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Radiation safety and radiation monitoring practices among medical radiation workers in Malaysia

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ABSTRACT

Background: The Background: To assess the radiation protection and radiation monitoring practices among medical radiation workers (MRWs) in Malaysian hospitals, and to identify demographic and occupational factors influencing the consistent use of radioprotective garments and dosimeters. ***Materials and Methods***: A link to an online survey was distributed to MRWs with the help of research coordinators at participating hospitals. A total of 387 respondents answered the online survey between April and June 2019. They reported the consistency with which they used radioprotective garments, dosimeters and other protective measures, together with the reasons for inconsistency. We then compared consistent and inconsistent groups by demographic and occupational data. ***Results***: The respondents exhibited excellent adherence to radiation protection but showed poor adherence to radiation monitoring. The main reasons for non-use of radioprotective garments were inadequate items and the need to prioritize others. Forgetfulness and fear of losing dosimeters were the common reasons for the non-consistent use of monitoring devices. Radiologists were the most consistent group using radioprotective garments compared to other job positions ($p<.050$). Middle-aged respondents were more consistent in using radioprotective aprons than younger respondents ($p<.005$). Work schedule, institution and gender also influenced the consistency of using radioprotective garments and dosimeters. ***Conclusion***: There is an urgent need to improve the personal dosimeter adherence rate in this country and any shortage of radioprotective garments should be tackled immediately. Ultimately, it is crucial to understand the workers' tasks and their safety measures to avoid underestimating occupational radiation exposure and risk.

INTRODUCTION

The escalating use of radiological modalities coupled with the complexities in imaging procedures may lead to higher cumulative occupational exposure to ionizing radiation in medical radiation workers (MRWs) [(1)]. This in turn, may be associated with increased risks of malignancy, cataract formation, congenital anomalies and other health complications [(2)].

MRWs must practice the main principle for radiation protection – as low as reasonably achievable (ALARA). This principle emphasizes the concept of minimum time for the radiology procedure, maximum distance from the radiation source and also the use of proper shielding (both fixed and personal) for protection [(3)]. This principle is comparable with the hierarchy of control to reduce occupational risk, which states that the utilization personal protective equipment is the least effective control in the hierarchy. Personal protective equipment should therefore be used in conjunction with more effective controls, such as engineering and administrative controls [(4)].

Thus, to ensure compliance with the international occupational radiation dose limits and reduce occupational health risks, it is essential to ensure that the ALARA principle and hierarchy of control are constantly practised in the workplace and radiation dose monitoring is conducted appropriately [(5, 6)]. There are many reports on radiation protection practices and cultures across healthcare institutions [(7-16)]. However, most of the prior studies reported adherence to radioprotective garments and radiation monitoring device usage without considering whether the workers had already practised higher control measures for radiation protection or whether the workers' nature of work fit the usage requirement.

For instance, workers reported non-use of the

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radioprotective apron and thyroid collar during a procedure, which could be due to higher control measures they have already taken, e.g., by distancing themselves from X-ray sources or utilizing fixed or mobile shielding [7, 10, 13-16]. Scoring their practices without ruling out these possibilities underestimated their actual radiation protection practice. Likewise, radioprotective gloves are only required for the physician whose hands are near the X-ray field meaning that studies assessing glove usage generally underestimate protection [8, 14, 16]. Radiation protection principles should be evaluated individually or hierarchically for an accurate practice assessment [9, 14, 16]. Assessments conducted on non-radiation health workers has also illustrated biased outcomes of poor adherence rates for the reasons above [11].

Amid the absence of a national registry of radiation protection and monitoring status [11], we aimed to obtain an overview of the radioprotection and radiation monitoring use among MRWs working in public and private sectors in Malaysia, an upper middle-income country. The assessment of practices among the workers was tailored to individual job tasks and included assessment of the entire range of safety measures taken by the workers, in order to obtain a full understanding of the workers' tasks, exposure level and control measures, which could avoid underestimating safety practices among workers and overestimating their occupational risks.

MATERIALS AND METHODS

Research conduct and ethical approval

The present study has been reviewed and approved by the Ministry of Health Malaysia ethical committee (NMRR-17-1029-35730) and the institutional review boards of the university and private hospitals (MREC2016104-4321; JKEUPM-2017-179; JEPeM/17100445; IREC2017-045; FF-2017-386). In order to maintain anonymity, no personal identifying information was collected.

