the use of ionizing radiation in the UAE. All medical workers in the UAE who are potentially exposed to ionizing radiation are equipped with thermoluminescence dosimeters (TLD) and instructed to wear the dosemeter during working hours on the upper torso according to the recommendations by the Federal Authority for Nuclear Regulations in the UAE. The TLD consists of a card and a holder. The Card is made from lithium fluoride chips doped with Mg, Ti, encapsulated between two sheets of Teflon and mounted on an aluminum sheet. The holder covers each TL chip with its unique filter, providing different radiation absorption thickness to allow estimation of the Hp(0.07) and Hp(10). Hp(0.07) represent the shallow dose measured at the skin surface, and Hp(10) represent the deep dose for the whole body measured at one cm under the skin surface[13]. TLDs have been the basis of many studies in radiation dosimetry because they are easy to calibrate and give reliable dose measurements[14]. The use of TLDs in dose measurements has several advantages in monitoring radiation. They have radiation dose range of 0.05 mSv–10 Sv. They are small, allowing accurate positioning and have reasonable spatial detail in dose measurement. TLDs can be reused after suitable thermal treatment, making them cost-effective and viable in the long term. Their dose-response is linear over a wide range of doses, although it increases in the higher dose region, exhibiting supra-linear behavior before it saturates at even higher doses[15].

Multiple studies have evaluated the occupational radiation dose and estimated the annual effective doses of workers in radiology settings worldwide[1, 3, 5, 16–19]. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has several reports about occupational radiation dose[20, 21]. However, the UNSCEAR report in 2000 and 2008 included occupational effective dose for medical workers from different countries, and there were no occupational dose results from the UAE[9, 20, 21].

The first aim of the present study was to analyze the occupational radiation exposure for medical workers in two hospitals to estimate the level of radiation exposure and to determine the differences in the level of radiation dose between hospitals and workers. The second aim was to assess the practice of radiation protection measure and correlate the level of radiation protection with the occupational dose.

MATERIALS AND METHODS

Design

A two-phased retrospective cross-sectional study analysed the occupational exposure and radiation protection practice among medical workers in two hospitals (2002–2016). Phase 1 evaluated the radiation protection practice, whereas phase two assessed the occupational dose. The cross-sectional cohort design offers advantages over traditional designs, especially in studies in which there is a long interval between exposures and outcomes[22].

Participants

The sample included medical workers exposed to ionizing radiation during their routine work in two hospitals (A and B) in the period 2002–2016. Participants were radiological technologists, radiologists, nurses, cardiologists and physicians (including all clinicians who are attending fluoroscopy procedures such as orthopedic, surgeons and urologist). The exclusion criteria included part-time workers, interns and radiography students. Ethical approvals were obtained from the Research Ethics Committee at the institution and the Ministry of Health and Prevention.

The context of the study

The study was conducted in two hospitals in the UAE. Both hospitals performed radiology examination in the radiology department and surgical suites with an average of 50 000 and 21.000 radiology procedures for the hospitals (A) and (B), respectively. In addition, hospital (A) had a cardiac catheterization lab performing diagnostic and interventional procedures. However, hospital (B) had no angiography examinations or cardiac catheterization lab[23].

Phase 1: practice of radiation protection measures

A questionnaire was used to assess the practice of radiation protection measures. The questionnaire was derived from previous studies[24–27] and comprised of two sections. Section 1 included demographic information (age, experience, hospital name, occupation and department). Section 2 consisted of 10 questions used to explore the participants' practice of radiation protection during their clinical work. The practice was assessed using four points Likert scale (4: always; 3: sometimes; 2: rarely and 1: never). The total score for each participant should be 40 points.

Pilot study

A pilot study was carried out to determine clarity, validity and reliability of the questionnaire. Fifteen participants were selected randomly. The questionnaire was accompanied by a cover letter explaining the purpose of the study. Participants were given the opportunity to comment on the questionnaire. Based on the results and comments received from the respondents, minor paraphrasing and rearrangement of questions were carried out. Data assembled from the pilot study were not included in the current analysis.

Data collection

Participation in the study was voluntary and informed consent was obtained from all participants. All participants were informed of their right to withdraw from the study at any time without any consequences. Participants were assured of confidentiality, and there was no penalty for non-participation. The aim and objectives of the study, along with the chosen methodology, were explained to all participants.

Table 1. Number and percentages of workers based on age in the hospitals (A) and (B).

	Hospital (A)		Hospital (B)		Total	
Age in years	*N*	%	*N*	%	*N*	%
18–25	9	15%	5	11%	14	14%
26–35	20	34%	15	34%	35	34%
36–45	13	22%	12	27%	25	24%
46–65	17	29%	12	27%	29	28%
Total	59	100%	44	100%	103	100%

Table 2. Number and percentages of workers based on years of experience in the hospitals (A) and (B).

	Hospital (A)		Hospital (B)		Total	
Experience	*N*	%	*N*	%	*N*	%
1–5 Years	9	15%	10	23%	19	18%
6–10 Years	14	24%	14	32%	28	27%
11–15 Years	9	15%	6	14%	15	15%
>16 Years	27	46%	14	32%	41	40%
Total	59	100%	44	100%	103	100%

Phase 2: occupational dose measurement

Dosimetry

All medical workers in the hospitals (A) and (B) wore a TLD with a unique identification code. The Ministry of Health and Prevention provides the TLDs, and the NRPC provides the dosimetry service. All workers are instructed to wear the dosemeter during working hours on the upper torso, between the neck and waist, and inside the protective lead suit when performing fluoroscopy examination according to NRPC recommendations. TLD readout and calibration are carried out quarterly in the NRPC, and new dosimeters are issued to all workers before the dosimeters in use are sent to the NRPC.

