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Effects of Exposures to Low-Dose X-Rays on Blood Cell Morphologies of Radiographers in Port Harcourt

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Abstract: *X-rays are electromagnetic waves that can traverse the human body due to their high energy levels (≥1.24 keV) and ultra-short wavelengths (≤10^{-10}m). Acute exposures have harmful health effects, affecting hematopoietic systems amongst others. X-ray unit workers experience these effects despite usage of Personal Protective Equipment (PPEs). This study spanned May 2018 to February 2019, and was aimed at determining the effects of exposures to low-dose x-rays on basic morphological characteristics of blood cells among radiographers in Port Harcourt. It was delimited to a target population of active radiographers who work for ≥ 6-hours daily; ≥ 5-days weekly; over ≥ 12-months, and a corresponding number of control subjects in premier five healthcare facilities. Cross-sectional comparative analytical research design was adopted. Questionnaires were administered with 100% response rate. Clinical laboratory examinations involved two sets of blood samples, collected 120 days apart. 30 exposed and 30 unexposed subjects, aged 25-54 years, participated in this study. Mean annual background radiation level at the x-ray units was 0.7724mSv (i.e. 0.6088mSv-0.8392mSv [p≤0.05]). Workers recorded 100% usage of PPEs and 86.7% (n=26) knowledge/awareness to adverse effects of x-ray exposures. Normal blood cell morphologies predominated in the unexposed group (76.6%, 86.7%), vis-à-vis the exposed group (53.3% & 50.0%), except forcodocytes (z = -1.000, p=0.317). This study showed that chronic exposures to low-dose x-rays alterblood cell morphologies, despite usage of PPEs.*

Key words: *Ionizing radiation, background radiation, blood cell morphology, poikilicytosis, anisocytosis, microcytosis, atypical lymphocytes, codocytes*

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I. Introduction

Ionizing radiations (such as x-rays) possess high energy levels (≥1.24 keV) and ultra-short wavelengths (≤10^{-10}metres), and can traverse organic/inorganic matter (Morris et al., 2004). Based on the recommendations of the International Commission on Radiological Protection (ICRP, 1998), acceptable annual effective dose limits for exposures to x-rays are 5-20mSv (i.e. ≤ 100mSv over a 5-year period) or a maximum of 50mSv (for radiation sector workers), and 0.5-1.0mSv (for the general public). Radiation exposure measuring devices include; alarm or luminescent dosimeters, film badges, fixed/portable radiation monitors etc. (NNRA, 2006). Global annual records show that clinical uses of x-rays account for 98% of man-made emissions, i.e. ≈20% of all radioactive emissions (WHO, 2016). Radiographers are healthcare workers concerned with the handling/operation of radiological materials forprocedures such as plain radiography, mammography, fluoroscopy, angiography, computed axial tomography etc. Frequent exposures to low-dose x-rays (also termed residual or 'scatter' radiation) become inherent in the course of their jobs. Hematological cells/tissues exhibit high sensitivity to ionizing radiation, and serve as intrinsic indicators for health effects. Basic blood cell morphologies include; normocytes, poikilocytes, anisocytes, codocytes, atypical lymhpocytes, etc.

Exposures to ionizing radiations have been implicated in the pathogenesis of diseases such as haematological cancers, sarcomas, ocular defect/malignancies, embryological/foetal defects affecting progenies of exposed persons, etc. (Cotran et al., 1994). The hematopoietic systems control the oxygen-carrying capacity of blood, competent immunological system, and spontaneous control of hemorrhages. Genetic or acquired pathological conditions could lead to abnormal morphologies in haematological cells. Human blood cells exhibit morphologies which range from the normal or normocytes (biconcave, measuring ~8µm in diameter), to the abnormal such as; anisocytes (vastly unequal RBC sizes), microcytic/macrocytes (MCV of <80fL or >100fL respectively), poikilocytes (vastly abnormally-shaped RBCs), spherocytes (sphere-shaped/hyper-hemoglobinizedRBCs), elliptocytosis (oval/elongated RBCs), and codocytes or 'target cells' (bell-shaped RBCs with abnormal hemoglobin content and altered membrane volume), among others. Normocytes possess a high surface-to-volume ratio that optimizes reversal of deformed cell shapes during microcirculation, due to their elasticity. The hemoglobin concentrations in the cells distinguish the normochromic (normal) from the hypo/hyperchromic (decreased/increased) RBCs, respectively (Ah-Moye et al., 2015).

Altered membrane properties are associated with abnormal morphologies, which causeincreased cellular fragility, compromised cellular integrity and physiological dysfunctions in oxygen/carbon dioxide transportation, which then lead to degrees of hypoxemia, immuno-suppression, coagulation accidents/disorders, etc. These manifest clinically as gross anemia, susceptibility to infections and septicemia, hemorrhagic episodes, etc. (Boon et al., 2006). Chronic exposures could potentially cause insidious but lethal effects, which could progress undetected.