Survey tool

A survey was created using the survey tool SurveyMonkey (Momentive Inc. San Mateo, California, USA). The survey contained questions that enquired about: personal and occupational information; the use of radioprotective items (radioprotective apron and thyroid shield); the application of ALARA principles; the use of personal dosimeters; and the reasoning behind non-adherence/non-use (if applicable). Questions were designed with the input of past studies [17-19] and experts including radiologists, radiographers and medical physicists from both the academic and government institutes. All authors agreed on the final survey items.

All the items applied skip-logic response questions and allowed multiple answer choices when appropriate. The order of answer options for the reasoning behind non-use was randomized for each respondent to reduce order bias. The survey was piloted on 31 medical radiation workers before commencing primary data collection, to identify any problems within the tool. Feedback was taken into consideration to improve the survey tool.

Survey distribution

An invitation was sent to all heads of the radiology departments in various public, private and university hospitals. The consenting departments were requested to assign research coordinators to assist in data collection who were sent an email containing instructions and the survey link. They were asked to forward the link to the MRWs in their department on two separate occasions over eight weeks between April 2019 and June 2019.

Data management

Participant responses were only accessible to the investigators. The survey data were downloaded for data cleaning, re-classifying and re-coding. Only respondents who required the use of radioprotective garments at work were included in the analysis.

Respondents whose answers implied 100% consistency in using radioprotective garments and dosimeters were coded as 'consistent user' and categorized as 'adherent to radiation protection practice' because they at least practised the lowest level of controls (using personal protective equipment).

Those who had less than 100% consistency in using radioprotective garments and dosimeters were coded as 'non-consistent user' and only categorized as 'adherent to radiation protection practice' if they answered 'Yes' to at least one of the questions regarding compliance with the ALARA principles or use of higher levels of controls (stand behind other shielding or/and keep a distance of 2 meters from radiation source). Otherwise, they were categorized as 'non-adherent to radiation protection practice'.

Statistical analysis

Descriptive statistics were used to determine the frequencies and percentages of related variables. The associations between categorical variables were determined using the Chi-Square test. Continuous variables were examined using Pearson's correlation and Cramer's V with unweighted data. Cramer's V values were interpreted as follows: >0.25 as a very strong relationship, >0.15 as a strong relationship, >0.10 as a moderate relationship, >0.05 as a weak relationship and 0.00 as no/very weak relationship [20].

Multivariable logistic regression was performed to ascertain the factors that were associated with consistent use of radioprotective garments and radiation monitoring devices. Odds ratios were

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adjusted for gender, age, education, type of organization, job position, working area, employment status, shift hour and length of service. Statistical significance was set at p=0.05. Analyses were performed with the Statistical Package for the Social Sciences (SPSS) tool version 25.0 (SPSS Inc., Chicago, Illinois, USA).

RESULTS

Respondents

Between April and June 2019, 411 respondents commenced the survey. However, only 387 respondents (94.2%) completed the radioprotective apron section, 372 respondents (90.5%) completed the thyroid shield section and 351 respondents (85.4%) completed the section on dosimeter use.

MRWs from the three types of hospital in this country were represented (table 1). The respondents mainly worked in general radiography, computed tomography and interventional radiology. More than half of them were female (57.1%), aged between 30 and 39 years old (52.5%), were diploma holders (55.8%) and worked in the public health sector (58.9%). A majority of the respondents were ethnic Malays (78.5%), worked as radiographers (75.5%) and held permanent positions (95.3%).

Use of radioprotection and radiation monitors

Figure 1 displays the proportion of good and poor radiation protection practices among MRWs. The respondents exhibited almost perfect adherence (99.0%) in practising ALARA, and there were only four respondents (1.0%) who neither practised ALARA nor used radioprotective aprons consistently.

Only 22.0% of respondents required thyroid shield usage from this cohort because they were involved in high radiation exposure procedures. The majority of these (87.8%) practised ALARA and used thyroid shields consistently. Ten respondents exhibited poor radiation protection practice during high-risk radiography procedures.

Less than two-thirds of the cohort used a personal dosimeter regularly (64.6%) and 124 respondents did not consistently use one during work, regardless of their type of radiation exposure.

