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Research article

Investigating knowledge of DRLs, image quality and radiation dose in PET/CT and CT imaging among medical imaging professionals

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A R T I C L E I N F O

Keywords:
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Protocol parameters

A B S T R A C T

Objective: To investigate the knowledge of diagnostic reference levels (DRLs), image quality, radiation dose and protocol parameters among Jordanian medical imaging professionals (MIPs) involved in PET/CT and CT scan procedures.
Materials and methods: A questionnaire was designed and distributed to MIPs in Jordan. The survey comprised four sections: demographic data, MIP knowledge on dose/protocol parameters, image quality, and DRLs. Statistical analyses were performed utilizing Pearson's correlation, t-tests, ANOVA, and linear regression, with a significance level of 95 % and a p-value threshold of <0.05.
Results: The study involved 147 participants. Most respondents were male (76.2 %), and most were aged 26–35 years (44.2 %). Approximately 51 % held a bachelor's degree, and the most common range of experience was 3–5 years (28.6 %). Participants showed a moderate level of knowledge regarding dose and protocol parameters, with a mean score of 61.8 %. The mean scores for knowledge of image quality and DRLs were 45.2 % and 44.8 %, respectively. The age group of the MIPs and the total experience were found to have a significant impact on the knowledge of the dose and protocol parameters, as well as the DRLs. Additionally, experience was found to have a significant influence on knowledge of the dose and protocol parameters. The study revealed a positive and significant effect of MIPs' knowledge of dose/protocol parameters and image quality on their knowledge of DRLs.
Conclusions: This study indicates that professionals across five specialties who are engaged in PET/CT and CT imaging possess a moderate understanding of dosage and protocol parameters. However, there is a notable gap in knowledge regarding DRLs and image quality. To address this issue, it is recommended that MIPs actively engage in educational programs emphasizing exposure parameters and their impact on image quality. Additionally, access to comprehensive education and training programs will enable MIPs to grasp the complexities of DRLs and their implications, facilitating their implementation in clinical practice.

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1. Introduction

Since its introduction in 1972, computed tomography (CT) technology has advanced significantly and is now integrated with hybrid imaging scanners such as PET/CT [1]. The use of CT technology enables medical imaging professionals to produce high-quality images of anatomical structures in a non-invasive manner [2,3]. Despite the widespread use of CT as a tool for medical diagnosis [4], there are concerns about the possible impact of ionizing radiation on living tissues, leading to an increase in the stochastic risk illness, such as cancer [5,6]. Additionally, efforts have been made to impart relevant knowledge on DRLs, ensuring that contemporary CT practices adhere firmly to radiation protection principles and are dedicated to applying the ALARA standard [1,2,6–8]. DRLs are used as benchmarks, together with dose optimization methods that aim to balance image quality and patient dose [9–11]. DRLs are not dose limits; instead, they are tools for optimization in medical imaging that use ionizing radiation. it provided an indication of the expected radiation dose that an average-sized patient would receive during a given imaging procedure. Dose itself refers to the actual amount of radiation received by a patient during a medical imaging procedure. DRLs are used to compare typical doses from medical imaging procedures and help identify where doses may be higher than needed and can be optimized without compromising image quality [11]. The knowledge and expertise of MIPs play a crucial role in the optimization process, as they directly influence not only the establishment of DRLs but also the determination of the correct dose for acceptable diagnostic image quality. Thus, it is essential to prioritize training courses for MIPs, as they represent the final stage in the sequence of radiation protection during examinations [12].