Presently, there are no records of published studies conducted on this topic in southern Nigeria. Briggs-Kamara et al. (2013) highlighted the knowledge, awareness and practice of radiographers in Port-Harcourt, Nigeria, to x-ray effects of exposure. Abubakar et al. (2016) assessed the ambient radiation doses at FMC Asaba, Nigeria. Eze et al. (2013), and Usen and Umoh (2014), assessed radiation protection practices among radiographers in Lagos (western), and Maiduguri (northern) Nigeria, respectively. The evaluation of x-ray effects on blood cellular morphologies in radiographers was beyond the scopes of these researches. However, Nureddin et al. (2016) in Libya (north), and Giragn (2016) in Ethiopia (east) Africa, respectively, determined the effects of x-rays on the blood cell parameters of radiographers, but their results may not be applicable to Nigeria due to the climatic differences between the countries involved. Given increasing global use of radio-imaging procedures (Brenner and Hall, 2007), the study intended to close out this gap, and form the empirical basis for early diagnosis and therapy in affected Nigerian workers.

This study was aimed at determining the effects of exposures to low-dose x-rays on the basic morphological characteristics of blood cells, among radiographers in Port Harcourt.

The objectives of this study were to:

1. Measure the monthly ambient doses of x-rays at the radiology units over a six-month period.
2. Assess the proper use of radiological Personal Protective Equipment (PPEs) using the availability, accessibility, application and viability as indices.
3. Assess the basic morphological characteristics of blood cells: normocytic/normochromic cells, poikilocytosis, anisocytosis, codocytosis, atypicallymhpocytosis, in the study groups over a period of six months.
4. Establish statistical correlations between the major finding(s), biographical indices, and the duration of work exposure to x-rays among radiographers, respectively.

This research was delimited to a target population of active radiographers (case subjects) who work actively for ≥ 6-hours daily and ≥ 5-days weekly, over a minimum duration of 12-months, and a corresponding number of medical laboratory technologists (radiation unexposed or control) subjects in the same healthcare facilities, within Port-Harcourt. All participants are Nigerians aged between 25 to 54 years and resident in Port-Harcourt for12-months prior to the study.The study consisted of two aspects, viz; the use of validated Questionnaire and Clinical laboratory examinations, preceded by informed consents of the subjects.

The study was conducted in five selected premier healthcare facilities in Port Harcourt, namely: Rivers State University Teaching Hospital (RSUTH), University of Port-Harcourt Teaching Hospital (UPTH), Dental and Maxillofacial Hospital (DMH), Rehoboth (Orthopedic) Specialist Hospital (RSH), and Intercontinental Diagnostics Centre (IDC). UPTH, RSUTH and DMH are public tertiary medical facilities, while RSH is a private specialist hospital, and IDC is a private specialist radiological outfit.

Port Harcourt is the metropolitan capital city of Rivers state in southern Nigeria, with geographical coordinates of longitude $07^{0}00'48''$ E - $07^{0}02'01''$ E and latitude $04^{0}46'38''$ N - $04^{0}49'27''$ N, and 16 metres elevation above sea level. Estimated human population is 1,960,000 (Demographia, 2016).

Some studies previously conducted on similar topics include the following:

Giragn, E. (2016), carried out a cross-sectional study on the effects of low-dose ionizing radiation on the haematological parameters in medical imaging and therapeutic technologists within hospitals in Ethiopia. Atypical lymphocyte morphologies (71.4%), Mean corpuscular hemoglobin (MCH), Platelet distribution width (PDW), and Platelet large cell ratio (P-LCR), weresignificantly higher in the exposed group, while total White blood cell (WBC), Lymphocyte, Monocyte, and Basophil counts, and Mean platelet volume (MPV), were lower in the same group. Conclusion: Low-dose ionizing radiations affect the hematological parameters in medical imaging technologists.

A case-control study at Diyala, Iraq, by Mohammed et al. (2013), on the effects of radiation on haematological parameters in x-ray technicians, showed that the ratio of atypical lymphocytes in exposed vis-a-vis unexposed subjects was significantly high ($p<0.01$) with a positive correlation of 0.67 with radiation exposure duration. Conclusion: chronic x-ray exposures may cause atypical alterations to lymphocyte morphology.

Nureddin et al. (2016), conducted a study on the effects of long-term exposure to latent x-rays on the blood constitution in radiology department staff of health centers within Libya, and reported that x-ray room technicians showed no statistically significant differences in the morphologies ofhaematological cells. However, statistically significant increases ($p<0.01$ and $p<0.05$) were noted in the mean values for platelets and WBCs in the exposed vis-a-visunexposed subjects. Conclusion:Chronic exposures to low x-rays cause some degree of hematological changes in the exposed.