Reasons for non-adherence to radioprotective garments and personal dosimeter use

Table 2 outlines the reasons for non-adherence to radioprotective garments by the level of consistency of use. The respondents reported that they needed to prioritize colleagues who were more in need of the radioprotective garments because of the inadequate supply of aprons and thyroid shields at their workplace. Other reasons for non-adherence in using a radioprotective apron were that the garment disrupted the workers' movements and was too heavy. Respondents also reported that the aprons were defective and too dirty. Other reasons for non-adherence to thyroid shields were that the shields were 'irritating', were commonly misplaced due to small size, that the protection sheet inside the thyroid shield was cracked, or the shield was too dirty.

The three most common reasons for not using personal dosimeters consistently included forgetting the device, fear of losing the dosimeter, and delayed supply of dosimeters (table 2).

Table 1. Respondents' characteristics.

Characteristics (N=387)	n (%)
Gender	
Male	166 (42.9)
Female	221 (57.1)
Age group (years old)	
20-29	62 (16.0)
30-39	203 (52.5)
40-49	98 (25.3)
50-59	21 (5.5)
60-69	3 (0.8)
Race	
Malay	304 (78.5)
Chinese	28 (7.2)
Indian	16 (4.1)
Sarawakian ethnic	18 (4.7)
Sabahan ethnic	20 (5.2)
Punjabi	1 (0.3)
Highest level of education	
Certificate and lower	9 (2.3)
Diploma	216 (55.8)
First degree	101 (26.1)
Postgraduate and higher	61 (15.8)
Job position	
Radiologist/Interventionalist	31 (8.0)
Registrar/Medical officer	18 (4.6)
Medical Physicist/Physics Science Officer	19 (4.9)
Senior radiographer/Radiographer	292 (75.5)
Nuclear medicine technologist	2 (0.5)
Medical assistant/Staff nurse/Attendant	16 (4.1)
Others[£]	9 (2.3)
Primary practice[¥]	
General/Mobile/Dental	234 (60.8)
Computed tomography	143 (36.7)
Interventional/Fluoroscopy	97 (25.2)
Mammography	36 (9.3)
Nuclear medicine	14 (3.6)
Non-radiation (MRI, Ultrasound)	54 (21.7)
QC/QA/Radiation protection	46 (12.0)
Radiation therapy	5 (1.5)
Organization	
Government hospital/health clinic	228 (58.9)
University hospital	127 (32.8)
Private hospital/clinic	32 (8.3)
Employment status	
Permanent	369 (95.3)
Contract	15 (3.9)
Part-time	3 (0.8)
Shift hours	
Yes	119 (30.7)
No	268 (69.3)
Experience with medical radiation (years)	
1 – 10	190 (49.1)
11 – 20	142 (36.7)
21 – 30	50 (12.9)
31 – 40	5 (1.3)

Note: [£]Medical lecturer, Imaging Manager, Lab technologist; [¥]More than one answer allowed, MRI=magnetic resonance imaging, QC=quality control, QA=quality assurance.

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3Factors associated with consistency in using radioprotective garments and personal dosimeters

Table 3 describes the associations between demographic factors and consistency in using the garments and dosimeters. Respondents who used aprons consistently tended to be younger (below 40 years of age) and consistent use was most common among radiologists and registrars and medical officers (92% were consistent). Only about a quarter of MRWs wore thyroid shields but those with university education were more likely to be consistent users. Only about 24% of radiographers wore thyroid shields. Regarding personal dosimeters, females and government workers were more likely to use them consistently than males and those in university or private organizations.

In the multivariate analyses (table 4), respondents above 40 years old were 2.31 times more likely to use radioprotective aprons consistently (95% CI =1.06,5.03) while private hospital employees were 50.7% less likely to be consistent than their counterparts in public hospitals (95% CI =0.28,0.87). Consistent use for thyroid shield was seen 13.67 times more often in respondents working with higher radiation procedures than workers involved with low radiation (95% CI =1.19, 157.43). For personal dosimeter use, females were almost two times more likely to be adherent to dosimeter usage (AOR=1.92; 95% CI =1.18, 3.10) than males. Respondents from private hospitals were less consistently using personal dosimeters than those in the public hospitals (AOR=0.50; 95% CI =0.29, 0.86). In addition, working regular hours was associated with increased use of dosimeters compared to those working in shifts (AOR=2.16; 95% CI =1.26, 3.70).

Table 2. The reasons for not using radioprotective garments and personal dosimeters according to the level of consistency.