Several studies revealed the level of awareness and knowledge of image quality, radiation biology, radiation protection, and DRLs in CT. For example, Foley et al. (2013) found that radiologists were generally unaware of the recommended DRLs [2]. Furthermore, a set of studies provides a reliable basis for the awareness and knowledge levels of different aspects of CT parameters. These studies have shown a considerable variation in the understanding of CT preceptors, particularly towards the operation of automatic tube current modulation (ATCM) and the influence of kVp and mAs on patient dose and image quality across countries. For example, in Jordan, 57.4 % of a sample of CT radiographers reported that they have sufficient skills to modify parameters without degrading image quality [3]. These studies almost uniformly agree on the importance of regular training and education of radiologists and radiographers. Furthermore, as suggested by the findings of various studies, it is necessary to identify the factors that contribute to low levels of knowledge and awareness among MIPs with regards to radiation dose, protocol parameters, image quality and DRLs [6,7,10,13–18]. To the best of the author's knowledge, no previous research had investigated the knowledge of MIPs engaged in the PET/CT process. Moreover, this is the first study in Jordan that investigate the knowledge of five disciplines who are all involved in the imaging process of PET/CT and CT scans. Therefore, the aim of this study is to assess the knowledge of DRLs, image quality, radiation dose and protocol parameters among Jordanian MIPs who are involved in PET/CT and CT scan procedures.

2. Materials and Methods

2.1. Population study and survey

This is a prospective cross-sectional study in which data were collected using an online survey tool (SurveyMonkey). The survey was distributed through social media invitations to MIPs who are involved in PET/CT and CT imaging in various hospitals, healthcare facilities, and diagnostic centres in Jordan. No personal information that could lead to the identification of participants was collected throughout this process. The survey's inclusion criteria required participants to be employed in positions directly related to PET/CT or CT procedures (i.e., PET/CT and CT radiographer/technologist, radiologist, NM physician or medical physicist). The sampling procedure utilized a nonprobability sampling approach, employing convenience and snowball sampling techniques.

2.2. Questionnaire

The survey consisted of four main sections: Section 1 collected demographic data and Section 2 collected data on the knowledge of MIPs regarding radiation dose/protocol parameters. In this section, 13 questions were posed to the MIPs. The assessment questions focused on changing the CT scan parameters (kVp, mAs, pitch, slice thickness, noise index, rotation time, and collimation) for different scenarios, determining whether changing PET/CT or CT protocol parameters decrease patient dose. Other questions were related to automated tube current modulation (ATCM). Section three is divided into three main parts, focusing on noise level, contrast resolution, and spatial resolution. This section collected data on the knowledge of the MIPs regarding image quality in PET/CT and CT data. A total of 15 question items focused on factors that affecting the noise level in CT images (i.e. using high pitch value, changing the kVp from 120 to 100, reducing the tube current, increasing the slice thickness, using the smoothing reconstruction kernel (filter) and scanning large patient size), technical factors that decrease contrast resolution in CT images (i.e., change in kVp from 120 to 100, reducing the tube current, using large slice thickness and scanning large patient size) and factors that increase spatial resolution in CT images (i.e., using large displayed field of view (DFOV), large slice thickness, high pitch value (more than 1) and smooth algorithm). Section 4 collected data on knowledge of DRLs. A total of 20 question items evaluated the scope and rationale of DRLs, such as DRL description in radiology, statements related to DRLs in PET/CT and CT, and factors that affect DRL values, coupled with the main DRL quantities.

A participant information sheet was provided to outline the purpose and scope of the study, as well as the role of the participants. Additionally, a consent form was included to obtain the participants' voluntary informed consent.

2.3. Validity, reliability, and normality

Validity: This questionnaire was subjected to a two-phase validation process [19,20]. The first phase included expert validation to ensure the validity of the content. The content validation process was carried out by an eight-member team of experts, which included university professors, medical physicists, NM physicians, CT and PET/CT specialists. The second validation process was Face validation, which was performed with the participation of 10 volunteer MIPs. The content validity index (CVI) and face validity index (FVI) were calculated and used [20,21]. The questionnaire showed a content validity index of item level (I-CVI) and a face validity index of item level (I-FVI) greater than 0.83 for both indices, indicating that the questions were clear, understandable, and comprehensible. This was followed by a pilot study, which aimed to improve the validity of the tool and provide ideas and approaches that may not have been previously anticipated, increasing the chances of obtaining clearer findings in the main study [22].

Reliability: The test-retest method was used to evaluate the reliability of the questionnaire. Since the questionnaire contained dichotomous items, its internal consistency could be determined using this method [23]. Twenty-two respondents completed the questionnaire twice, with a two-week interval between responses. The results showed a Pearson correlation coefficient of 0.875, indicating high internal consistency (>0.8). Therefore, the questionnaire was considered valid, reliable, and strong in measuring the intended parameters.

