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Occupational radiation exposures for medical workers in Pakistan – An overview

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Abstract

The imperative use of ionizing radiation in medicine causes the inevitable occupational exposure of the medical workers during the course of routine duties. The magnitude of health risk due to such radiation exposures has been described in terms of occupational radiation doses. In this context, it is obligatory to monitor, measure and document the radiation dose of occupationally exposed medical workers. This study aims to review the whole-body occupational radiation exposures of medical workers in Pakistan. Specifically, online literature published during 2000-2018 was reviewed for the occupational radiation exposures of Pakistani medical workers. Analysis of the extracted personal dosimetry data revealed that the total number of monitored medical occupational workers was 26046. The range of total cumulative and annual average effective doses was 94-15785 Person-mSv and 0.66-7.37 mSv, respectively. A significant number of the workers (25477; ~98%) received an annual dose below 5 mSv, while only 18 workers received an occupational exposure exceeding the annual dose limit of 20 mSv. It is expected that this study will provide a useful reference for evaluating and improving radiation protection and safety policies in the country.

Key words: occupational exposure; radiation protection; effective dose; dose limits.

Introduction

Occupational radiation exposures are defined as the exposure of workers to ionizing radiation as a result of their work in the radiation fields, both natural and man-made, except for exposures from the standards, practices or sources exempted by standards [1-2]. Occupational radiation exposure of the workers during the course of routine duties is inevitable and pose an inherent health risk if ample efforts for protection are not ensured [3-5]. In this context, one of the most important aspects of radiation protection is to monitor the occupational radiation exposure of each individual worker, primarily to keep the occupational workers below the known thresholds for the manifestation of deterministic effects and to minimize the probability of stochastic hazards of ionizing radiations. Moreover, exposure monitoring of occupational workers also provides information regarding the capability and effectiveness of the radiation protection program. In addition, individual monitoring program also aims to reveal compliance with maximum permissible dose limit as required by the national regulations and international recommendations and standards [6-8].

Among others, ionizing radiations are extensively used in medicine, both for diagnostic and therapeutic purposes [9]. Specifically, many medical diagnostic applications exploit

ionizing radiations either external or internal to the patient in the form of diagnostic radiology or nuclear medicine, respectively. Likewise, the medical therapeutic applications of ionizing radiations are also conventionally classified into two categories- based on whether the source of radiation is placed external (i.e., teletherapy) or internal (i.e., brachytherapy and internal nuclear medicine) to the patient [2,9]. All these radiation-based medical procedures are carried out with the help of specially trained medical staff- the occupational workers. It is obvious that this subset of medical staff (i.e., the occupational workers) is at elevated risk of radiation hazards which needs to be appropriately assessed in terms of monitoring the radiation dose received by each individual worker.

Medical institutes/centers in Pakistan that exercise radiation-based practices comprise one or more of the following mainstream departments; diagnostic radiology (DR) department which offers conventional diagnostic facilities such as x-ray unit, computed tomography, mammography, fluoroscopy, etc. Nuclear medicine (NM) departments make use of unsealed radionuclides (e.g., Tc-99m, I-131, etc.) for both diagnostic and therapeutic purposes. Radioimmunoassay (RIA) is also considered an allied part of NM departments. In addition, few NM departments are also equipped with

cyclotron and ^{18}F fluorodeoxyglucose positron emission tomography (^{18}F FDG PET) systems. Radiotherapy (RT) departments comprise of medical linear accelerators, cobalt-60 teletherapy and brachytherapy units. The medical workers of the above-mentioned departments are occupationally exposed to ionizing radiations and thereby their radiation doses are monitored and documented, as per the guidance and obligations of national (i.e., Pakistan Nuclear Regulatory Authority; PNRA) [10] and international (i.e., International Commission on Radiological Protection; ICRP and International Atomic Energy Agency; IAEA) agencies [11-17].