Eze et al. (2013) carried out a study to assess the knowledge, attitude and practice of safe radiation work protection in radiographers within Lagos, Nigeria. A high level of knowledge (75%) was noted, but attitudes and practice to safe radiation work among the respondents was poor. This was attributed to obsolete x-ray equipment and lack of modern radiation PPEs.

A research paper by Silva et al. (2016) on the toxicogenic biomonitoring of workers to ionizing radiation exposure in Teresina, Brazil, showed no changes in the workers' haematological biomarkers (e.g cellular morphology. Significant increases ($p<0.05$) in frequency of karyolysis, karyorrhexis, and nuclear aberrations (e.g. micronuclei, sprouts, bi-nucleates etc.), were noted. Significant correlations ($p< 0.05$) were noted in the toxicogenic biomarkers with age, tobacco use, alcohol consumption, and duration of work. Conclusion: Ionizing radiation may affect genetic instability in disease conditions.

A study by Alnahhal et al. (2017) in government hospitals at Gaza Strip, Palestine, on the assessment of hematological parameters among radiographers, indicated that hematological parameters (e.g cell morphology) showed no statistical significant differences between the case and control groups. Also, no statistical significant differences were noted between the duration of radiation exposure and hematological parameters of radiographers. The researchers concluded that hematological parameters may not be significantly affected by chronic exposures to x-rays.

A study by Abubakar et al. (2016) at FMC-Asaba, showed that the mean indoor post exposure dose rate ranged between 0.09-0.20 μSv/hr (i.e. 0.60-2.01 mSv/yr); the diagnostic x-ray room had the highest irradiation level (2.01±4.11 mSv/yr), while the interns' general room had the lowest level (0.60±0.3 mSv/yr). The Mean Indoor Post-Exposure (MIPE) level was 0.88±0.28mSv/yr. Conclusion: FMC-Asaba was radiologically safe, as the ambient radiation value was less than the ICRP recommended limits of 1mSv/year.

Usen and Umoh (2014), assessed the level of radiation protection among radiation workers at Teaching Hospital Maiduguri, Nigeria, and reported that 96.7% used PPEs, and 86.7% practiced proper collimating of radiation beams during procedures.

II. Materials And Methods

The study employed the cross-sectional comparative analytical research method. This case-control type of study design is used in the fields of medicine, psychology, ecology and other sciences, to evaluate effects of certain variables on comparative subjects.

Proportionate stratified random sampling method, without ballot replacement, was adopted for the sample selection. According to Gay (2014), and Roscoe (2004), to achieve 80% statistical power and 95% confidence level (or 0.05 risk level) in analytical studies, a representative sample size for a large target population (≥ 30 units), should be greater or equal to 10% of the population, i.e.;

$$n \geq N \times 10/100, \text{ where } n = \text{sample size and } N = \text{target population size} \quad (3.1)$$

30 case subjects (36.1% of the 83 radiographers), and 30 controls (31% of the 97 medical laboratory technologists) within Port Harcourt, partook in this study.

Primary data were gathered using validated questionnaire copies and clinical laboratory examinations which entailed venipuncture/aspiration of venous blood samples from the subjects. Secondary data were obtained via hospital records of subjects. Required additional information were obtained via Journals, text books etc. The questionnaire copies were administered and retrieved within 7-days.

Venipuncture and aspiration of 2-ml peripheral venous blood from each subject using 20G needles into potassium ethylene-diamine-tetraacetic acid (K_2-EDTA) anti-coagulant vials, was carried out (for baseline samples), and analyzed within 1-hour using Sysmex XP-300^{TM}haematological auto-analyzer. Leishmann dye-stained smears were used to observe the cellular morphologies. The procedures were repeated on the same subjects (for second sample sets) after 120 days. Portable radiation monitors (GQ GMC-320 *plus*^{TM}) were used to measure the ambient radiation doses at the x-ray units.

The data obtained were subjected to the following statistical analyses using Microsoft excel and version 22.0 of the statistical package for social sciences (SPSS): Descriptive statistical tools, Kendall's coefficient of concordance (W), Independent samples T-test and ANOVA single factor, Wilcoxon's signed ranks test, and Pearson Chi Squraecorrelation test. A value of ≤0.05 was used to indicate the level of statistical significance (Nwaogazie, 2011).

A pilot test, which confirmed statistical reliability of the questionnaire, was conducted on subjects not actually included in the study, but representative of the case and control subjects, so as to assess their understanding of the questionnaire items, consistency of responses, and reproducibility of the instrument. Content validation of the items was done by radiologists and experts from the Association of Radiographers of Nigeria (ARN) to ascertain the degree to which they measured the theoretical construct they were intended to measure. The items were logically linked and representative of the study objectives (Nwaogazie, 2011).