Reasons for non-consistent use of radioprotective apron#	**Level of consistency (%)**					**Total**
	Usually (80%)	Often (60%)	Sometimes (40%)	Seldom (20%)	Never (0%)	
Prioritize other workers	17	6	3	5	-	31
Limited supply/Not available	15	2	1	3	2	23
Disrupting movement	9	5	1	1	2	18
Too heavy / Worsen backpain	13	1	2	1	-	17
Defected (cracked, broken, torn)	5	-	1	-	-	6
Other protection is available	-	1	1	-	-	2
Too dirty/Unpleasant appearance of garment	2	-	-	-	-	2
Exposed to a very low dose	1	-	-	1	-	2
Lazy	1	-	-	-	-	1
Reasons for non-consistent use of thyroid shield#	Usually (80%)	Often (60%)	Sometimes (40%)	Seldom (20%)	Never (0%)	**Total**
Limited supply/Not available	8	8	4	9	4	33
Prioritize other workers	7	6	3	2	3	21
Irritating	-	1	3	2	-	6
Always being misplaced	2	1	3	-	-	6
Defected (cracked, broken, torn)	1	-	1	3	-	5
Too dirty/Unpleasant appearance of garment	1	-	2	-	-	3
Forgotten	1	-	-	-	-	1
Reasons for non- consistent use of personal dosimeter#	Usually (80%)	Often (60%)	Sometimes (40%)	Seldom (20%)	Never (0%)	**Total**
Forgotten	52	12	8	5	0	77
Afraid of losing	22	8	8	3	2	43
Delay in supply	14	1	1	1	0	17
Hassle to attach and detach according to the working unit	6	1	2	0	0	9
Disturbing work	3	0	0	3	0	6
Not important	1	2	1	0	0	4
Could expose to contamination	4	0	0	0	0	4
Others do not use it	2	0	2	0	0	4
Afraid of the possibility to stop work if exposure exceeds the limit	1	0	0	0	0	1
Not MRI-compatible	0	0	0	1	0	1

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Table 3. The associations between demographic data and consistency in using radioprotective garments (apron and thyroid shield) and personal dosimeter.

