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ASSESSING RADIATION EXPOSURE LEVELS AMONG RADIOTHERAPY STAFF AT USMANU DANFODIYO UNIVERSITY TEACHING HOSPITAL, SOKOTO, NIGERIA, ON ANNUALLY BASIS

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Abstract

The evaluation of occupational exposure to external ionizing radiation in diagnostic and therapeutic applications is essential for understanding regulatory compliance and technological progress. This research presents an analysis of occupational radiation exposure in the Radiotherapy, Dental department of Usman Danfodiyo University Teaching Hospital (UDUTH) Sokoto, comparing it with relevant studies. A total of 19 Radiotherapists, each assigned a TLD

Introduction

Ionizing radiations', such as x-rays and the gamma rays from radioactive materials, are electromagnetic in nature. They can penetrate matter and cause damage when absorbed in it. They are useful in many ways, but there is a flip side; they can be harmful if used without due care [ICRP, 2007].They are capable of killing living cells, or they can produce

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code instead of worker names. Various parameters, including Average Annual Effective Dose (AAED), Annual Collective Dose (ACD), Individual Distribution Ratio (NRE), Collective Dose Distribution Ratios (SRE), and Probability of Cancer Lifetime Risks (LFTR), were analyzed using SPSS version 21.0. For Radiotherapy workers, the AAED was 1.35 $\pm$ 0.73 mSv, with an ACD of 25.66 $\pm$ 0.73 man mSv. The NRE and SRE indicated that 46.88% of received doses exceeding 1 mSv, while none exceeded 10 and 15 mSv. The LFTR for all medical radiation workers at UDUTH was less than 1mil, suggesting low cancer lifetime risks.

Key: Ionization, Effective, Collective, Doses, Cancer.

Undesirable changes in cells without killing them. Thus, they pose a potential hazard to anyone using them. In your line of work, you use this type of radiation. As a result you should know what the risks are, and how they compare with the other hazards of everyday life. You should also know how they could be reduced to a safe level. These questions will be answered in this handbook.

All X-ray equipment operators and users of radioactive materials should be certified according to a recognized standard, and must possess qualifications required by any relevant Nigeria regulations or statutes.

All operators must:

I. Be aware of the contents of the Nigeria Radiation Act, regulations, and licence conditions.
II. Be aware of the radiation hazards associated with their work and that they have a duty to protect themselves and others.
III. Have a thorough understanding of their profession, of safe working methods and of special techniques.

IV. Through conscientious use of proper techniques and procedures, strive to eliminate or reduce to lowest practical values all exposures.
V. Be 18 years of age or older.

A female operator should be encouraged to notify her employer if she believes herself to be pregnant, in order that appropriate steps may be taken to ensure that her work duties during the remainder of the pregnancy are compatible with accepted maximum radiation exposure, as set out in this regulation (ICRU, 1998).
The action of x-rays; X-rays travel outward from the focal spot of the x-ray tube (like light from a light bulb), and they can be blocked out to cast a shadow. Just as light is scattered in all directions from an object it strikes, so are x-rays. But unlike light, x-rays are not stopped at the first surface they encounter. They penetrate materials to a degree depending upon how they are generated and upon the nature of the material. Bone shows up in a radiographic image because it absorbs more x-rays than does soft tissue. Lead and steel absorb x-rays even more effectively and are used as protective barriers to x-rays. X-rays are emitted in all directions when the x-ray tube is energized. Lead incorporated into the tube housing stops x-rays from escaping in all directions. The maximum size of the useful x-ray beam is determined by the size of the opening in this shield. The beam size (as set by the diaphragms) determines how much of the object can be seen at a time, and also how much scattered x-radiation is produced. This scattered radiation, which emanates from anything struck by the x-ray beam, goes in all directions, and must be blocked if it is not to pose a personnel hazard. It is not nearly as intense as the primary x-ray beam, but is present in the space around an object

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while the x-ray beam is striking it. The intensity (and hence the hazard) of both primary and scattered x-rays decreases very rapidly with distance from the source, just as the intensity of light diminishes with distance. In fact, if the distance is doubled, in both cases, the intensity goes down by a factor of four. If the distance is tripled, the intensity is down to one-ninth, and so on.

X-rays are present only when an x-ray machine is turned on. They are not present when the unit is off.

Neither the operator nor the material under examination becomes radioactive during or after a x-ray exposure just as you don't glow in the dark when a light is turned off.

Gamma rays, on the other hand, are emitted by radioactive materials continuously, and cannot be turned off by the flick of a switch. Their intensity and penetrating ability depends upon the radioisotope from which they are emitted. In all other ways, they are similar to x-rays.