The NRPC use Harshaw 6600 Plus Automated TLD Reader to obtain the readings of TLDs[28]. The system can take up to 200 dosimeters per cycle and saves significant time by its automatic calibration capabilities. The Harshaw TLD reader is connected to a personal computer operated through installed menu-driven WinREMS software. The system calculates the personal dose equivalent values Hp (0.07) and Hp (10)[28]. The calculated dose data is then transferred automatically to the dose management system where they are stored. Dose values can be tabulated on Microsoft Word and monitoring reports sent to the institutions and copies kept as a reference. Dose data for individuals and groups can be retrieved quickly, at any period, through the dose management system. The NRPC dosimetry service and measurement laboratory are both accredited to international standards, and a full program of quality control and quality assurance is in place.

Radiation dose collection

Radiation dose records for medical workers who are working in the hospitals (A) and (B) were retrieved from the NRPC dosimetry service for a period of 15 years (2002–2016). The dose record included the worker's identification number, department, occupation (radiographers, radiologists, nurses, cardiologists and physicians) and two occupational dose metrics: Hp(10) and Hp(0.07).

According to the 1993 report by the International Commission on Radiation Units (ICRU), the whole-body doses are reported in terms of the personal dose equivalent, Hp(10). By using conversion factors, the personal dose equivalent gives an estimate of the Effective dose[13]. Thus, Hp(10) is considered when calculating the monitored annual effective dose.

Statistical analysis

All data were grouped into categories based on the occupation. Data were collected, categorized, and processed by using Statistical Package for Social Sciences (SPSS), software package version 25. The quantitative variables were expressed as mean $\pm$ Standard Deviation (SD), and comparison

Table 3. Number and percentages of workers based on occupation in the hospitals (A) and (B).

	Hospital (A)		Hospital (B)		Total	
Occupation	*N*	%	*N*	%	*N*	%
Physician	15	25%	9	20%	24	23%
Nurse	11	19%	9	20%	20	19%
Radiological technologist	24	41%	22	50%	46	45%
Cardiologist	3	5%	0	0%	3	3%
Radiologist	6	10%	4	9%	10	10%
Total	59	100%	44	100%	103	100%

Table 4. Number and percentages of workers per department in the hospitals (A) and (B).

	Hospital (A)		Hospital (B)		Total	
Department	*N*	%	*N*	%	*N*	%
X ray	32	54%	28	64%	60	58%
Operation theater	12	20%	15	34%	27	26%
Cardiac catheterization lab	8	14%	0	0%	8	8%
Others	7	12%	1	2%	8	8%
Total	59	100%	44	100%	103	100%

was made using paired students *t*-test and analysis of variance (ANOVA). Levels of p value < 0.05 were considered statistically significant. To our knowledge, there is no documented scale for measuring the practice of radiation protection measures. Thus, the total score (40 points) was divided into following three levels: >36 points (90%) counted as good practice, 28–<36 points (70–89%) considered as average, and <28 points (<70%) considered as poor.

RESULTS

Phase 1: practice of radiation protection measures

One hundred and thirty-four medical workers were invited to participate in the study from the hospitals (A) and (B), and the response rate was 77% ($n = 103$). Fifty-nine participants (57%) were from the hospital (A) and 44 (43%) from the hospital (B). The majority of the respondents (40%, $n = 41$) had >16 years of experience, and 35% were aged 26–35 years old (Tables 1 and 2). The distribution of respondents according to their job position and department are shown in Tables 3 and 4.

The evaluation of the practice of radiation protection measures showed that 96% ($n = 99$) adhered to wearing TLDs, and 61% ($n = 63$) wearing thyroid collars during interventional radiology and in operating rooms. However, 30% of radiologists were not wearing lead aprons during fluoroscopy. Moreover, 67% ($n = 16$) of the physicians tracked their occupational radiation dose for sometimes, while 21% rarely checked their radiation dose (Table 5). Fifty-two percent ($n = 54$) have good compliance with radiation protection measures as they scored 28–35 points (70–89%), while 42% ($n = 43$) were average (Table 6).

The relationship between participants' occupation and department with their practice of radiation protection measures were reviewed using the ANOVA test. There was no statistically significant relationship between good radiation protection practice and occupation or department ($p > 0.05$). In addition, the correlation test for age and years of experience with radiation protection practice did not show any significant association at $p < 0.05$.

Phase 2: assessment of occupational radiation dose

Readings of 952 TLD were obtained during the study period. The number of TLD's increased during this period for the hospital (A) and a major upsurge in 2016 for both hospitals (Figure 1).

The average annual dose for both hospitals

The average annual effective dose for all medical workers was 0.60 mSv. The highest was 0.83 mSv in 2005 and 2014 (Figure 2). The analysis of average effective dose for a period of five consecutive years

Table 5. The practice of radiation protection measures among medical workers in the hospitals (A) and (B).