Normality: A normality test was performed using skewness and kurtosis [24] as well as a normal Q-Q plot to test the normality of demographic variables (gender, age, job position and years of experience) and dependent variables (knowledge of the dose/protocol parameters in PET/CT and CT, knowledge of image quality in CT and knowledge of DRLs). The results indicate a normally distributed sample, allowing for a valid parametric statistical analysis.

2.4. Statistical analysis

Survey data were analysed using the Statistical Package for Social Sciences software (SPSS, IBM Statistical Package Version 29). The data were subjected to descriptive and inferential statistical tests, including Pearson's coefficient, independent sample *t*-test, one-way ANOVA, Scheffe's post hoc test, and multiple linear regression at a 95 % confidence level ($p < 0.05$). Each question had one correct answer, resulting in binary true/false responses. The knowledge test had a maximum score of 48, with correct answer scored as 1 and incorrect answer scored as 0, indicating that higher scores reflected greater knowledge. To pass each section, a score equal to or greater than the median score was considered [3]. Consequently, the results were classified as follows: low for scores less than 60 %, moderate for scores between 61 % and 70 %, good for scores between 71 % and 80 %, and excellent for scores above 80 % [25]. The calculated sample size, determined by the Steven Thomson equation [26], was 136.

2.5. Ethical considerations

This study was approved by the Research Ethics Committee (REC) of The National University of Malaysia (number UKM/PPI/111/8/JEP-2021-501), and the Institutional Review Board (IRB) of Jordan University of Science and Technology (number 3/141/2021).

Table 1
Demographic variables.

	N (%)
Gender	
- Male 112 (76.2 %)	
- Female	35 (23.8 %)
Age groups	
– 20-25	23 (15.6 %)
– 2 6-35	65 (44.2 %)
– 36-45	44 (29.9 %)
- More than 45	15 (10.2 %)
Highest academic qualification	
- Diploma	15 (10.2 %)
- BSc (Bachelor's degree)	75 (51 %)
- MSc (Master's degree)	19 (12.9 %)
- MD (Medical Doctorate)	37 (25.2 %)
- Post graduate diploma	1 (0.7 %)
- CT radiographer/technologist	56 (38.1 %)
- PET-CT Radiographer/Technologist	20 (13.6 %)
- Medical physicist	24 (16.3 %)
- Nuclear Medicine Physician	31 (21.1 %)
- Radiologist	16 (10.9 %)
– 0–2 years	36 (24.5 %)
– 3–5 years	42 (28.6 %)
– 6–10 years	30 (20.4 %)
– 11 and above.	39 (26.5 %)

3. Results

The demographic characteristics of the study respondents included a total of 147 participants. Table 1 shows the demographic details of the participants. The results revealed that most of the respondents (N = 112; 76.2 %) were male, with the largest age group being (26–35) years old (N = 65; 44.2 %) and the highest level of academic qualification being a bachelor's degree (N = 75; 51 %). The predominant job title among the respondents was CT radiographer/technologists (N = 56; 38.1 %), while the highest reported range of years of experience was 3–5 years (N = 42; 28.6 %). Fig. 1 shows the mean total scores for the three knowledge domains, with the highest scores observed among males aged over 45 years, individuals holding an MSc degree, NM physicians, and those with more than 11 years of experience.

3.1. Knowledge of MIPs: dose/protocol parameters, image quality, and DRLs

In this section, respondents' knowledge of dose/protocol parameters, image quality, and DRLs was analysed. The mean score of knowledge towards the dose/protocol parameters was 8.03 ± 2.13 (61.8 %). Of the 147 participants, 84 passed this section. The mean score for image quality was 7.38 ± 2.18 (49.2 %). 75 respondents passed this section. Finally, the mean knowledge score for DRL was 8.96 ± 2.82 (44.8 %), with 79 participants achieving a pass score. The data are summarized in Table 2.