Apart from the radiation exposure received from the use of x-rays and radioisotopes, all members of the human race are exposed to a background level of "environmental radiation", and have been since the dawn of time. This environmental radiation comes from cosmic rays from outer space, from in the radioactive air we breathe in our natural surroundings, and in the radioactivity of our own bodies. So any exposure we receive from occupational sources is an addition to this "background", which varies somewhat from place to place on the earth.

The biological effects of radiation; X - and gamma rays have been found to be indispensable in diagnostic and therapeutic medicine, and in various aspects of industry and research. It is inevitable, therefore, that people will be exposed to them. The problem is to determine a level of

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radiation exposure (over the inevitable background) which is acceptable compared to other hazards of everyday life.

The International Commission on Radiation Protection (ICRP) is a body of experts, which for many years have collected and analysed data on the effects of radiation on humans. Periodically, it has published so called recommended limits of radiation exposure” which it considers reasonable [IAEA, 1999].

These recommended limits for radiation exposure (over and above the unavoidable background) have been reduced from time to time over the past fifty years. This is not because of any adverse effects being observed at the previous levels. Rather, it is because it has been found possible to reduce the levels without seriously limiting the use of radiation for medical and other purposes. This "As Low As is reasonably Achievable", or ALARA principle, is applied to all radiation risk levels, and includes patients under examination as well as occupationally exposed personnel (Abu-Jarad F, 2008).

The effects of radiation on humans; A great deal is known about the effects of radiation - more than is known about the effects of chemicals such as insecticides, fungicides, etc. The two effects, which may be produced by the small amounts of radiation received by people involved in the use of x-rays, are genetic changes and cancer induction (Oyeyinka et al., 2012).

The badges; which are available to monitor personal exposure, contain two tiny crystalline chips, which are sensitive to very small amounts of radiation. They should be worn for a reasonable period (normally three months) before being returned for measurement of the exposure received. The reported results indicate what the badge received during the three-month period (Oyeyinka et al., 2012).

Since we are interested in the radiation exposure the individual wearing the badge receives, the badge should be protected from radiation at all times when it is not being worn. It should also be worn next to the body when x-rays are being used. If a badge is not worn, there is no way of determining how much radiation the individual receives. The individual issued the badge must be responsible for wearing it when x-rays are likely to be present (Cember, H. 1996).

The utilization of ionizing radiation in medical contexts, including procedures like x-rays, fluoroscopy, mammography, and computed tomography, constitutes the second largest contributor to the cumulative dose of ionizing radiation globally (as stated by UNSCEAR in 2000). There's been a valid concern regarding the increasing employment of ionizing radiation for medical diagnostic purposes (discussed by Joseph et al. in 2017). Moreover, the potential biological risks linked to ionizing radiation exposure leading to conditions such as radiation sickness, cellular damage, tissue and organ harm, cancers, and cataract development have been documented at various levels of radiation exposure (highlighted by Mohsen et al. in 2014).

METHODOLOGY

Data for this study were gathered from personnel working in the Radiotherapy Departments of Usman Danfodiyo University Teaching Hospital Sokoto, Nigeria. We acquired anonymous records containing quarterly dosage measurements from these departments covering the time span of 2014 to 2018. The documented information about the doses of medical radiation exposure was procured. The collected documents did not disclose the identities of the workers to comply with the regulations of the Health Research Ethics Board (HREB). Instead, a unique TLD code was assigned to each participant, ensuring their anonymity. These depersonalized and coded records encompassed details regarding the quarterly whole body and extremity doses for medical radiation workers within the department, from which the cumulative annual dose was calculated. The subsequent equation (Rahman et al., 2016) was utilized for this purpose.

$$\mathrm{D} = \frac{HT}{WR} \qquad 1$$

Where D = Absorbed dose

H_T = Equivalent dose

W_R = Radiation weighing factor

The time between irradiation and readout should be the same to keep fading from one calibration to another for all TLDs (Rahman *et al.*, 2016). The calibration factor is defined (Rahman *et al.*, 2016) as:

TLDs. The calibration factor is defined as follows:

$$f_{calibration} = \frac{D_{ionization\ chamber\ (mGy)}}{TLD_{reading\ (n)}} \qquad 2$$

Absorbed dose due to irradiation is obtained after background subtraction using equation 3

$$D_{TLD} = D_{av} - BG \qquad 3$$

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The absorbed dose is obtained for each TLD using equation3.4

$$D(mGy) = f_{cal}\left(\frac{mGy}{nC}\right) X\, TLD_{reading}(nC) \qquad 4$$

For every individual measurement, the smallest detectable amount (referred to as MDL or minimum detection level) is 0.05 mSv within 3 months after accounting for the background. This MDL serves as a threshold for recording doses. Consequently, workers who have received doses lower than this MDL are classified as having not been exposed. The reader for Thermoluminescent Dosimeters (TLD) provides values for shallow dose equivalent (referred to as Skin dose) and deep dose equivalent (referred to as DDE), both of which are manually inputted into a Microsoft Excel spreadsheet. This input is then utilized to calculate the respective personnel dose equivalents, denoted as Hp(0.07) and Hp(10).