Previously, a large cohort of studies focusing on the assessment of occupational exposed medical worker has been reported from around the globe, including Pakistan [6-9,18-35]. These studies, in particular those reported from Pakistan, are scattered, discuss/ focus on different dosimetry indices and non-overlapping study periods, all confounding a meaningful analysis and comparison. In this context, a comprehensive compilation and objective analysis of the studies reporting on the occupational exposure of Pakistani medical workers seems of potential importance. Specifically, such analysis will not only facilitate insights into the adherence with the obligatory requirements but also culminate a cross-platform comparison of our personal dosimetry patterns with other studies. With these objectives, we start with a brief history and evolution of radiation protection in Pakistan, followed by a comprehensive online literature review aimed at the occupational radiation exposure of Pakistani medical workers. Dosimetry analysis of the workers has also been based on the respective departments. Finally, the compiled dosimetry data has been compared to similar international studies. This work will provide a useful reference for the assessment and up-gradation of radiation protection and safety policies.

Radiation Protection in Pakistan; History and Evolution

The promulgation of the Pakistan Atomic Energy Commission (PAEC) ordinance in 1965 introduced the first comprehensive layout of the radiation protection program for occupational workers in Pakistan [36]. To further improve the radiation protection culture in the country, the first statutory structure, named as Directorate of Nuclear Safety and Radiation Protection (DNSRP) was established in 1984. Afterward, Pakistan signed the International Convention on Nuclear Safety (ICNS) in 1994; composition of an independent nuclear regulatory body, responsible for the legislative and regulatory framework (and its implementation) governing nuclear power and the use of ionizing radiation in the country, was among the various commitments as imposed by ICNS. To this end, Pakistan Nuclear Regulatory Board (PNRB) was established as a transitory measure, with the mandate to separate the regulatory functions from the promotional aspects of the nuclear program. In 2001, the Pakistan Nuclear Regulatory

Authority ordinance No.III was promulgated; consequently, the PNRA was established as a competent and independent body for the regulation of nuclear safety and radiation protection in the country [37]. Overall, these initiatives taken by the Government of Pakistan were aimed to regulate, safeguard, and monitor the activities pertaining to the use of ionizing radiations in the country.

Presently, PNRA is working as an independent regulatory body with the mission to protect radiation workers, the general public and the environment from the harmful effects of ionizing radiation by formulating and implementing effective regulations. In this perspective, PNRA has issued several regulations and guides as part of its regulatory framework on radiation protection for the management of/reducing occupational exposures. In particular, PNRA regulation PAK/904, focused on the safety of occupational workers, adopted the maximum permissible occupational dose limit as per the recommendations of IAEA and ICRP. Specifically, the maximum annual effective dose of occupational workers was set at 20 mSv averaged over a period of 5 years, with a stipulation that the individual dose should not exceed 50 mSv in any single year [10]. PNRA monitor all radiation-based facilities (including medical centers) in the country to ensure adherence to its regulations.

Methods

Online Literature Search

To compile the relevant data, a thorough search of the online literature pertaining to the studies published in peer-reviewed journals on the subject of occupational exposure in medical practices in Pakistan was conducted. Specifically, the online search was started with the relevant key words such as radiation protection, occupational exposure, effective dose, ionizing radiation, dose limit, etc. and was subsequently segregated to Pakistan. Four online international bibliographic databases i.e., PubMed, EMBASE, Scopus and Google Scholar were searched. Moreover, for relevant studies published in national research journals, the search was conducted using the “PakMediNet” database. The search was restricted to studies published from January 2000 to December 2018 in the English literature only. The references cited in each useful publication were traced for the identification of other relevant publications.

Study Selection Procedure and Criteria

The selection of relevant studies was performed as per the following procedure: One reviewer (MA) carried out the initial searches and identified the studies. In the case of duplicate studies, only one was included. Two independent reviewers (IA and AK) screened the title and abstract of all the identified studies to determine their relevance towards the objectives of the present work. The inclusion criteria were: English language literature published during 2000-2018, focused on the assessment and analysis of the whole body radiation exposure

of medical workers in Pakistan. Disagreement, if any, regarding the inclusion/exclusion of a given study in this work was resolved through discussion between the two reviewers.