3.2. Relationships between knowledge of dose/protocol parameters, image quality, and DRLs

The results, as shown in Table 3, indicate a moderately positive significant correlation (r = 0.334) between knowledge of dose/protocol parameters and knowledge of DRLs. Furthermore, a weak positive significant correlation (r = 0.234) was found between knowledge of image quality and knowledge of DRLs.

3.3. The effects of gender, age, education, job position, and years of experience on knowledge of MIPs towards dose/parameters, image quality, and DRLs

The effect of gender, age, education, job position, and years of experience on MIP knowledge was examined. As shown in Table 4, there were no significant differences in the means of gender, education level, or job position. However, there was a significant difference in age groups related to knowledge of the dose/protocol parameters and the DRL (p = <0.001, p = 0.003), respectively. There was no significant difference in means towards knowledge of image quality. Furthermore, there was a significant difference in knowledge of dose/protocol parameters according to years of experience exists, with (p = 0.001). The. A post hoc test was performed to determine which age groups and years of experience had significant differences in terms of MIP knowledge of dose and protocol parameters, as well as their knowledge of DRL. The results revealed a significant difference in knowledge of the dose and protocol parameters between the age groups 20–25 and 36–45 (p = 0.038), and between the age groups 20–25 and > 45 (p = 0.018). While for knowledge of DRLs, the post hoc test results revealed a significant difference between the age groups 20–25 and > 45 (p = 0.016). Finally, Table 5 summarized the results for years of experience and knowledge of dose and protocol parameters. The post hoc test showed significant differences between years of experience 0–2 and >11) (p = 0.011), and between years of experience 3–5 and >11 (p = 0.03).

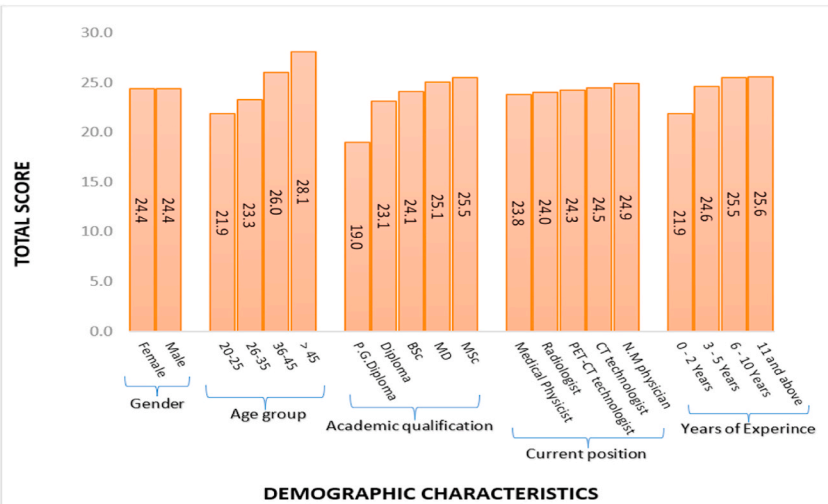

Fig. 1. Total knowledge mean score out of (48 points) versus demographic characteristics.

Table 2
Knowledge Scores on dose/protocol parameters, image quality and DRLs.

Statistics	Knowledge of Dose/protocol parameters. (13 points)	Knowledge of Image quality (15points)	Knowledge of DRLs (20 points)
Mean score ± SD (%)	8.03 ± 2.13 (61.8 %)	7.38 ± 2.18 (49.2 %)	8.96 ± 2.82 (44.8 %)
Median score	8	8	9
N (%)	84 (57.14 %)	75 (51.02 %)	79 (53.74 %)
Max Score	13	12	15
Min Score	3	3	3

N = number of participants who got a score of ≥median score.

Table 3
Correlations between knowledge of dose/protocol parameters, knowledge of image quality, and knowledge of DRLs (N = 147).

Characteristics	1	2	3
1. Knowledge (Dose and Parameters)	1		
2. Knowledge (Image Quality)	0.070	1	
3. Knowledge (DRL)	0.334*	0.234[a]	1

[a] *The correlation was significant at the 0.05 level.*

Table 4
Impact of age on knowledge of dose/parameters, image quality, and DRLs.