The formulas for calculating Skin and deep doses are outlined in Equations 3.5 and 3.6, as detailed in the work by Hasford et al. (2011).

Skin dose: Hp(0.07) = [(1.2958Rskin) + 0.0097] Msv 5

Deep dose: Hp(10)= [(1.3772Rdeep) + 0.0566]mSv 6

Dose reporting was performed on quarterly basis and only those workers with doses exceeding a minimum detection level (MDL) of 0.05 mSv (exposed workers) after background subtraction will be considered. The workers with doses less than MDL are considered as non-exposed.

Data Analysis

In this study, one quantity recommended by UNSCEAR, (2008) was used to analyze individual doses for the stipulated period. The recommended quantity is, average annual effective dose.

a. Absorbed dose (D)

Energy imparted to matter from any type of radiation,

$$D = E/m \qquad 7$$

D: Absorbed dose

E: Energy absorbed by the body of mass (m).

Equivalent dose (H_T)

Accounts for biological effect per dose

$$H_T = W_R \times D \qquad 8$$

W_R: Radiation weighing factor.

Individual average annual effective dose

Risk related parameter, taking relative radio sensitivity of each organ or tissue into account.

$$E_i(Sv) = \sum_T W_T \times H_T \text{ (EPA 2009)} \qquad 9$$

W_T: tissue weighing factor for organ T

H_T: equivalent dose received by organ or tissue T

RESULTS AND DISCUSSION

This study investigated the levels of occupational exposure to radiation among employees at Usmanu Danfodiyo University Sokoto Teaching

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Hospital, where ionizing radiation sources were utilized from 2014 to 2018. The report detailed the average effective dose on annual basis for workers in the field of Radiotherapy, and the findings are presented as follows:

Medical Radiation doses received by Radiotherapy workers

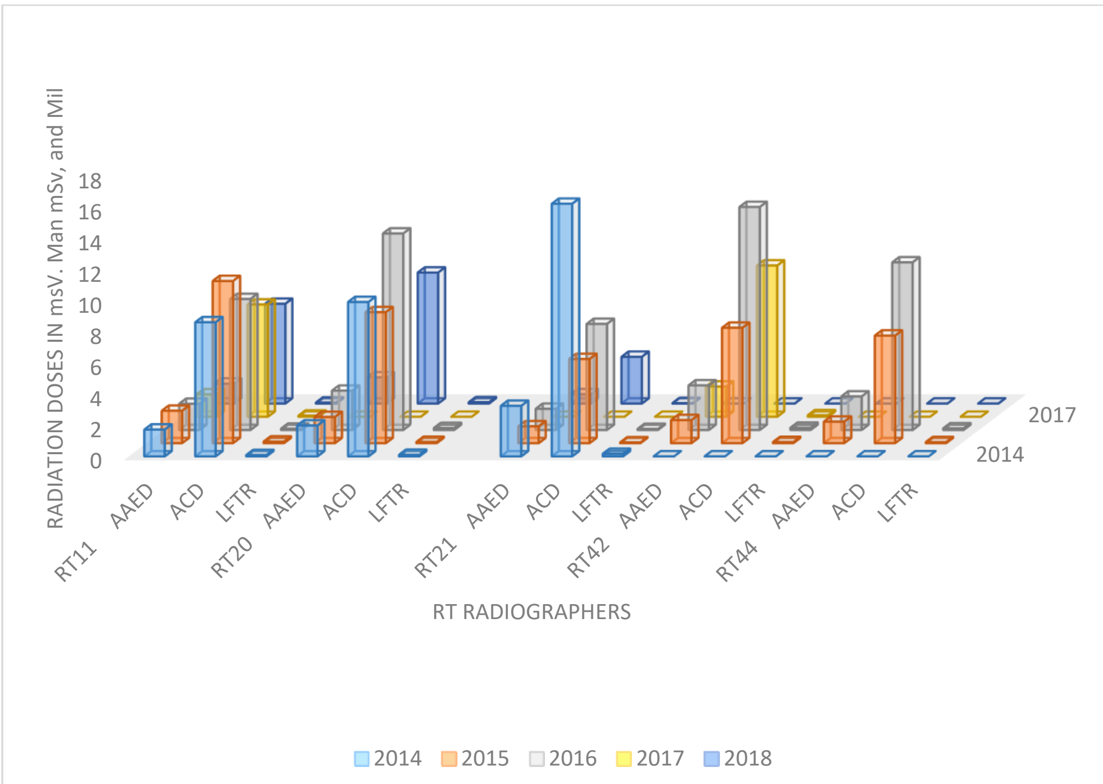

Figure 1 RT Radiographers Radiation doses

The outcomes illustrated in Figure 4.0 indicate variations in Average Annual Effective Dose (AAED), Annual Collective Dose (ACD), and the probability of cancer lifetime risk across several radiotherapy workers. For instance, RT11 exhibited AAED fluctuations from 1.44 mSv in 2017 to 2.08 mSv in 2015, with ACD ranging from 7.20 man mSv to 10.40 man mSv. Probability of cancer lifetime risk ranged from 0.072 mil to 0.104

mil. Similarly, RT20 displayed AAED variations from 1.68 mSv in 2014 and 2018 to 2.52 mSv in 2016, with ACD ranging from 8.40 man mSv to 12.60 man mSv and LFTR ranging from 0.084 mil to 0.099 mil. RT21, RT42, and RT44 also demonstrated varying AAED, ACD, and LFTR values in different years.

The fluctuations in these results may be attributed to increased workload or non-adherence to radiation protection protocols. It is noted that the results surpassed those recorded by Mohammed et al. (2016), exceeded the 0.19 mSv recorded in Australia (1990-1994), and surpassed the 1.34 mSv world recommended dose (1990-1994).

The one-way ANOVA test revealed no statistical significance ($p < 0.05$), implying that the variations in doses were not statistically significant. Moreover, approximately 68% of Radiographers received AAED exceeding 1 mSv, while 32% received lower than 1 mSv. None of the Radiographers received doses exceeding 5, 10, and 15 mSv, in line with UNSCEAR (2008) recommendations.

The study highlighted a linear relationship between the probability of cancer lifetime risks and exposure time, indicating that increased exposure may elevate the risk of cancer induction. However, the risk was comparatively lower at Usman Danfodiyo University Teaching Hospital Sokoto (UDUTH) compared to Kuwait (Al-Abdulsalam et al., 2014). The results emphasized that the five monitored Radiographers had induced cancer risks below 1 mil, underscoring the improvement in radiation protection protocols at UDUTH. While acknowledging the potential increase in cancer risk with long-term exposure, the assessment suggested that confidence among Radiographers could be built through proper workload management to minimize the risk of cancer induction.

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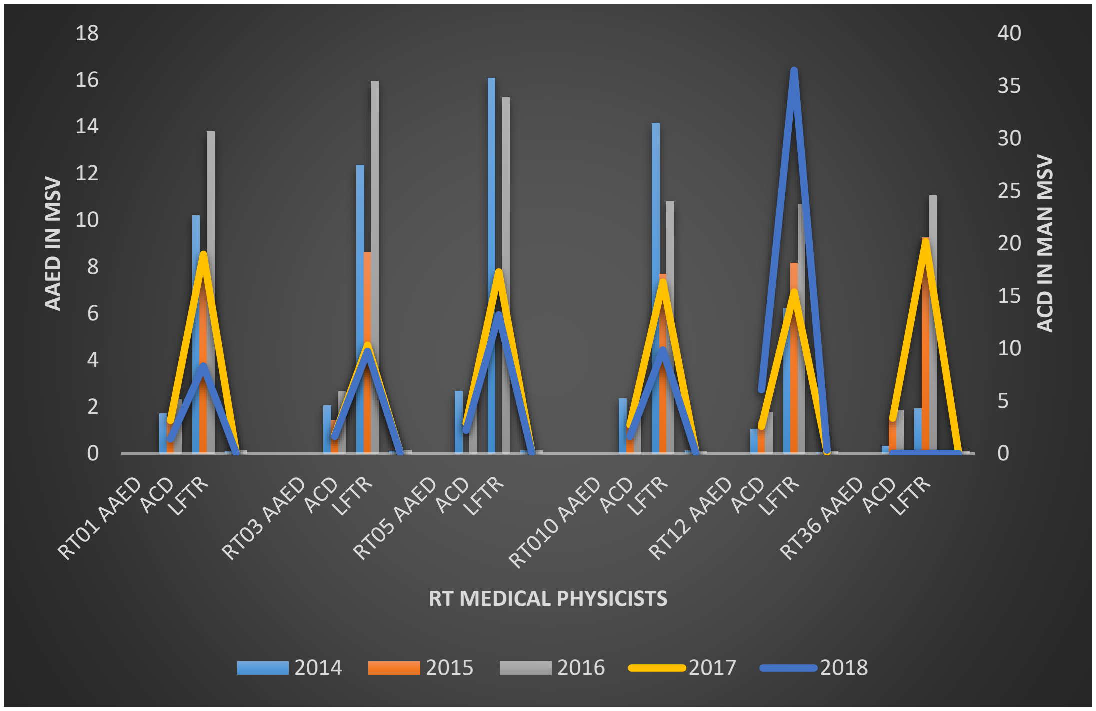