Consistency for using radioprotective apron (N=384)							
Variables	**Categories**	**Consistent, n (%)**	**Not consistent, n (%)**	**χ^2**	**df**	**p-value**	**ϕ_c**
Gender	Male	122 (31.8)	42 (10.9)	0.001	1	.972	0.002
	Female	164 (42.7)	56 (14.6)				
Age	<40 years old	184 (47.9)	80 (20.8)	***10.164***	***1***	***.001*****	***0.163***
	≥40 years old	102 (26.6)	18 (4.7)				
Education	Diploma & below	160 (41.7)	65 (16.9)	3.243	1	.072	0.092
	First degree & above	126 (32.8)	33 (8.6)				
Type of organization	Government	179 (46.6)	49 (12.8)	4.981	2	.083	0.114
	University	86 (22.4)	38 (9.9)				
	Private	21 (5.5)	11 (2.9)				
Job position	Radiologist	31 (8.1)	2 (0.5)	***12.031***	***5***	***.034****	***0.177***
	Registrar/M.O.	14 (3.6)	2 (0.5)				
	Medical Physicist	12 (3.1)	7 (1.8)				
	Radiographer	208 (54.2)	83 (21.6)				
	Nuc. Med. Tech. & Others	8 (2.1)	1 (0.3)				
	M.A./Nurse/Attendant	13 (3.4)	3 (0.8)				
Working area	No – low exposure	123 (31.8)	53 (13.7)	2.811	2	.245	0.085
	Medium exposure	87 (22.5)	27 (7.0)				
	High – Very high exposure	76 (19.6)	21 (5.4)				
Employment status	Permanent	270 (70.3)	96 (25.0)	2.998	2	.223	0.088
	Contract	14 (3.6)	1 0.3)				
	Part-time	2 (0.5)	1 (0.3)				
Working shifts	Yes	83 (21.7)	36 (9.4)	1.973	1	.160	0.072
	No	202 (52.7)	62 (16.2)				
Length of service	≤20 years	240 (62.5)	90 (23.4)	3.789	1	.052	0.099
	>20 years	46 (12.0)	8 (2.1)				
Consistency for using thyroid shield (N=82)							
Variables	**Categories**	**Consistent, n (%)**	**Not consistent, n (%)**	**χ^2**	**df**	**p-value**	**ϕ_c**
Gender	Male	17 (20.7)	29 (35.4)	2.821	1	.093	0.0185
	Female	20 (24.4)	16 (19.5)				
Age	<40 years old	29 (35.4)	33 (40.2)	0.280	1	.597	0.058
	≥40 years old	8 (9.8)	12 (14.6)				
Education	Diploma & below	15 (18.3)	29 (35.4)	***4.666***	***1***	***.031****	***0.239***
	First degree & above	22 (26.8)	16 (19.5)				
Type of organization	Government	21 (25.6)	18 (22.0)	2.425	2	.298	0.172
	University	15 (18.3)	26 (31.7)				
	Private	1 (1.2)	1 (1.2)				
Job position	Radiologist	8 (9.8)	1 (1.2)	***13.699***	***5***	***.018****	***0.409***
	Registrar/M.O.	4 (4.9)	2 (2.4)				
	Medical Physicist	1 (1.2)	1 (1.2)				
	Radiographer	20 (24.4)	36 (43.9)				
	Nuc. Med. Tech. & Others	0 (0.0)	3 (3.7)				
	M.A./Nurse/Attendant	4 (4.9)	2 (2.4)				
Working area	Medium exposure	0 (0.0)	2 (2.4)	1.686	1	.194	0.143
	High – Very high exposure	37 (45.1)	43 (52.4)				
Employment status	Permanent	35 (42.7)	42 (51.2)	0.056	1	.812	0.026
	Contract	2 (2.4)	3 (3.7)				
Working shifts	Yes	7 (8.5)	18 (22.0)	***4.258***	***1***	***.039****	***0.228***
	No	30 (36.6)	27 (32.9)				
Length of service	≤20 years	36 (43.9)	40 (48.8)	2.117	1	.146	0.161
	>20 years	1 (1.2)	5 (6.1)				
Consistency for using a personal dosimeter (N=350)							
Variables	**Categories**	**Consistent, n (%)**	**Not consistent, n (%)**	**χ^2**	**df**	**p-value**	**ϕ_c**
Gender	Male	85 (24.2)	64 (18.2)	***6.589***	***1***	***.010****	***0.137***
	Female	142 (40.5)	60 (17.1)				
Age	<40 years old	155 (44.2)	84 (23.9)	0.011	1	.917	0.006
	≥40 years old	72 (20.5)	40 (11.4)				
Education	Diploma & below	134 (38.2)	70 (20.0)	0.219	1	.640	0.025
	First degree & above	93 (26.5)	54 (15.4)				

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Continued table 3. The associations between demographic data and consistency in using radioprotective garments (apron and thyroid shield) and personal dosimeter.

Consistency for using a personal dosimeter (N=350)							
Variables	**Categories**	**Consistent, n (%)**	**Not consistent, n (%)**	**χ^2**	**df**	**p-value**	**ϕ_c**
Type of organization	Government	139 (39.6)	65 (18.5)	***6.607***	***2***	***.037****	***0.137***
	University	66 (18.8)	52 (14.8)				
	Private	22 (6.3)	7 (2.0)				
Job position	Radiologist	23 (6.6)	9 (2.6)	3.687	5	.595	0.102
	Registrar/M.O.	8 (2.3)	5 (1.4)				
	Medical Physicist	11 (3.1)	6 (1.7)				
	Radiographer	174 (49.6)	93 (26.5)				
	Nuc. Med. Tech. & Others	6 (1.7)	4 (1.1)				
	M.A./Nurse/Attendant	5 (1.4)	7 (2.0)				
Working area	No – low exposure	100 (28.5)	58 (16.5)	2.408	2	.300	0.083
	Medium exposure	72 (20.5)	30 (8.5)				
	High – Very high exposure	55 (15.7)	36 (10.3)				
Employment status	Permanent	216 (61.5)	119 (33.9)	2.329	2	.312	0.081
	Contract	11 (3.1)	4 (1.1)				
	Part-time	0 (0.0)	1 (0.3)				
Working shifts	Yes	58 (16.6)	48 (13.7)	***6.454***	***1***	***.011****	***0.136***
	No	168 (48.0)	76 (21.7)				
Length of service	≤20 years	193 (55.0)	106 (30.2)	0.014	1	.907	0.006
	>20 years	34 (9.7)	18 (5.1)				

Note: Italic bold variable indicates significant association, *p<0.05, **p<0.005, ***p<0.001

Table 4. Logistic regression of explanatory variables for consistency in radioprotective garments and personal dosimeter usage.