Domain	Age groups	N	Mean	SD	*p-value*
Knowledge (Dose and Parameters)	20–25	23	7.17	1.56	**<0.001**
	26–35	65	7.58	2.04	
	36–45	44	8.70	2.18	
	More than 45	15	9.33	2.09	
	Total	147	8.03	2.13	
Knowledge (Image Quality)	20–25	23	6.91	2.02	0.289
	26–35	65	7.18	2.07	
	36–45	44	7.70	2.37	
	More than 45	15	8.00	2.24	
	Total	147	7.38	2.17	
Knowledge (DRL)	20–25	23	7.78	2.97	**0.003**
	26–35	65	8.54	2.40	
	36–45	44	9.59	2.87	
	More than 45	15	10.73	3.15	
	Total	147	8.96	2.82	

3.3.1. The effect of knowledge of dose/protocol parameters and image quality on knowledge of DRLs

Multiple regression analysis was conducted to determine the extent to which knowledge dose/protocol parameters and image quality predicted the knowledge of DRLs. The results indicated a positive relationship between both the dose/protocol parameters/ image quality knowledge and the knowledge of the DRL, with a moderate correlation strength of 0.40. Multiple regression analysis for DRL knowledge suggested that knowledge dose/protocol parameters and image quality were considered predictors of DRL knowledge than any individual variable alone. The overall model was statistically significant ($F (2,144) = 13.34$, $p < 00.001$) and represented 15.6 % of the variance in knowledge of DRLs. The regression coefficients, standard errors, and significance levels for each predictor variable are presented in Table 6.

4. Discussion

This study aimed to investigate the knowledge of DRL, image quality, and dose among MIPs involved in PET/CT and CT procedures in Jordan. This study emphasized the importance of DRLs, understanding the protocol parameters that affect both image quality and radiation dose, and incorporating this knowledge into clinical practice to avoid subjecting patients to unnecessary radiation doses while achieving acceptable image quality [2,9,10,25]. It also emphasized the need to follow the safety guidelines recommended by international organizations to achieve both justification and optimization in medical imaging examinations. According to our findings, identifying knowledge gaps and developing continuous education programs are critical to ensuring safe and effective medical imaging procedures [6,7,10,13–18,25].

In Jordan, Alhasan et al. (2016) conducted two studies to assess the knowledge of radiation doses among radiographers and radiologists [15,27]. The results indicated that the participants had a low level of awareness and knowledge, with radiographers scoring less than 50 % and radiologists scoring 57.4 %. One possible reason is the lack of adequate training and education in these areas. Rawashdeh et al. (2018) reported that CT radiographers had a good understanding of exposure parameters and their effects on image quality and patient dose, with an average score of 68.3 % [28]. This study produced lower results compared to Rawashdeh et al. (2018)

Table 5
Effect of years of experience on knowledge of dose/parameters, image quality, and DRLs.

Domain	Years of experience	N	Mean	Std. Deviation	*P-value*
Knowledge (Dose and Parameters)	0–2 years	36	7.28	2.023	**0.001**
	3–5 years	42	7.50	2.121	
	6–10 years	30	8.60	1.976	
	11 and above.	39	8.87	1.989	
	Total	147	8.03	2.127	
Knowledge (Image Quality)	0–2 years	36	6.61	2.032	0.094
	3–5 years	42	7.79	2.343	
	6–10 years	30	7.47	2.113	
	11 and above.	39	7.59	2.074	
	Total	147	7.38	2.178	
Knowledge (DRL)	0–2 years	36	7.97	2.646	0.110
	3–5 years	42	9.33	2.969	
	6–10 years	30	9.40	2.848	
	11 and above.	39	9.13	2.687	
	Total	147	8.96	2.823	