Figure 2 RT Medical Physicists Radiation doses

The results depicted in the figure above for 6 Medical Physicists highlight the variability in Average Annual Effective Dose (AAED), Annual Collective Dose (ACD), and the probability of cancer lifetime risk over the years. In 2014, AAED ranged from 0.32 to 2.68 mSv, with ACD ranging from 1.92 to 16.08 man mSv, and LFTR ranged from 0.016 to 0.134 mil by RT36 and RT05 respectively. Similar fluctuations were observed in subsequent years, such as in 2015, 2016, 2017, and 2018, indicating potential correlations with increased workload or non-compliance with radiation protection protocols. In 2018, it was noted that RT12 had higher exposure, possibly due to an increased workload. The results obtained exceeded those recorded by Mohammed et al. (2016), surpassed the 0.19 mSv recorded in Australia (1990-1994), and exceeded the 1.34 mSv world recommended dose (1990-1994).

The one-way ANOVA test revealed no statistical significance ($p < 0.05$). Analyzing the results, it was found that approximately 76.67% of Medical Physicists received AAED exceeding 1 mSv, 23.33% received lower than 1 mSv, and 3.33% received doses exceeding 5 mSv. None of the Medical Physicists received doses exceeding 10 and 15 mSv, aligning with UNSCEAR (2008) recommendations.

The study demonstrated that the probability of cancer lifetime risks increased with the rise in dose. However, the risk of cancer induction at Usman Danfodiyo University Teaching Hospital Sokoto (UDUTH) for exposed workers was five times lower than the risk in Kuwait (Al-Abdulsalam et al., 2014). The results indicated that the 6 Medical Physicists monitored had induced cancer risks below 1 mil, highlighting an improvement in the radiation protection protocol at UDUTH. Although long-term exposure may elevate the risk of cancer, the assessment suggested that instilling confidence among Medical Physicists workers at UDUTH could be achieved by minimizing the risk of cancer induction through workload management.

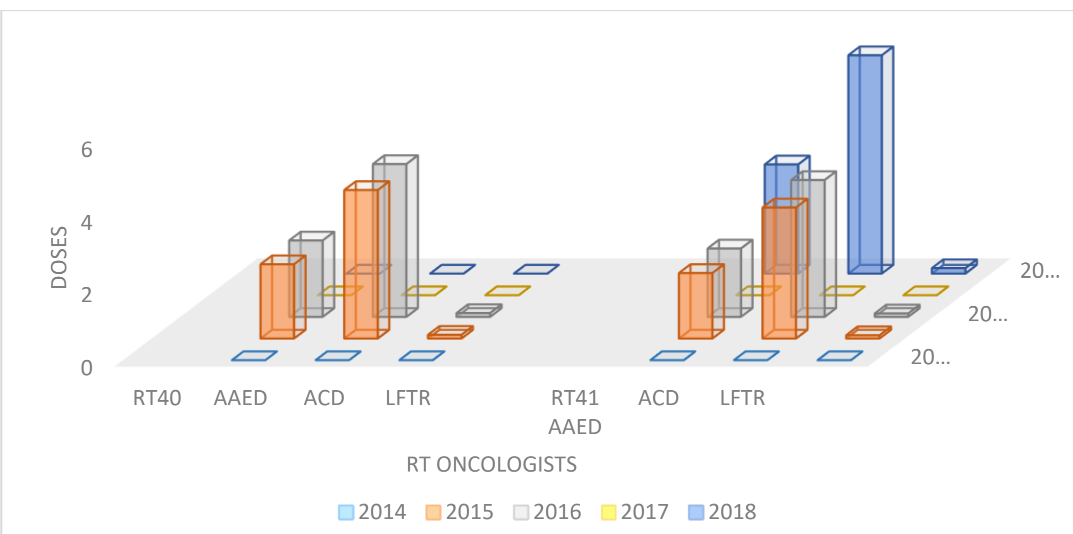

Figure 3 RT Oncologist Radiation doses

The results obtained for 2 Oncologists, as depicted in the figure, showcase variations in Average Annual Effective Dose (AAED), Annual Collective Dose (ACD), and the probability of cancer lifetime risk over the study period. Notably, in 2014 and 2017, none of the Oncologists were present, possibly due to internship or contract staff status for the entire five-year period.