		Cardiologist		Nurse		Physician		Radiological Technologist		Radiologist		Total	
		N	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%
Wearing TLD during the work	Always	3	100%	19	95%	21	88%	46	100%	10	100%	99	96%
	Sometimes			1	5%	3	13%					4	4%
	Rarely												
	Never												
Wearing Lead apron during fluoroscopy/ CR-arm	Always	3	100%	17	85%	24	100%	38	83%	7	70%	89	86%
	Sometimes			3	15%		0%	8	17%	3	30%	14	14%
	Rarely												
	Never												
Wearing lead gloves during fluoroscopy	Always					2	8%					2	2%
	Sometimes			6	30%	12	50%	32	70%	7	70%	57	55%
	Rarely			12	60%	7	29%	4	9%	3	30%	26	25%
	Never	3	100%	2	10%	3	13%	10	22%			18	17%
Wearing a thyroid collar during interventional radiology/OT	Always			12	60%	12	50%	34	74%	5	50%	63	61%
	Sometimes	3	100%	8	40%	7	29%	9	20%	5	50%	32	31%
	Rarely					3	13%	3	7%			6	6%
	Never					2	8%					2	2%
Ensure using lead apron for all co-patient or staff available during procedures	Always	3	100%	10	50%	18	75%	18	39%	7	70%	56	54%
	Sometimes			10	50%	5	21%	26	57%	2	20%	43	42%
	Rarely				0%	1	4%	2	4%	1	10%	4	4%
	Never												
Ensure the room door is closed during exposure	Always	1	33%	14	70%	17	71%	30	65%	6	60%	68	66%
	Rarely	1	33%			1	4%			2	20%	4	4%
	Sometimes	1	33%	6	30%	6	25%	16	35%	2	20%	31	30%
	Never												
Ensure there is no co-patient or staff during exposure	Always	2	67%	16	80%	24	100%	36	78%	6	60%	84	82%
	Sometimes	1	33%	3	15%		0%	9	20%	4	40%	17	17%
	Rarely			1	5%			1	2%			2	2%
	Never												
Track your radiation dose measurement using the TLD Reading	Always	2	67%	5	25%	2	8%	23	50%	4	40%	36	35%
	Sometimes	1	33%	13	65%	16	67%	15	33%	5	50%	50	49%
	Rarely			2	10%	5	21%	8	17%	1	10%	16	16%
	Never					1	4%					1	1%

Table 6. Score of the respondents towards the practice of radiation protection measures.

	Poor < 28 points (below 70%)		Average 28– < 36 points (70%–89%)		Good 36 points (90%)		Total
	N	%	*N*	%	*N*	%	
Physicians	0	0%	16	67%	8	33%	24
Nurses	1	5%	10	50%	9	45%	20
Radiologists	1	10%	4	40%	5	50%	10
Cardiologists	0	0%	1	33%	2	67%	3
Radiological Technologists	4	9%	12	26%	30	65%	46
Total	6	6%	43	42%	54	52%	103

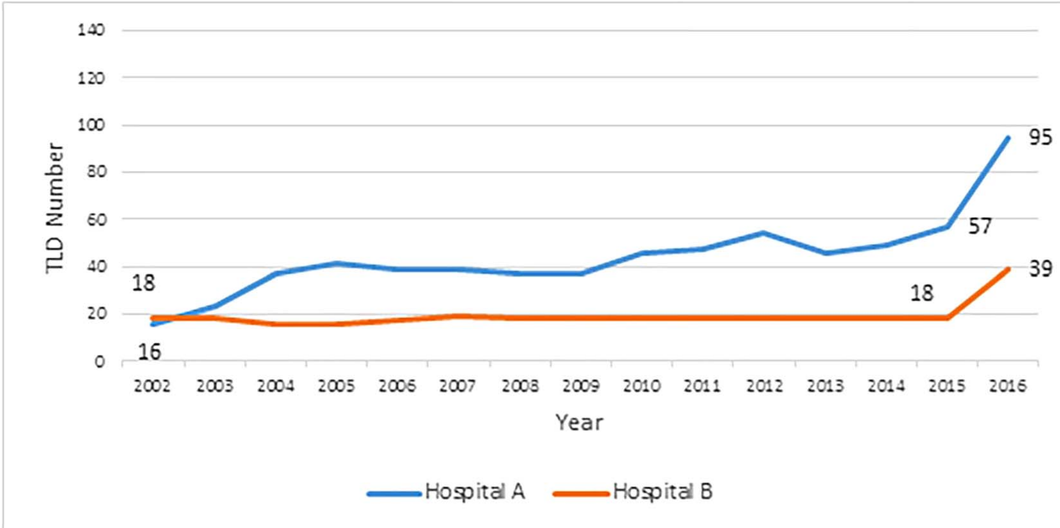

Figure 1. The total number of TLD readings for medical workers in the hospitals (A) and (B) from 2002 to 2016.

was 0.62 mSv (2002–2006), 0.52 mSv (2007–2011) and 0.65 mSv (2012–2016).

The average annual dose for the hospitals (A) and (B)

The average annual effective dose and the standard deviation was calculated for the hospital (A) and (B) (Figure 3). In hospital (B) the average dose increased from (0.44 mSv ± 0.15) in 2002 to (0.60 mSv ± 0.25) in 2016. On the contrary, the lowest average radiation dose of the hospital (A) was (0.324 mSv) in 2002 and increased to more than 0.8 mSv in 2005, 2006, 2013 and 2014. There were 13 outliers readings ranged from 3.56 to 8.63 mSv. Therefore, hospital (A) showed a high standard deviation in the year 2004, 2005, 2006, 2013 and 2014; therefore, error bars passed below zero in these years. The probability of exceeding the dose constraint set by FANR[12] was 1.4% ($n = 13$), and it is worth mentioning that the 13 cases exceeded the dose constraint were from the hospital (A).