Explanatory variables	**Radioprotective apron** (R^2=0.149, accurate classification=74.4%)					**Thyroid shield** (R^2=0.556, accurate classification=73.0%)					**Personal dosimeter** (R^2=0.118, accurate classification=64.6%)				
	B	Exp(B)	95% C.I. for Exp(B) Lower	Upper	Sig.	B	Exp(B)	95% C.I. for Exp(B) Lower	Upper	Sig.	B	Exp (B)	95% C.I. for Exp(B) Lower	Upper	Sig.
Gender (Female)	0.20	1.23	0.74	2.04	0.431	-0.66	0.52	0.09	3.14	0.475	0.65	1.92	1.18	3.10	***0.008****
Age (≥40 years old)	0.84	2.31	1.07	5.03	***0.034****	0.30	1.35	0.07	25.87	0.844	-0.14	0.87	0.44	1.72	0.687
Education (First degree & above)	0.47	1.60	0.86	3.00	0.142	1.44	4.24	0.34	52.48	0.261	-0.33	0.72	0.40	1.30	0.271
Type of organization					***0.033****					0.106					***0.024****
University hospital	-0.68	0.51	0.21	1.23	0.132	0.61	1.83	0.01	436.21	0.828	0.22	1.25	0.47	3.33	0.659
Private hospital	-0.71	0.49	0.28	0.88	***0.016****	-2.24	0.11	0.01	1.07	0.057	-0.69	0.50	0.29	0.86	***0.012****
Job position					0.178					0.474					0.600
Registrar/Medical officer	-0.44	0.65	0.08	5.20	0.682	2.25	9.49	0.08	1097.77	0.353	-0.33	0.72	0.18	2.95	0.651
Medical Physicist	-2.13	0.12	0.02	0.69	0.017	.	.	.	.	.	-0.17	0.84	0.22	3.22	0.803
Radiographer	-1.46	0.23	0.05	1.09	0.064	-1.43	0.24	0.01	10.49	0.458	-0.12	0.88	0.34	2.32	0.802
Nuc. Med. Tech. & Others	-0.84	0.43	0.03	6.21	0.539	-3.30	0.04	0.00	12.43	0.267	-0.64	0.53	0.10	2.79	0.450
Medical assistant/ Nurse/Attendant	-1.20	0.30	0.04	2.35	0.253	.	.	.	.	.	-1.27	0.28	0.06	1.34	0.112
Working area					0.173										0.234
Medium exposure	0.06	1.07	0.57	1.98	0.842	1.08	2.94	0.31	27.89	0.347	0.52	1.68	0.92	3.06	0.090
High – Very high exposure	0.63	1.88	0.95	3.75	0.071	2.62	13.67	1.19	157.43	***0.036****	0.27	1.31	0.71	2.42	0.385
Employment status					0.150										0.539
Contract	2.07	7.92	0.97	64.61	0.053	1.86	6.41	0.58	70.68	0.129	0.74	2.09	0.57	7.64	0.266
Part-time	-0.34	0.71	0.05	10.74	0.805	.	.	.	.	.	-21.43	0.00	0.00	-	1.000
Working shifts (No)	-0.02	0.98	0.57	1.70	0.946	-1.30	0.27	0.04	1.74	0.170	0.77	2.16	1.27	3.70	***0.005****
Length of service (>20 years)	0.23	1.26	0.44	3.57	0.669	2.08	8.02	0.29	224.25	0.220	0.10	1.10	0.46	2.62	0.827

Note: Bold value indicates significant association, *p<0.05, **p<0.005, ***p<0.001.