In 2015 and 2016, RT40 exhibited AAED ranging from 2.04 mSv to 2.10 mSv and ACD of 4.04 – 4.20 man mSv, with LFTR ranging from 0.102 – 0.105 mil. RT41, on the other hand, showed AAED fluctuations from 1.80 mSv to 3.0 mSv, ACD ranging from 3.60 to 6.0 man mSv, and LFTR ranging from 0.09 to 0.094 mil in 2015 and 2018, respectively. The results surpassed those recorded by Mohammed et al. (2016), exceeded the 0.19 mSv recorded in Australia (1990-1994), and exceeded the 1.34 mSv world recommended dose (1990-1994).

The one-way ANOVA test indicated no statistical significance ($p < 0.05$). Analyzing the results revealed that approximately 50% of the Oncologists received AAED exceeding 1 mSv, 50% received lower than 1 mSv, and 20% received doses exceeding 5 mSv. None of the Oncologists received doses exceeding 10 and 15 mSv, aligning with UNSCEAR (2008) recommendations.

The study demonstrated that the probability of cancer lifetime risks increased with the rise in dose. However, the risk of cancer induction at Usman Danfodiyo University Teaching Hospital Sokoto (UDUTH) for exposed workers was five times lower than the risk in Kuwait (Al-Abdulsalam et al., 2014). The results indicated that the 2 Oncologists monitored had induced cancer risks below 1 mil, underscoring an improvement in the radiation protection protocol at UDUTH. While acknowledging the potential risk associated with long-term exposure, the assessment suggested that instilling confidence among Oncologists workers at UDUTH could be achieved by minimizing the risk of cancer induction through workload management.

Moreover, the additional information noted that RT41 was exposed more to radiation due to the high dose received, emphasizing the importance of closely monitoring and managing radiation exposure for individual practitioners.