The average annual dose in each department

The operating theater (OT) department in the hospital (A) showed a lower average annual dose compared to the OT department in hospital (B). The highest average annual dose was recorded in the cardiac catheterization lab in the hospital (A) as shown in Table 7. Nevertheless, the evaluation of annual dose showed fluctuation in the average annual effective dose in the Cardiac catheterization lab in hospital (A) ranged from 0.44 mSv in 2007 to 1.89 mSv in 2013. The average annual effective dose in the X-ray department was similar in both hospitals. Hospital (B) had a stable range of annual dose from 0.42 mSv in 2015 to 0.57 in 2005 and only 0.71 mSv in 2016, while hospital (A) demonstrated the more extensive range of annual dose from 0.32 mSv in 2002 to 0.95 in 2014. Results of one-way ANOVA test revealed no statistical significance variation in annual dose between departments in the hospitals (A) and (B) ($p < 0.05$).

The annual effective dose for each occupation

Table 8 shows that cardiologists and nurses had higher average annual effective dose compared to other occupations throughout the study period. The yearly analysis showed that cardiologists had the highest average annual effective dose (7.230 mSv) in 2006, but it worth to mention that there was one cardiologist in the cath lab (Figure 4). A statistically significant mean of occupational radiation dose across jobs was observed for the years 2003–2005, 2008–2009, 2011–2013 and 2015, indicating that the radiation dose varied based on the performed job.

The annual equivalent dose for skin

The annual equivalent dose for skin Hp(0.07) in the current study ranged from 10.83–0.03 mSv, with an average of 0.63 mSv. The average annual equivalent

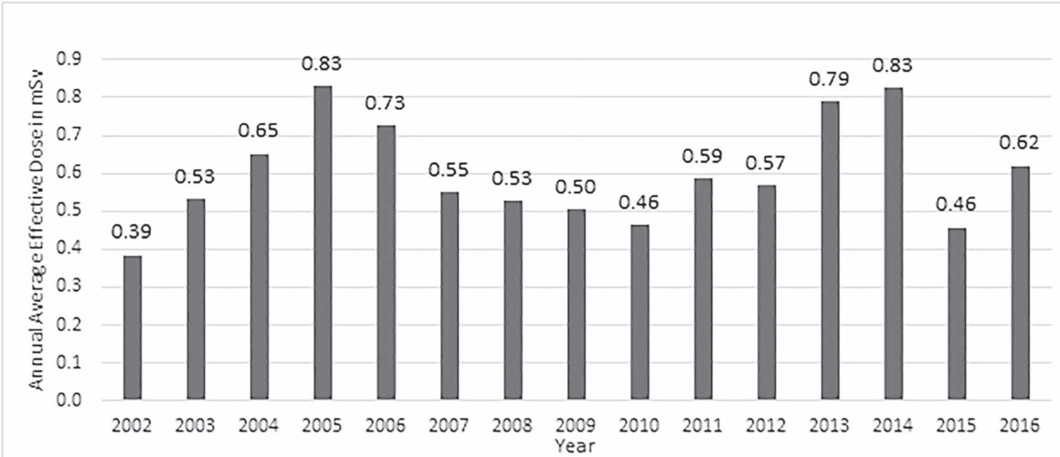

Figure 2. Average annual effective dose in mSv for medical workers in both hospitals.

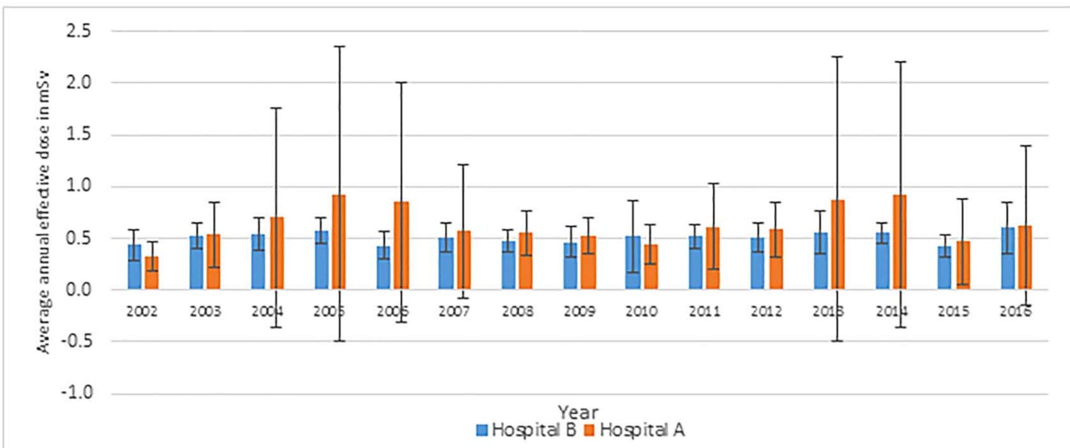

Figure 3. Average annual dose in mSv for medical workers in the hospitals (A) and (B).

Table 7. Average annual effective dose for each department in the hospitals (A) and (B).

Department	Hospital (A): Cath lab	Hospital (A): OT	Hospital (A): X-ray	Hospital (B): OT	Hospital (B): X-Ray
Average Annual Effective Dose	1.05	0.31	0.54	0.51	0.52

Table 8. Average Annual Effective Dose for each occupation in the hospitals (A) and (B).