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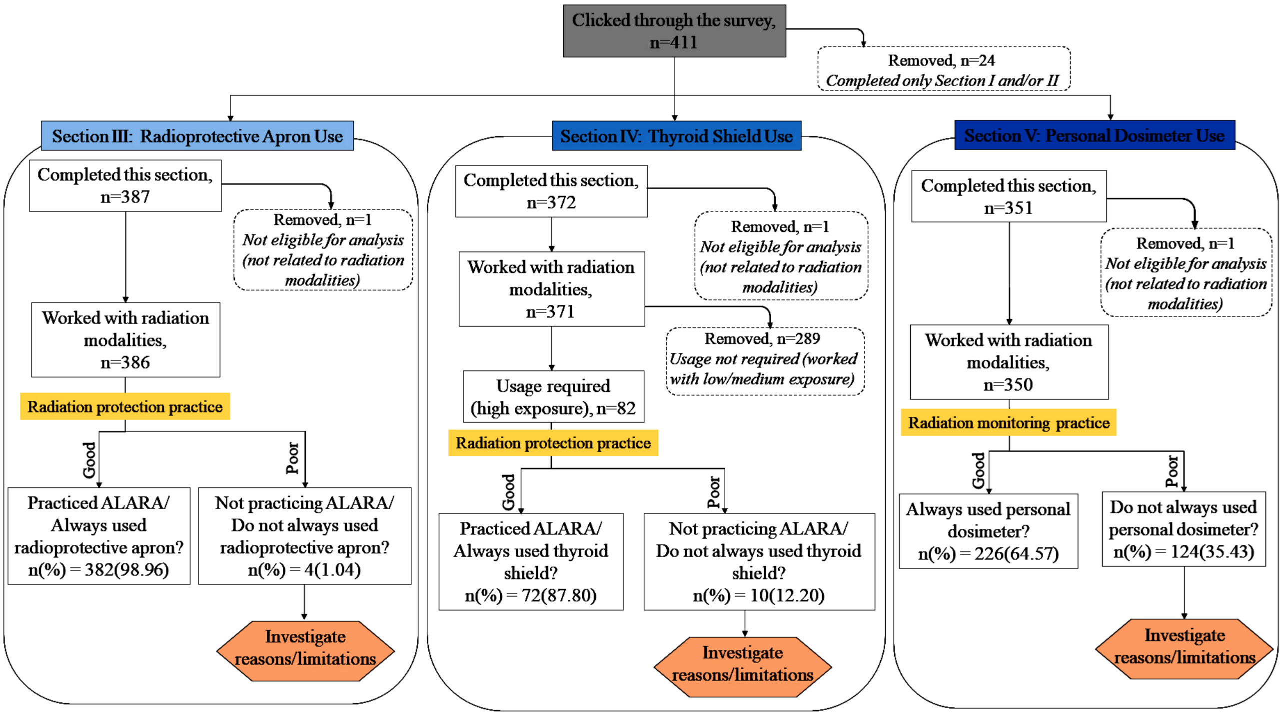

Figure 1. The status of radioprotection and radiation dose monitoring practices among MRWs in this study.

DISCUSSION

Overall, MRWs in Malaysia were poorly adherent to the important radiation monitoring practices. While they applied ALARA principles religiously and exhibited an acceptable rate of adherence to use of radioprotective aprons and thyroid shields, the rate of using dosimeters remained suboptimal. More than one-third of the respondents did not consistently use dosimeters although they had reported that they had received at least one unit.

Studies conducted in other parts of the world have also found low rates of adherence with about 50% to 70% of medical staff rarely or never using their assigned dosimeters (13, 21-23). Forgetfulness was often cited as a reason for non-use in previous studies, as well as scepticism about the risk of exposure to ionizing radiation, negligence, and lack of supervision (22, 24). These reasons were not entirely in line with our study in which, fear of losing the device was a commonly cited reason, particularly in MRW who never used their dosimeters. Our prior qualitative research also substantiates this finding (18). Losing a dosimeter involved a hefty penalty in our setting and our study has shown that this practice may potentially result in MRWs being exposed to higher doses of radiation at work, because they abandoned the monitoring system to avoid the penalty. As alternatives, employers may consider introducing a scheme to insure the dosimeters for any non-negligent loss or damage, or substituting the penalty for dosimeter loss with a penalty for dosimeter non-use or non-adherence.

A previous study in Malaysia reported that 69% of participants in public health facilities used dosimeters, similar to our finding (11). It appears that Malaysia still lagging far behind other parts of the world in relation to dosimeter use: For instance, radiographers in Nigeria, healthcare workers in United Arab Emirates and the radiologists in Jordan have reported higher compliance rates of 97.0% (Nigeria), 96.0% (United Arab Emirates) and 93.5% (Jordan) in using dosimeters (7,10,16). We hypothesize that the local regulations or safety policies may influence local practice. In many countries workers who lose dosimeters need to report the loss to the responsible officer, provide the information necessary to investigate and estimate the worker's radiation exposure during the relevant period (25-27). However, this is not part of the Malaysian guidelines and none of the workers in our previous study mentioned it (18). No mention of any fine or penalty for dosimeter loss was found for other countries.