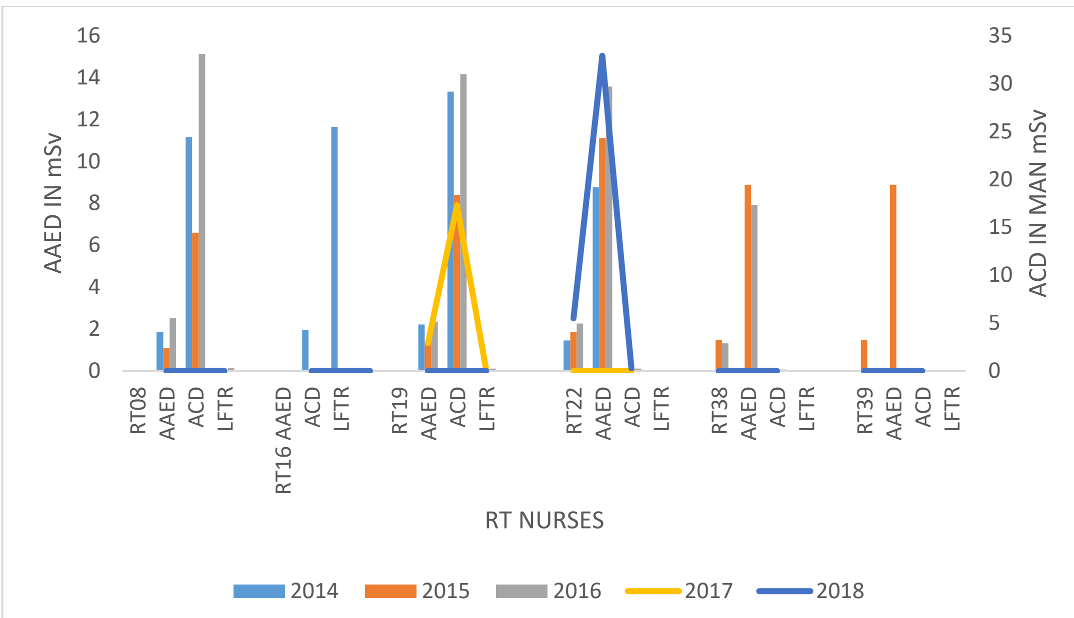

Figure 4 RT Nurses Radiation doses

The results for six Nurses, as illustrated in the study, reveal insights into Average Annual Effective Dose (AAED), Annual Collective Dose (ACD), and the probability of cancer lifetime risk over the five-year period. RT08 recorded AAED ranging from 1.10 to 2.52 mSv, ACD from 6.60 to 15.12 man mSv, and LFTR from 0.055 to 0.126 mil in 2015 and 2016, respectively. RT16 received 1.94 mSv, 11.64 man mSv, and 0.097 mil in 2014, while the remaining Nurses were not present for the entire four years, possibly due to internship or contract staff status. RT19 exhibited AAED fluctuations from 1.40 to 2.88 mSv, ACD from 8.40 to 17.28 man mSv, and LFTR from 0.07 to 0.144 mil, potentially indicating non-adherence to radiation protection protocols or increased workload. Over the entire five-year period, RT22 received AAED, ACD, and LFTR ranging from 1.46 to 5.48 mSv, 8.76 to 32.88 man mSv, and 0.073 to 0.274 mil, respectively.

RT38 displayed AAED ranging from 1.32 to 1.48 mSv, ACD from 7.92 to 8.88 man mSv, and LFTR from 0.066 to 0.074 mil in 2015 and 2016. RT39 was only present in 2015 and received AAED of 1.48 mSv, ACD of 8.88 man mSv, and LFTR of 0.074 mil. Notably, none of the Nurses received doses exceeding the 20 mSv recommended by UNSCEAR (2008).

The results surpassed those recorded by Mohammed et al. (2016), exceeded the 0.42 mSv recorded in India (1990-1994), and exceeded the 1.34 mSv world recommended dose (1990-1994).

The one-way ANOVA test indicated no statistical significance for most pairwise comparisons but revealed significance for the comparisons of RT16 with RT22, RT38, and RT39 ($p < 0.05$). RT16 received the highest AAED in these comparisons. Analysis of the results showed that approximately 46.67% of RT Nurses received AAED exceeding 1 mSv, 52% received lower than 1 mSv, and 3.33% received doses exceeding 5 mSv. None of the Nurses received doses exceeding 10 and 15 mSv, consistent with UNSCEAR (2008) recommendations.

The study demonstrated an increase in the probability of cancer lifetime risks with rising doses. However, the risk of cancer induction at Usman Danfodiyo University Teaching Hospital Sokoto (UDUTH) for exposed workers was five times lower than the risk in Kuwait (Al-Abdulsalam et

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al., 2014). The results indicated that the 6 Nurses monitored had induced cancer risks below 1 mil, suggesting an improvement in the radiation protection protocol at UDUTH. Although long-term exposure may elevate the risk of cancer, the assessment suggested that building confidence among Nurses workers at UDUTH could be achieved by minimizing the risk of cancer induction through workload management. Additionally, the information pointed out that the probability of LFTR is in a linear relationship with exposure time, indicating that if anyone gets overexposed, the risk of cancer induction can be minimized by reducing workload.