with 61.8 % for dose and protocol parameters and 49.2 % for image quality. However, Rawashdeh et al. (2018) found a lack of knowledge of DRLs, with only 17 % of the participants correctly stating it, these findings were justified by the low level of participation. whereas our study produced higher, but still low score level, with a 44.8 % correct answer rate [28]. The main reasons for these low level of knowledge may referred to that the concept of DRLs is relatively new in Jordan, with only a few studies initiated to establish DRLs for CT protocols since 2019 [29,30]. Additionally, there are no NDRLs or LDRLs established for PET/CT in Jordan, except for one recent study published in 2024 and this study was not published yet at the time of the survey [31]. Moreover, the involvement of MIPs in establishing DRLs at the national and local levels is minimal, as most of the established ones are carried out by academic staff. Furthermore, some studies have noted that lack of training on DRL establishment is one of the main factor affecting the knowledge level, as observed in studies from KSA [32]. In addition, these findings emphasize the importance of radiation dose training and education for medical imaging personnel to ensure that appropriate measures are taken to minimize radiation exposure to patients while maintaining image quality in clinical practice. Furthermore, the importance of customized educational initiatives for MIPs in Jordan, particularly in DRLs and exposure parameters, lies in acknowledging factors that affect their participation in emerging technologies. This is especially important given the recent introduction of DRLs in the country.

it is crucial for MIPs in Jordan to continuously update their skills to stay up to date with the latest technological advancements. Implementing customized educational initiatives is critical to ensure compliance with DRL, optimizing radiation doses, and prioritizing patient safety. To improve patient outcomes and minimize radiation-related risks, it is crucial for MIPs to have the necessary expertise and proficiency to employ the most advanced imaging techniques as the field of medical imaging progresses at an accelerated pace [33]. Customized education is essential in this context because it enables MIPs to effectively manage advanced imaging technologies. Furthermore, education is vital to address patient safety concerns, as DRLs and exposure parameters have significant implications for medical image quality and radiation doses. A comprehensive understanding of these parameters is necessary to optimize doses while maintaining image quality and fostering a culture of safety. The varied skill levels among MIPs, resulting from variations in experience and training, underscores the need for customized educational programs. Tailoring initiatives help address proficiency variations, bridge skill gaps, and promote a standardized skill set across the workforce. The dynamic nature of protocols and guidelines in medical imaging requires ongoing education [33,34]. The continuous emphasis on education ensures that MIPs remain aligned with evolving protocols, facilitating compliance with industry standards. However, the implementation of these recommendations faces challenges such as resource limitations, limited access to educational materials, and time constraints. Overcoming resistance to change, rooted in established practices, requires strategies to foster a mindset of continuous learning [35]. Integrating education into MIPs' daily workflow demands careful planning and support, balancing clinical responsibilities with learning initiatives.

Upon comparing our findings with those of studies conducted at regional and international levels, notable variations were observed. The outcomes of this study regarding knowledge of dose and protocol parameters exhibited both higher and lower levels in comparison to previous research. For instance, Nigerian radiographers demonstrated a lower understanding of CT parameters (42 %) compared to our results, whereas our findings were inferior to those reported in the UAE, Ireland, and Malaysia (72.2 %, 70.3 %, and 63 %, respectively). Conversely, in this study, the knowledge of DRLs was found to be 44.8 %, which was notably higher compared to the UAE (13.2 %) and Malaysia (32.6 %), but nearly similar to that of Nigeria (45.8 %), and lower than that of Ireland (86 %) [2,9,10,25]. The variations observed in knowledge levels between different studies could be attributed to several factors, including differences in educational systems, access to training programs, and awareness of radiation safety protocols. Furthermore, variations in the

Table 6
Multiple regression coefficients.

Variable	B	SE	Beta	p
Knowledge of Dose/protocol Parameters	0.42	0.10	0.32	<0.001
Knowledge of image quality.	0.28	0.10	0.21	0.006

availability of resources and guidelines in different regions may contribute to the differences in the level of knowledge observed.

4.1. Demographics

This study not only delves into protocols and parameters but also recognizes a crucial element in the image formation equation (i.e., the human aspect). The role of MIPs is critical and extends beyond executing procedures for various patients. MIPs often collaborate to develop protocols that are tailored to various characteristics of the patient, such as size, age, and clinical indication. This study aimed to highlight and underscore the importance of optimizing all aspects involved in the imaging process, incorporating the perspectives of MIPs engaged in standard practice to uphold accepted clinical standards. The research involved all participating MIPs in decision-making processes for PET/CT imaging. As stated by Romans et al. (2018), PET/CT technologists as part of the MIPs in this study, carry a unique blend of responsibilities from nuclear medicine and CT technology, yet are rarely trained in both modalities [36]. Each discipline has distinct requirements related to clinical procedures, radiation protection, and clinical history due to the nature of ionizing radiation. In addition, some imaging departments perform standard diagnostic CT scans on PET/CT scanners, highlighting the need for a versatile set of skills for technologists as well as the collaboration between radiologists and N.M physicians and a follow up with medical physicists to ensure that all procedures are planned, performed, and interpreted in a standardised way.