Occupation	Nurse	Physician	Rad Tech	Radiologist	Cardiologist
Average Annual Effective Dose	0.81	0.38	0.53	0.63	1.49

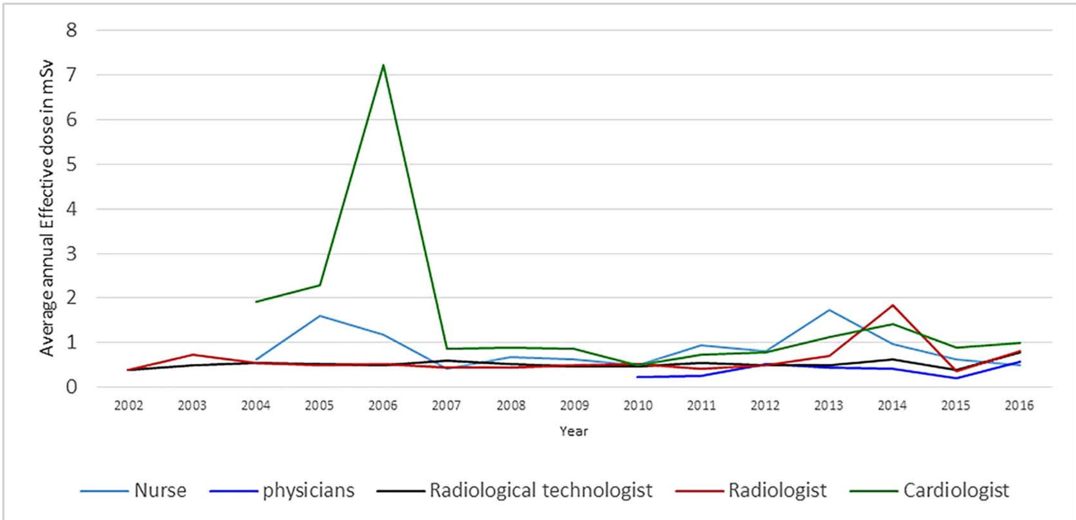

Figure 4. Average annual effective dose for each occupation in the hospitals (A) and (B).

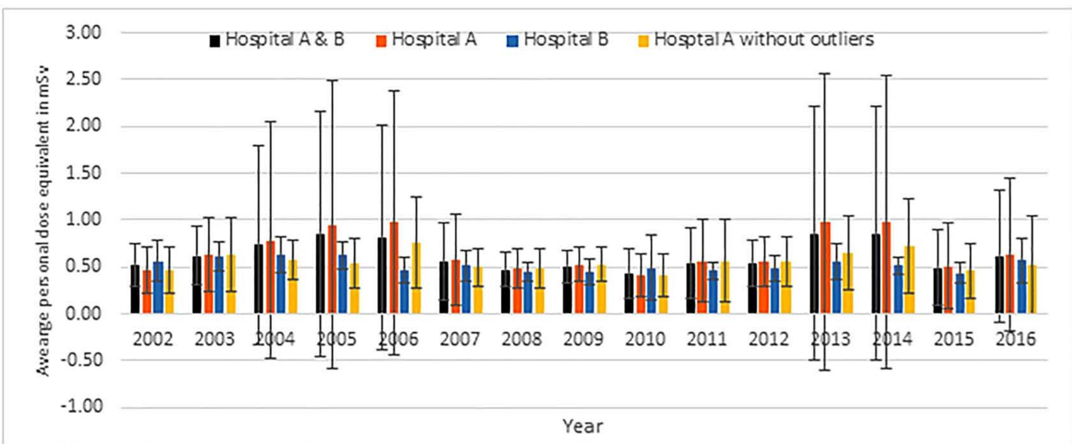

Figure 5. Average annual equivalent dose for the skin for medical workers in the hospitals (A) and (B).

dose for skin dose and the SD was calculated for the hospitals (A) and (B) (Figure 5). Yet again, hospital (A) showed outliers readings ranged from 3.1 to 10.86 mSv. Therefore, hospital (A) showed a high standard deviation in the year 2004, 2005, 2006, 2013 and 2014, and error bars passed below zero in these years (Figure 5).

Summary of results

The result of the current study provides an insight into occupational radiation dose and radiation protection practice for medical workers in the UAE. The average annual effective dose for both hospitals was significantly lower than the standard of 20 mSv per year. However, hospital (B) should stable range of average annual effective dose while a high fluctuation observed in the hospital (A). It was found that the cardiology department at the hospital (A) contributed extensively to the high mean of radiation dose recorded by the hospital, and professionals receiving the highest dose were cardiologists and nurses. The probability of exceeding dose constraint set by FANR was 1.4%, as 13 workers have annual effective dose above three mSv. The evaluation of radiation protection measures revealed that 52% of

Table 9. Average effective annual dose based on occupational monitoring in counties of the world and (UNSCEAR) report 2000.

Country	Dose (mSv)
Australia (1990–1994)	0.19
Canada (1990–1994)	0.35
India (1990–1994)	0.42
Thailand (1990–1994)	0.58
Greece (1990–1994)	3.86
Brazil (1990–1994)	2.58
China (1986–2000)	1.85
Lithuania (1996–2000)	1.48
Pakistan (2003–2007)	3.39
Kuwait (1992–1994)	1.56
Syria (1990–1994)	4.4
Jordan (1990–1994)	1.33
World (1990–1994)	1.34

medical workers have a good practice of radiation protection, while 42% of the workers demonstrated an average level of radiation protection practice. However, there were no statistically significant relationships between good radiation protection practice and occupation, age, experience, or department, there was a statistically significant relationship between annual effective dose and occupation.