Data Extraction from Included Studies and the Analysis

Data extraction from the included studies was performed by another reviewer (KAS) and verified by two independent reviewers (AAK and JA). The following data were extracted for each study: author identification, study duration, publication year, workers monitored, department of the worker, annual effective dose, maximum and minimum occupational dose and distribution of workers in various effective dose intervals. From this data, we calculated total collective effective dose (TCED) and annual average effective doses (AAED) using the following relations:

$$TCED = \sum_i^N E_i \quad \text{Eq. 1}$$

$$AAED = \frac{TCED}{N} \quad \text{Eq. 2}$$

where E_i is the annual effective dose received by the i th worker and N is the total number of occupational workers in each study. Discrepancies in opinion about a data point were reviewed, and the consensus was achieved through discussion. Moreover, the primary authors of the studies with insufficient information were contacted, whenever possible, to acquire and verify the data. All data and statistical analyses were performed in Microsoft Excel.

Results

The initial search of the five online databases (i.e., PubMed, EMBASE, Scopus, Google Scholar and PakMediNet) identified 3178 studies that were related to radiation exposures. Of them, 1019 studies appeared in more than one database and were thereby considered only once. Next, the titles and abstracts of the remaining 2159 studies were thoroughly analyzed to select the studies focused on the occupational exposures only; 2071 studies were screened out in this step due to the fact that these studies did not report on occupational exposures. Out of the remaining 88 full-text articles, 46 studies were not related to occupational medical exposure, 31 studies did not assessed radiation doses for workers, 1 study reported insufficient data for extraction and the data presented in 2 studies was almost identical (and thereby considered only once). Finally, only 9 studies fulfilled the complete inclusion criteria and were included in the review. A flow chart diagram illustrating the major steps of this online literature review and segregation process is shown in **Figure 1**.

Figure 1. Summary of the online literature review process. The online literature search via five bibliographic databases (i.e., PubMed, EMBASE, Scopus, Google Scholar and PakMediNet) identified 3178 studies. The number of studies that appeared in more than one database was 1019; screening the title/abstract showed that 1697/374 studies did not reported on occupational exposures, 46/31 studies were not related to occupational medical exposure/assessed radiation doses for workers, 01 study reported insufficient data and 01 study were almost identical to the other study. Excluding all these studies, 09 studies finally qualified the complete criteria for inclusion in the review.

The overall summary of the studies included ($n = 09$) in this work is presented in **Table 1**. The total number of monitored medical occupational workers was 26046, with the sample size (i.e., the number of workers) of individual studies ranged from 52 to 13237. The range of TCED (**Table 1**, column 4) was 94-15785 Person-mSv, while that of AAED (**Table 1**, column 5) was 0.66-7.37 mSv, as calculated with **Equation 1** and **2**, respectively. It is noteworthy that, for easy comparison, both these dosimetry metrics were normalized for the duration of the study and the number of workers monitored.

The level of radiation dose received by occupational workers is typically correlated with the nature of the radiation field pertaining to the working environment. To this end, we also analyzed the level of radiation doses of the individual workers based on their working departments such as DR, RT, NM, ^{18}F FDG PET and RIA. The department-wise radiation doses of the workers are summarized in **Table 2**.

Table 1. The overall summary of annual effective dose and TCED for the occupationally exposed medical workers (2000-2018).