According to the results, most of the MIPs were male and mostly middle-aged (26–35 years) with an academic qualification of bachelor's degree. The highest number of participants worked as CT radiographers/technologists. Even though demographic variables such as gender, job position and education had no significant effect on MIPs' knowledge of dose/protocol parameters, image quality, and DRL. Age and experience did have a significant influence. However, this was observed only for dose/protocol parameters in relation to experience, and for both dose/protocol parameters and DRL in relation to age [9,32]. It is worth highlighting a significant variance between the youngest and oldest age groups; it is possible that more experienced staff members have had greater opportunities for both further training and professional development over time. Additionally, less experienced staff may have recently completed tertiary education and therefore may have received more up-to-date training. It is important to note that these are general trends observed within this study, but individual circumstances may still exist.

The results suggest that age and years of experience are important factors that influence knowledge of MIP towards dose and protocol parameters in PET/CT and CT procedures, as well as their knowledge of DRLs. It is important for MIPs to continuously update their knowledge and skills, particularly with advances in technology and changes in protocols and guidelines. Training and education programs can be implemented to address knowledge gaps among staff and improve patient safety and outcomes.

4.2. Dose, protocol parameters, and image quality

According to the International Commission on Radiological Protection (ICRP) and American College of Radiology (ACR) practice guidelines, it is crucial for medical personnel to be synchronous when designing dose/protocol parameter settings and balancing image quality with radiation dose to minimize radiation exposure while obtaining accurate diagnostic information [37–39]. However, only 61.8 % and 45.2 % of the MIPs surveyed had competent knowledge of dose/protocol parameters and image quality parameters, respectively. This indicates suboptimal knowledge of the dose and image quality parameters in PET/CT and CT procedures, and this may be due to technical complexity of PET/CT and CT imaging, which involve complex technology and physics.

In Jordan, hybrid imaging procedures require the coordination of various MIPs, each with a different role. For example, nuclear medicine physicians are responsible for interpreting PET/CT images, while radiologists offer consultations on CT images within hybrid images, especially if PET/CT scans are performed in conjunction with contrast-enhanced CT scans. Physicists oversee the optimization process by reviewing imaging protocols, and technologists, who play a vital role in imaging practice, may specialize in one aspect of the process (i.e., their background experience as either a CT technologist or N.M technologist). Hence, there is a need for a new generation of technologists who are skilled in both techniques and capable of managing diverse scenarios. This includes navigating different scan protocols, understanding various clinical indications, utilizing CT for different purposes within PET/CT, and adjusting protocols to accommodate variations in patient size and age. This necessity becomes even more pronounced if the technologists responsibilities entail working in rotations across different modalities in their departments.

It can be challenging for individuals without specialized training to fully understand the different factors that would affect image quality and dose [36]. Furthermore, as PET/CT and CT imaging technology evolves, it may be challenging for healthcare providers to stay abreast of the current developments in the field [40]. This can make it difficult to stay up to date on best practices for optimizing image quality and dose. Furthermore, some of the individuals who participated in the survey did not have a role in developing or altering imaging protocols [25]. It is important to note that suboptimal theoretical knowledge, as revealed by the questionnaire, does not imply malpractice because most of those radiographers/technologists would follow the parameters established by the application specialist and/or senior colleague(s). However, such knowledge would remain invaluable in dealing with unusual situations and optimizing their daily routine work with confidence.