DISCUSSION

The current study showed that medical workers have good radiation protection practice (52%), while (42%) showed an average practice. In contrary, Alavi *et al*.[29] showed a lower level of radiation protection practice[29]. The results of this study indicated that age and years of experience are not associated with the enhancement of radiation protection practice. These findings were contradicting with previous studies, which indicated a significant correlation between years of experience and adherence to radiation protection practice among medical workers[29, 30]. Unlike similar studies were poor radiation protection practice was reported among cardiologists[31], the current established a good level of radiation protection practice. Likewise, radiation protection tools were not fully utilized by interventional cardiology staff[31], physician[32], and radiologists[33]. It is important for all medical workers using ionizing radiation to wear TLD dosimeters during imaging procedures[34]. Training in radiation protection is essential to reduce occupational radiation dose and cancer risk[33–35]. Thus, adequate education and training for medical workers utilizing ionizing radiation are essential[36, 37]. It is vital to use radiation protection tools to support radiation safe practice. Moreover, training and experimentations are important to educate medical workers about the significance of shielding in radiology. Tracking occupational radiation dose might have a positive impact on the reduction of occupational radiation dose.

The number of medical workers has increased in recent years[38], a trend demonstrated in the current study. An escalation of 400% was observed in the current study (Figure 1). Despite the significant increase in the number of medical workers during the study period, no decrease in the average annual effective dose was observed. This might be due to the increase in the number of radiology procedures.

However, the average annual effective dose throughout the study period is less than the national and international effective dose limits set by FANR and ICRP, it is higher compared to Australia, Canada and some countries in the UNSCEAR Report 2000[9] as shown in Table 9. Nevertheless, the dose was comparable to the dose measurement in the region, such as the Kingdom of Saudi Arabia 0.66 mSv in 2009–2010[1]. Likewise, the average annual effective dose was less in comparison to Brazil, Greece and China. Similarly, it was less compared to regional countries reported in the UNSCEAR Report 2000[9], for instance, Kuwait, Syria, and Pakistan, as shown in Table 9.

Correspondingly, the average annual effective doses reported by UNSCEAR 2008 report ranged from 0.9 mSv/year (years 1975–1979) to 0.5 mSv/year (1990–1994, 1995–1999 and 2000–2002)[21]. Results of the current study are similar to the global average annual effective dose levels. Generally, the results of the current study are considered within the international range, as some studies reported 0.5–1.2 mSv/year[39] and 0.81 mSv/year[40]. Furthermore, the current analysis revealed that the dose constraint level (3 mSv) was exceeded in 13 incidents (1.4%) by different occupations including radiographers, nurses, cardiologist, and radiologist. Thus, it is important to consider role-specific dose constraints and investigate any dose >3 mSv in diagnostic radiology to ensure safe practice.

The cardiology department contributed extensively to the high occupational radiation dose recorded by the hospital (A) since the highest dose was from cardiologists. Despite the fact that cardiologists had good adherence to radiation protection measures, they are nonetheless exposed to a significant higher dose. It can be concluded that the workers in a cardiac catheterization laboratory are exposed to a relatively higher dose compared to other medical workers[1, 41, 42]. Experimental studies in the cardiac catheterization laboratory are required to identify the possibilities of reducing radiation dose to workers using ergonomics and different body positions.

Radiation protection requires an appropriate transfer of knowledge into practice. Thus, cultivating a radiation protection culture can result in a substantial reduction of radiation dose for both patients and staff. Continuous evaluation and regular improvement are needed to fill the gap between theory and practice and improve radiation protection measures[43]. To decrease the occupational radiation dose, personalized dose feedback can be provided to medical workers in fluoroscopy-guided interventions[44]. Moreover, assessment of radiation dose for medical workers is important to clarify risks because exposure to chronic low dose increases the risk of cancer[4, 6, 8].

CONCLUSION

The study provided an outline of the occupational radiation dose for medical workers in the UAE. The number of medical workers exposed to radiation in the two hospitals increased significantly over the 15-year study period. The occupational radiation dose to workers at different medical departments within the two hospitals was well below the average of 20 mSv per year, as recommended by the ICRP[10] and the national organizations (FANR)[11]. Good radiation protection practice was demonstrated through the appropriate use of radiation protection tools. However, continuous monitoring and evaluation of radiation protection practice are important to sustain adherence to safety measures.

FUTURE DIRECTIONS

Experimental studies in the Cardiac Catheterization lab are required to identify the possibilities of reducing radiation dose to workers. Ergonomics and different body positions can be simulated in real working settings to measure their effect on occupational radiation dose. To support radiation safe practice, it is a necessity to ensure continuity of the radiation protection program and to ensure all exposures are low as reasonably achievable (ALARA principle). It is recommended that all medical must demonstrate good radiation protection practice, and the radiation safety culture is cultivated.

ACKNOWLEDGEMENTS

The authors thank Ms. Samah Jarbou for technical assistance during the study and Dr. Mika Kortesniemi for consultation and comments.