Respondents in this current study showed a universal use of radioprotective apron but not the thyroid shield, which confirmed a previous study's finding (28). Most workers who answered that they used thyroid shields less than 100% of the time practised protection habits by applying the ALARA principles to reduce radiation exposure to protect themselves. However, the small number of MRWs who required the thyroid shield usage but neither used it nor practised ALARA principles stated that there were no available thyroid shields, and this was also found in previous qualitative explorations (17, 29). The thyroid shields are small in size, so are easily

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worn out and misplaced. However, they are very expensive so are not always replaced when they are lost or damaged. In addition, the shield design contributed to the non-adherence as respondents in our study and others have reported skin irritation and annoyance when using them [17].

Due to the limited availability of thyroid shields, radiologists were more consistent in using them compared to other workers. This finding is related to the fact that radiologists need to be physically close to the patient during irradiation, resulting in other workers prioritizing the radiologists using the thyroid shield [17]. In the current study, working in high exposure procedures such as interventional radiology was an important factor for MRWs to use the thyroid shield. Interventionalists in a previous study recorded more than 95% usage of the thyroid shield, aided by the adequacy of the shields [15].

Interestingly, MRWs who work office hours were more consistent in using thyroid shields and dosimeters than those working shift hours. It has been suggested that the presence of supervisors to monitor the workers during regular office hours may explain the workers' behaviours [30].

The gender factor was found significant only in dosimeter use. Female workers were more likely to be consistent in measuring their radiation exposures, which corresponds with reports that health and protective behaviour is gender-sensitive, being more positive in females than males [31, 32]. Previous studies also reported better adherence to the use of dosimeters among female radiation workers [12, 33]. This finding may also relate to the known risks if a woman is pregnant.

Respondents in private hospitals were less consistent in using radioprotective aprons and dosimeters compared to respondents from public hospitals. Khoshakhlagh *et al.* (2019) who studied safety culture among nurses considered that the Ministry of Health invested more heavily in quality and safety than the profit-making hospitals [34].

Age was a significant factor for adherence to the radioprotective aprons, with the older respondents being more consistent. As reported previously, middle-aged adults are less willing to engage in risky conditions regarding the health domain as they are more prone to health risks than younger workers [35].

Despite the fact that previous studies have reported poor radiation protection practices among MRWs, they often did not examine other exposure reduction techniques taken by the workers, such as keeping a distance of more than two metres from the patient/radiation source, minimizing the time during irradiation, or utilizing structural affixed or mobile shielding [36, 37]. Without such data, it is not surprising that many of the prior reports tended to overestimate the exposure of MRW to ionizing radiation and deemed them as poorly practising radiation protection [7-16]. Likewise, if other control measures were not taken into account for each respondent in our study, the adherence rates for radioprotective aprons and thyroid shields were only 74% and 31% respectively which is lower than we found. Overall, this study proved the importance of accurately assessing radiation protection and monitoring practices to tackle the real occupational safety and health issues among MRWs.

The independent explanatory variables (personal and occupational data) in this study explained only a small proportion of the variance in radioprotective garments and dosimeters usage consistencies. Thus, a fixed conclusion cannot be made because human behaviour is complex. In order to further understand the workers' conduct in radiation safety, some behavioural studies should be embarked on.

Study limitations

Our study has some limitations. There may be response bias as the survey tool required the respondents to self-report their behaviours, and selection bias as those concerned by radiation protection practices may have been more willing to complete the survey. Moreover, the number of respondents in this study represented a small fraction of the total MRWs population in Malaysia (N=10,621) [38]. We acknowledge that a larger sample size would allow a better characterization of adherence to radiation protection practices.

Study strengths and contribution

Strengths of our study were a large sample size, and the involvement of MRWs in various job positions from all types of medical institutions in this country. In addition, this study has provided valuable findings about the use of ALARA principles in radiation protection, as radiation safety assessment should not be made solely on personal protective equipment usage.

CONCLUSION

The assessment of radiation protection and radiation monitoring practices is more accurate when we understand the workers' tasks, exposure level and control measures. Including all levels of controls will avoid underestimation of safety practices among workers and overestimation of their occupational risks. Shortages of personal protective equipment should be dealt with wherever possible. There is an urgent need to improve the adherence rate of personal dosimeter usage in Malaysia by reviewing all the suggested strategies in order to comply with the occupational radiation monitoring requirements.

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