Comparisons of different cadres in Radiotherapy Department

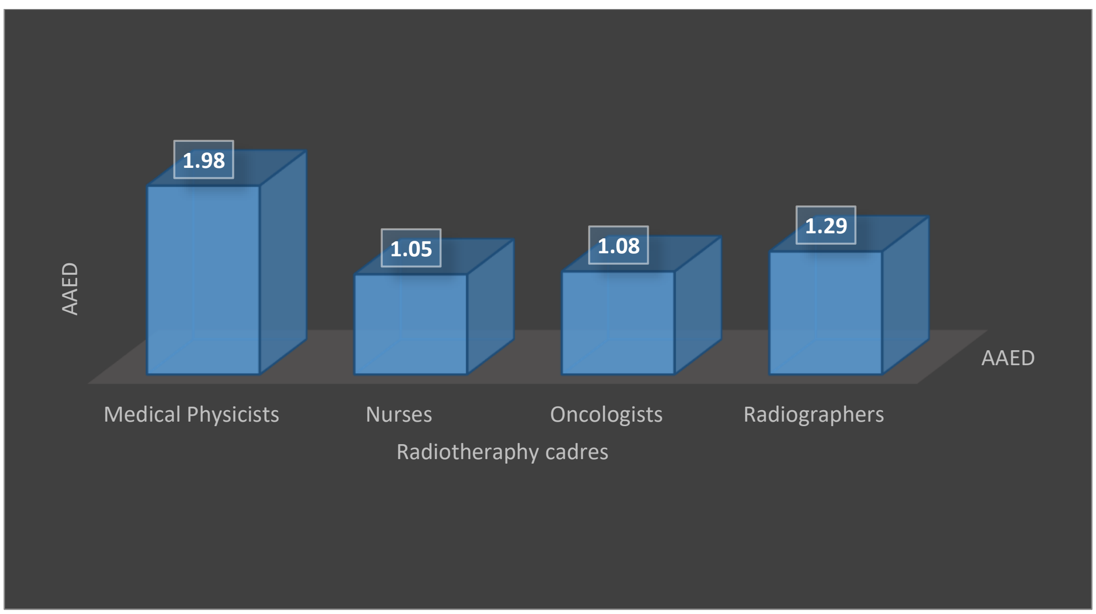

Figure 5 RT Different Cadres

The presented results indicate that Medical Physicists received the highest Annual Average Effective Dose (AAED) over the five-year period, whereas Nurses received the lowest. The fluctuations observed in the doses are attributed to potential lapses in adhering to radiation protection protocols. The statistical analysis, particularly the pair-wise comparisons, revealed that the differences in doses among Medical Physicists were statistically significant with a p-value less than 0.05.:

Variability in Doses: The data presented a range of doses among different professional groups, with Medical Physicists experiencing the highest AAED. This could be due to the nature of their work, exposure to specific procedures, or other job-related factors.

Adherence to Protocols: The fluctuations in doses suggest that there might be instances where individuals in these professions did not fully adhere to established radiation protection protocols. This could be due to lapses in compliance, inadequate training, or a lack of awareness of safety measures.

Statistical Significance: The statistical significance in pair-wise comparisons for Medical Physicists indicates that their radiation doses were significantly different from those of other professional groups. This emphasizes the need for targeted interventions or specific safety measures for this group.

CONCLUSION AND RECOMMENDATION

CONCLUSION

This study provides a comprehensive assessment of occupational radiation exposure among medical radiation workers at Usman Danfodiyo University Teaching Hospital, offering both encouraging and concerning insights.

Compliance with Dose Limits: All the radiotherapists adhered to the national administrative dose limit of 20 mSv, ensuring no worker received excessive radiation exposure. This highlights the effectiveness of national regulations and commitment to worker safety.

Low Average Doses: While exceeding the 1 mSv threshold in some percentages, the average annual effective doses in Radiotherapy department (1.35 mSv), remained relatively low. This suggests proper implementation of radiation safety measures in most cases.

No High-Level Exposure: Importantly, no worker across any department received annual doses exceeding, 10, or 15 mSv, indicating the absence of serious exposure incidents. This further reinforces the overall picture of responsible radiation practices.

Minimal Cancer Risk: The estimated probability of cancer causation for all the medical workers were below the screening limit.

RECOMMENDATIONS

The study's findings suggest several areas for improvement and further research:

1. Regular Calibration: To improve the accuracy of dosimetry measures, it's crucial to always calibrate the Harshaw 4500 manual TLD reader with a 137Cs beam exposure before each use. This ensures consistent and reliable dose assessments for workers.
2. Upgrade Dosimetry Technology: Consider exploring the use of the Harshaw automatic TLD reader 8800/6600 model in future studies. This advanced technology offers higher precision and accuracy, potentially leading to more reliable data on radiation exposure.
3. Comprehensive Risk Assessment Models: Develop or update existing models to simultaneously assess both Excess Relative

Risk (ERR) and Excess Absolute Risk (EAR) of cancer based on radiation exposure. This provides a more comprehensive picture of the potential long-term risks faced by workers.

4. Expand Study Scope: Include occupational radiation exposure assessment for additional personnel within the hospital, such as porters, who might also encounter radiation during their work. Expanding the study scope provides a more holistic understanding of radiation safety within the medical facility.
5. Workload Optimization: Implement measures to reduce the workload on radiation workers, such as Radiologists, Radiotherapists, and Dental workers. Options include affordable time-scheduling practices to minimize fatigue and human error.
6. Improved Cancer Detection Models: Develop or refine models that can detect cancer in any radiosensitive organ, not just those traditionally associated with radiation exposure. This ensures broader protection for workers' health.
7. Optimal TLD Reading Timing: Considering the warm temperatures in Sokoto, ensure TLD reading is done within one month of badge collection to avoid potential fading of the dosimetry chips, which could lead to inaccurate dose readings.
8. Staffing Considerations: To further reduce workload and improve efficiency within the departments, consider allocating additional staff resources to support ongoing operations and ensure optimal safety practices.

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