Reference	Study period	Workers monitored	TCED (Person-mSv)	Annual effective dose (mSv)		
				Average	Range	SD
Jabeen et al. [2]	2003-07	11003	15785	1.43	1.23-1.65	0.16
Rahim et al. [38]	2000-08	442	718	1.60	1.03-2.11	0.36
Masood et al. [39]	2007-11	304	258	0.84	0.43-1.43	0.4
Memon et al. [40]	2007-11	175	238	1.36	-----	
Zafar et al. [41]	2003-12	13237	8800	0.66	0.48-0.85	0.11
Younas et al. [42]	2009-13	95	700	7.37	2.4-9.0	2.35
Ghadi et al. [43]	2000-13	378	609	1.61	0.66-2.08	0.37
Razzaq et al. [44]	2013-14	52	94	1.81	1.65-1.97	0.23
Ahmad et al. [45]	2009-16	360	469	1.30	1.14-1.50	0.12

TCED = Total Collective Effective Dose; SD = Standard Deviation;

Table 2. The distribution of occupationally exposed medical workers from different departments in various AAED intervals..

Reference	Department	No. of Workers	AAED (mSv)	AAED intervals (mSv)			
				< 5	5-9.99	10-20	>20
Jabeenet et al. [2]	RT	1833	1.17	1819	10	4	-----
	NM	2008	1.55	1947	59	1	1
	DR	7162	1.47	6897	197	54	14
Rahim et al. [38]	RT	217	1.32	211	4	2	-----
	NM	124	2.15	120	1	-----	3
	DR	45	1.65	45	-----	-----	-----
	RIA	56	1.40	56	-----	-----	-----
Masood et al. [39]	RT	137	0.88	134	3	-----	-----
	NM	132	1.12	129	3	-----	-----
	DR	35	0.52	35	-----	-----	-----
Memon et al. [40]	RT	70	1.15	70	-----	-----	-----
	NM	65	1.69	63	2	-----	-----
	DR	20	1.49	20	-----	-----	-----
	RIA	20	0.87	20	-----	-----	-----
Zafar et al. [41]	RT	4570	0.70	4535	35	-----	-----
	NM	5854	0.63	5799	55	-----	-----
	DR	2813	0.68	2782	31	-----	-----
Younas et al. [42]	¹⁸ FDG PET	95	7.37	5	90	-----	-----
Ghadi et al. [43]	RT	206	1.43	206	-----	-----	-----
	NM	148	1.88	148	-----	-----	-----
	DR	24	1.49	24	-----	-----	-----
Razzaq et al. [44]	RT	15	1.67	15	-----	-----	-----
	NM	15	1.97	15	-----	-----	-----
	DR	22	1.79	22	-----	-----	-----
Ahmad et al. [45]	RT	180	1.23	180	-----	-----	-----
	NM	147	1.39	147	-----	-----	-----
	DR	33	1.30	33	-----	-----	-----

AAED = Average Annual Effective Dose; RT = Radiotherapy; NM = Nuclear Medicine; DR = Diagnostic Radiology; RIA = Radioimmunoassay;

¹⁸FDG PET = ¹⁸fluorodeoxyglucose Positron Emission Tomography

Poland also demonstrated that 97.8%, 98%, and 97% of worker received radiation doses below 5 mSv, respectively [25,46,47]. Review and analysis of the data showed that 18 workers received an occupational exposure exceeding the annual dose limit of 20 mSv (**Table 2**); however, no worker received the maximum annual dose limit of 50 mSv in any single year. To appropriately investigate and address such overexposures, each medical institute/ center follows a slightly different indigenous action plan. In general, each institute had established an action level (typically 50% of the regulatory annual dose limit; i.e., 10 mSv) where annual doses higher than 10 mSv are probed by the local radiation protection committee to explore and document the reasons. Alternatively, annual doses higher than 20 mSv are interrogated by both the local radiation protection committee and the national regulatory body (i.e., PNRA) to explore the possible cause(s). Overexposure records that are not found factual in such investigation are discarded. That said, the studies reporting annual doses higher than 20 mSv did not discuss their specific reasons/action plans. Nevertheless, the implementation of extensive educational programs for the medical staff will likely reduce the occupational radiation exposure, potentially minimizing the chances for such overexposures [45].