4.3. DRLs

The efficacy of DRLs can be determined by their ability to optimize and ensure that patients are not subjected to excessive radiation doses, while providing high-quality diagnostic images [41]. However, only 44.8 % of the MIPs surveyed had adequate knowledge of DRLs in PET/CT and CT procedures. This suggests that there is a lack of emphasis on this topic in training and education programs, and there is a need to improve knowledge on how to use and establish DRLs in medical imaging. The same pattern has been observed in other works due to the lack of emphasis on DRLs in training and education programs, the lack of awareness of the latest guidelines, and the lack of resources and training opportunities [3]. Regular updates and staying up-to-date with the latest recommendations are important to ensure safe and appropriate use of radiation in medical imaging procedures [41].

Finally, the positive relationship implies that, as one gains knowledge of dose/protocol parameters and image quality, one gains knowledge of DRLs. This outcome makes intuitive sense because understanding the proper use of dose/protocol parameters and image quality is critical in setting and maintaining DRLs. Furthermore, multiple regression analysis revealed that the combined effects of dose/protocol parameters and image quality were better predictors of the knowledge of DRLs than any individual variable alone. This result implies that understanding DRLs requires knowledge of both dose/protocol parameters and image quality.

4.4. Conclusions

The MIPs involved in PET/CT and CT had a moderate understanding of dosage and protocol parameters, but their knowledge was lacking in some areas (e.g. image quality parameters including spatial and contrast resolution and some factors affecting the noise level). To address this, it would be beneficial for them to participate in educational programs focused on exposure parameters. Staff knowledge of DRLs and image quality needs to be improved through a timely plan. Making information more accessible within institutions, as well as offering educational courses, would be beneficial. It is critical to reduce dose while maintaining acceptable image quality; thus, continuous education regarding optimization is required. Furthermore, the findings indicate that the knowledge of the dose/protocol parameter and image quality are important predictors of the knowledge of the DRL and that their combined effects are more accurate than any individual variable alone. The study emphasizes the importance of radiology professional education and training programs to improve their understanding of DRLs and the factors that contribute to them.

5. Recommendations

The findings of this study will be shared with all participating hospitals to actively involve them in the process of improvement and to encourage evidence-based practice (EBP). It is notable that radiographers, for instance, rely on their tertiary education and personal experience for imaging technique decisions, emphasizing the necessity of EBP. Although they depend on personal experience, they may not consistently align with best practices or research. Therefore, the integration of evidence-based principles, encompassing research, patient circumstances, and clinical experience, is crucial for optimal decision-making and care [42]. Subsequently, to address the benefits and implications of our research, we have outlined concrete steps. First, we will implement regular continuous professional development (CPD) programs in collaboration with the Jordanian Society of Nuclear Medicine (JOSNM) and the Jordanian Society of Radiographers (JSR) and other stakeholders in order to improve the knowledge and skills of medical imaging professionals and to provide specialized training tailored to the specific needs of MIPs [43]. Second, our objective is to develop standardized protocols for the effective use of DRLs, ensuring consistency and quality in imaging practices [44]. These actions are designed to translate our research findings into tangible improvements in clinical practice and patient care.

6. Limitations

The questionnaire focuses solely on MIP knowledge on DRLs, dose, and image quality topics and does not cover some other aspects like radiobiology and radiation protection principles, which means that the participants' full knowledge and awareness may not be fully reflected. Additionally, the study sample may not fully represent the general population as it only includes individuals who voluntarily completed the questionnaire, resulting in a response rate of 70.3 %, with some categories, such as radiologists being underrepresented due to non-completion. It is important to note that the researcher has no control over the environment in which the participants complete the questionnaire, which may affect the precision of their responses.

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Data availability statement

Data associated with this study will be available upon request.

CRediT authorship contribution statement

Qays Alhorani: Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Akram Al-Ibraheem:** Writing – review & editing, Resources, Investigation, Data curation. **Mohammad Rawashdeh:** Writing – review & editing, Validation, Supervision, Formal analysis, Conceptualization. **Essam Alkhybari:** Writing – review & editing, Validation, Supervision. **Akmal Sabarudin:** Writing – review & editing, Validation, Supervision, Methodology, Formal analysis, Conceptualization. **Rukiah A. Latiff:** Writing – review & editing, Validation, Supervision, Conceptualization. **Mazlyfarina Mohamad:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e30030.

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