REFERENCES

1. Nassef, M. H. and Kinsara, A. A. *Occupational radiation dose for medical workers at a University Hospital*. J. Taibah Univ. Sci. **11**(6), 1259–1266 (2017).
2. IAEA. *International basic safety standards for protecting against ionizing radiation and for the safety of radiation sources*. (Vienna, Austria: International Atomic Energy Agency (IAEA)) (1996).
3. Salama, K. F., AlObireed, A., AlBagawi, M., AlSufayan, Y. and AlSerheed, M. *Assessment of occupational radiation exposure among medical staff in health-care facilities in the Eastern Province, Kingdom of Saudi Arabia*. Indian J. Occupational Environ. Med. **20**(1), 21 (2016).
4. Linet, M. S., Kim, K. P., Miller, D. L., Kleinerman, R. A., Simon, S. L. and de Gonzalez, A. B. *Historical review of occupational exposures and cancer risks in medical radiation workers*. Radiat. Res. **174**(6b), 793–808 (2010).
5. Mora, P. and Acuña, M. *Assessment of medical occupational radiation doses in Costa Rica*. Radiat. Prot. Dosimetry **147**(1–2), 230–232 (2011).
6. Sun, Z., Inskip, P. D., Wang, J., Kwon, D., Zhao, Y., Zhang, L. *et al. Solid cancer incidence among C hinese medical diagnostic x-ray workers, 1950–1995: estimation of radiation-related risks*. Int. J. Cancer **138**(12), 2875–2883 (2016).
7. Yoshinaga, S., Mabuchi, K., Sigurdson, A. J., Doody, M. M. and Ron, E. *Cancer risks among radiologists and radiologic technologists: review of epidemiologic studies*. Radiology **233**(2), 313–321 (2004).
8. Lee, W. J., Choi, Y., Ko, S., Cha, E. S., Kim, J., Kim, Y. M. *et al. Projected lifetime cancer risks from occupational radiation exposure among diagnostic medical radiation workers in South Korea*. BMC Cancer **18**(1), 1206 (2018).
9. United Nations Scientific Committee on the Effects of Atomic Radiation. *Sources and effects of ionizing radiation*, United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2000 Report. **Volume I**. (2000).
10. Valentin, J., Ed. *ICRP Publication 103, The 2007 Recommendations of the International Commission on Radiological Protection*. (New York: Elsevier) (2007).
11. Federal Authority for Nuclear Regulation (FANR), Regulation for Radiation Dose Limits and Optimisation of Radiation Protection for Nuclear Facilities (FANR-REG-04); 2010. Available from: https://www.fanr.gov.ae/en/Documents/20101128_fanr-reg-04-dose-limits-version-0-english-13.07.10.pdf.
12. Federal Authority for Nuclear Regulation (FANR) Radiation Safety (FANR-RG-007); 2012. Available from: https://fanr.gov.ae/en/rules-regulations/regulations-guides/regulatory-guides.
13. International Commission on Radiation Units. *Quantities and units in radiation protection dosimetry*. (Bethesda: International Commission on Radiation Units) (1993).
14. Harrison, J. D. and Streffer, C. *The ICRP protection quantities, equivalent and effective dose: their basis and application*. Radiat. Prot. Dosimetry **127**(1–4), 12–18 (2007).