Comparison of the occupational doses of various radiation workers illustrated that the highest AAED was received by the workers involved in performing ^{18}F FDG PET studies (i.e., AAED = 7.37 vs. < 2 mSv; **Table 1**) [42]. In the context of relatively higher occupation doses, the rapid growth of ^{18}F FDG PET facilities in Pakistan demands objective education of the workers engaged in ^{18}F FDG PET through training and hands-on workshops towards strengthening the radiation protection and safety. In addition, albeit these AAED values appear consistent with the previous literature, a one to one comparison with other similar reports is difficult because of the variability in technique, protocols, image acquisition times, injected radioactivity and workload, among others [48-57]. More specifically, the AAED values for the workers of ^{18}F FDG PET have been previously reported to vary in the range of 1.93-12 mSv. The higher radiation exposure in ^{18}F FDG PET procedures has been attributed to the high energy gamma rays emitted during the procedure, the amount of radioactivity administered and the longer time durations of radiation exposure [51,58,59].

The comparison of AAED values received by the occupationally exposed medical workers of Pakistan with other countries is presented in **Table 3**. The AAED (**Table 3**, column 3) for all medical occupational workers in Pakistan was 1.06 mSv, as calculated by **Equation 2**. This indicates that radiation exposure to medical occupational workers is well below the annual dose limit. The AAED data for other countries demonstrate large variations, with the minimum/maximum AAED values of 0.30/4.36 mSv reported for the workers of Poland/Chile. These variations in AAED may be attributed to several factors, including the data recording procedure in the national database, the range of procedures performed by the

medical worker and the variability in protective measures in different countries, among others. For instance, the criteria for monitored workers differ considerably from country to country. Specifically, the national database of some countries only registers the exposed workers while dropping the non-exposed workers, based on the MDL of the dosimeters used. More specifically, the workers receiving radiation doses below the MDL of the dosimeter used; the dose recorded in the national database may be zero (as is the case in Argentina, Brazil, Canada, India, etc.), a pre-designated level (e.g., for China, Kuwait, and Poland the pre-designated value is 0.015, 0.1 and 0.25 mSv, respectively) or the MDL itself (e.g., in Pakistan, Cuba, Indonesia, etc.) [35,60]. Such practices potentially enable misleading conclusions when attempting to compare the AAED values of different countries.

Table 3. Comparison of AAED values for occupationally exposed medical workers of Pakistan with other countries.

Country	Study Duration	AAED (mSv)	Reference
Pakistan	2000-2018	1.06	This study
China	1991-1995	1.5	[31]
	1996-2000	1.4	
Ghana	2000-2009	0.69	[29]
Ireland	2001-2005	0.32	[27]
China	1999	1.30	[1]
Poland	1999	0.3	[47]
Turkey	1995-1999	0.38	[20]
	2003	0.12	[19]
Argentina	2000-2002	2.22	[60]
Greece	2000-2002	2.28	[60]
Canada	2000-2002	1.16	[60]
Slovenia	2000-2002	0.44	[60]
Romania	2000-2002	0.89	[60]
Lithuania	2000-2002	2.63	[60]
Spain	2000-2002	0.79	[60]
Japan	2000-2002	1.33	[60]
Chile	2000-2002	4.36	[60]
Worldwide	1990-1994	1.39	[60]

Conclusion

In this review, whole body occupational radiation exposure of Pakistani medical workers has been discussed. In particular, analysis of the online literature demonstrated that the AAED values ranged from 0.66 to 7.37 mSv, with the highest occupational radiation dose received by the workers engaged in ^{18}F FDG PET studies, followed by NM and DR. Moreover, ~98% of the medical workers received an annual dose below 5 mSv, indicating that the radiation protection and safety protocols are adequate and appropriately implemented. A small fraction of the workers (n = 18; 0.07%) received doses above the annual dose limit of 20 mSv. This study will not only facilitate a cross-platform comparison of our personal dosimetry patterns but also stage a ready reference for monitoring and improving radiation protection practices in the country.

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