15. International Atomic Energy Agency. In: *Diagnostic radiology physics: a handbook for teachers and students*. Dance, D. R., Christofides, S., ADA, M., ID, M. L. and Ng, K. H., Eds. (Vienna: International Atomic Energy Agency) (2014).
16. Gadhi, M. A., Fatmi, S., Gadhi, M. S., Mahmood, U., Shakil, M. and Buzdar, S. A. *Variation of annual effective dose from external ionizing radiation among radiation workers of Bahawalpur Institute of Nuclear Medicine and Oncology (BINO), Pakistan*. Int. J. Radiat. Res. **14**(3), 229–235 (2016).
17. Kortesniemi, M., Siiskonen, T., Kelaranta, A. and Lappalainen, K. *Actual and potential radiation exposures in digital radiology: analysis of cumulative data, implications to worker classification and occupational exposure monitoring*. Radiat. Prot. Dosimetry **174**(1), 141–146 (2016).
18. Pekkarinen, A., Siiskonen, T., Lehtinen, M., Savolainen, S. and Kortesniemi, M. *Potential occupational exposures in diagnostic and interventional radiology: statistical modeling based on Finnish national dose registry data*. Acta Radiol. **60**(1), 68–77 (2019).
19. Alramlawi, S. A., Alsaqr, A. S., AL Zayat, D. and Galal, M. *Assessing the occupational radiation doses for medical workers at Cairo University Hospital based on job categories*. AJNSA. **48**(1), 40–43 (2015).
20. UNSCEAR. Annex E. *Occupational radiation exposures*. In: UNSCEAR 2000 Report to the General Assembly, with Scientific Annexes. (New York: United Nations Scientific Committee on the Effects of Atomic Radiation) (2000).
21. UNSCEAR. Annex. *B: Exposures of the public and workers from various sources of radiation*. In: UNSCEAR 2008 Report: Sources of Ionizing Radiation. (Vienna: United Nations Scientific Committee on the Effects of Atomic Radiation) (2010).
22. Hudson, J. I., Pope, H. G. Jr. and Glynn, R. J. *The cross-sectional cohort study: an underutilized design*. Epidemiology **16**(3), 355–359 (2005).
23. Ministry of Health and Prevention – UAE, The Statistics and Research Department; 2017. Available from: https://smartapps.moh.gov.ae/ords/f?p=105:551:6116682598405::NO:RP:P551_YEAR.
24. Ahmed, R. M., Elamin, A. M. T., Elsamani, M. and Hassan, W. B. *Knowledge and performance of radiographers towards radiation protection, Taif, Saudi Arabia*. IOSR J. Dental Med. Sci. **14**(3), 63–68 (2015).
25. Chun-sing, W., Bingsheng, H., Ho-kwan, S., Wai-lam, W., Ka-ling, Y. and Tiffany, C. Y. C. *A questionnaire study assessing local physicians, radiologists and interns' knowledge and practice pertaining to radiation exposure related to radiological imaging*. Eur. J. Radiol. **81**(3), e268 (2012).
26. El-Sallamy, R. M., Kabbash, I. A., El-Fatah, S. A. and El-Feky, A. *Physical hazard safety awareness among healthcare workers in Tanta university hospitals, Egypt*. Environ. Sci. Pollut. Res. Int. **25**(31), 30826–30838 (2018).
27. Rahman, N., Dhakam, S. H., Shafqut, A., Qadir, S. and Tipoo, F. A. *Knowledge and practice of radiation safety among invasive cardiologists*. J. Pak. Med. Assoc. **58**(3), 119 (2008).
28. Model 6600 Plus Automatic TLD reader user manual [Internet].; 2007 [cited 14 Feb 2018]. Available from: https://www.thermofisher.com/order/catalog/product/6600PLUSDXTRAD.
29. Alavi, S. S., Dabbagh, S. T., Abbasi, M. and Mehrdad, R. *Medical radiation workers' knowledge, attitude, and practice to protect themselves against ionizing radiation in Tehran Province, Iran*. J. Educ. Health Promot. **6**, 58 (2017).
30. Shabani, F., Hasanzadeh, H., Emadi, A., Mirmohammadkhani, M., Bitarafan-Rajabi, A., Abedelahi, A. *et al. Radiation protection knowledge, attitude, and practice (KAP) in interventional radiology*. Oman Med. J. **33**(2), 141 (2018).
31. Valuckiene, Z., Jurenas, M. and Cibulskaite, I. *Ionizing radiation exposure in interventional cardiology: current radiation protection practice of invasive cardiology operators in Lithuania*. J. Radiol. Prot. **36**(3), 695 (2016).
32. Jentzsch, T., Pietsch, C. M., Stigler, B., Ramseier, L. E., Seifert, B. and Werner, C. M. *The compliance with and knowledge about radiation protection in operating room personnel: a cross-sectional study with a questionnaire*. Arch. Orthop. Trauma Surg. **135**(9), 1233–1240 (2015).
33. Abdelrahman, M. A., Alfwares, A. A., Alewaidat, H., Alhasan, M., Rawashdeh, M. A. and Al Mousa, D. S. *Compliance with radiation protection practices among radiologists*. Health Phys. **115**(3), 338–343 (2018).
34. Durán, A., Hian, S. K., Miller, D. L., Heron, J. L., Padovani, R. and Vano, E. *A summary of recommendations for occupational radiation protection in interventional cardiology*. Catheter. Cardiovasc. Interv. **81**(3), 562–567 (2013).
35. Vano, E., Gonzalez, L., Fernandez, J. M., Alfonso, F. and Macaya, C. *Occupational radiation doses in interventional cardiology: a 15-year follow-up*. Br. J. Radiol. **79**(941), 383–388 (2006).
36. Kargar, E., Parwaie, W., Farhood, B., Atazadegan, Z. and Afkhami Ardekani, M. *Assessment of radiographers' awareness about radiation protection principles in hospitals of Bandar Abbas, Iran*. Iran. J. Med. Phys. **14**(1), 47-52 (2017).
37. Faggioni, L., Paolicchi, F., Bastiani, L., Guido, D. and Caramella, D. *Awareness of radiation protection and dose levels of imaging procedures among medical students, radiography students, and radiology residents at an academic hospital: results of a comprehensive survey*. Eur. J. Radiol. **86**, 135–142 (2017).
38. Gerry, C. J. and Sheiman, I. *The health workforce of the Russian Federation in the context of the international trends*. Higher School of Economics Research Paper No. WP BRP, 1 (2016).
39. Al-Haj, A. N. and Lagarde, C. S. *Statistical analysis of historical occupational dose records at a large medical center*. Health Phys. **83**(6), 854–860 (2002).
40. Bašić, B., Beganović, A., Skopljak-Beganović, A. and Samek, D. *Occupational exposure doses in interventional procedures in Bosnia and Herzegovina*. Radiat. Prot. Dosimetry **144**(1–4), 501–504 (2010).
41. Miller, D. L., Vanó, E., Bartal, G., Balter, S., Dixon, R., Padovani, R. *et al. Occupational radiation protection in interventional radiology: a joint guideline of the*

cardiovascular and interventional radiology Society of Europe and the Society of Interventional Radiology. Cardiovasc. Intervent. Radiol. **33**(2), 230–239 (2010).
42. Peruzzo Cornetto, A., Aimonetto, S., Pisano, F., Giudice, M., Sicuro, M., Meloni, T. *et al. The contribution of interventional cardiology procedures to the population radiation dose in a 'health-care level I'representative region*. Radiat. Prot. Dosimetry **168**(2), 261–270 (2015).
43. Ploussi, A. and Efstathopoulos, E. P. *Importance of establishing radiation protection culture in radiology department*. World J. Radiol. **8**(2), 142 (2016).
44. Sailer, A. M., Vergoossen, L., Paulis, L., van Zwam, W. H., Das, M., Wildberger, J. E. *et al. Personalized feedback on staff dose in fluoroscopy-guided interventions: a new era in radiation dose monitoring*. Cardiovasc. Intervent. Radiol. **40**(11), 1756–1762 (2017).