Subjects with previous diagnosis with blood or debilitating medical conditions (such as immune-suppressive medications/diseases, gross anemia, diabetes mellitus, auto-immune, renal or cardiovascular diseases, pregnancy, and/or malignancies, etc.), or frequent users of tobacco products, were excluded from the study. Case subjects with less than 12-months of x-ray unit activities, and control participants exposed to x-rays in the preceding 12-months, were also excluded. Healthcare facilities that had defective x-ray machines were also excluded from the study.

III. Results And Discussion

3.1 *Presentation of data and analyses*

30 exposed (case)& 30 unexposed (control)subjects from the same healthcare facilities participated in this study. 60 questionnaire copies were administered and returned, (i.e. 100% response rate), and none was voided. All haematological analyses were conducted at the same tertiary medical laboratory.

3.1.1 *Age and gender distribution of subjects*

21.67% of the study population (n=13) were aged 25-34 years; 68.33% (n=41) were aged 35-44 years; and 10% were 45-54 years. Male subjects consisted 80% (n=48), while females consisted 20% (n=12).

Table 3.1: Age and gender distribution of exposed and non-exposed subjects

Parameters Age (years)/Gender	**Exposed (n=30) Number (%)**	**Unexposed (n=30) Number (%)**	**Total Number (%)**
25-34	8 (26.67)	5 (16.67)	13 (21.67)
35-44	19 (63.33)	22 (73.33)	41 (68.33)
45-54	3 (10)	3 (10)	6 (10)
TOTAL	**30 (100)**	**30 (100)**	**60 (100)**
Male	27 (90)	21 (70)	48 (80)
Female	3 (10)	9 (30)	12 (20)
TOTAL	**30 (100)**	**30 (100)**	**60 (100)**

3.1.2 *Duration of work experience and use of PPEs by case subjects*

Fig 3.1 shows that 20% (n=6) had ≤5 years' experience, 60% (n=18) had 6-10 years, while 20% (n=6) had >10 years' work experience.Table 3.2 shows that PPE availability and accessibility was 100% (n=30). 80% (n=24) had proper PPE usage, while 70% confirmed bi-annual PPE viability inspections.

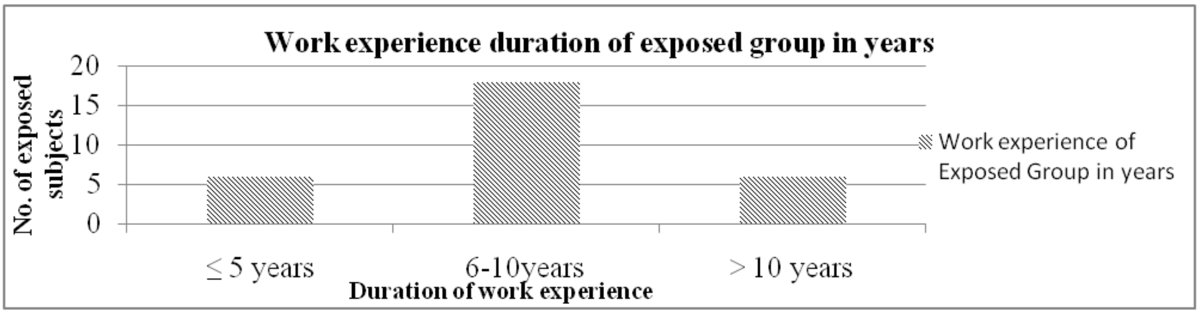

Fig 3.1: Work experience of case subjects

Table 3.2: Assessment of Usage of PPEs

Indices	**Number (%)**
Availability	30 (100)
Accessibility	30 (100)
Proper application (usage)	24 (80)
Viability tests	21(70)

3.1.3: *Ambient (background) radiation levels at x-ray units of facilities*

Annual values ranged from 0.6088mSv/year to 0.8392mSv/year ($p \leq 0.05$) at the respective units.

Table 3.3: Mean values of background radiation levels in respective radiology facilities

Facility	Dose rate (μSv/hr)		Mean ±Std dev.	Annual dose rate (mSv/year)
	Minimum	Maximum		
RSUTH	0.0510,	0.0880,	0.06950 ±0.02616,	0.6088
UPTH	0.0771,	0.1040,	0.09055 ±0.01902,	0.7932
DMH	0.0822,	0.1094,	0.09580 ±0.01923,	0.8392
RSH	0.0814,	0.1072,	0.09430 ±0.01824,	0.8261
IDC	0.0789,	0.1025,	0.09070 ±0.01669,	0.7945

3.1.4 ***Knowledge, awareness and re-training of radiographers on adverse x-ray effects and preventive measures***

86.7% (n=26) had regular re-training sessions and exhibited adequate knowledge. 13.3% had no re-trainings and showed limited knowledge of the subject matter.

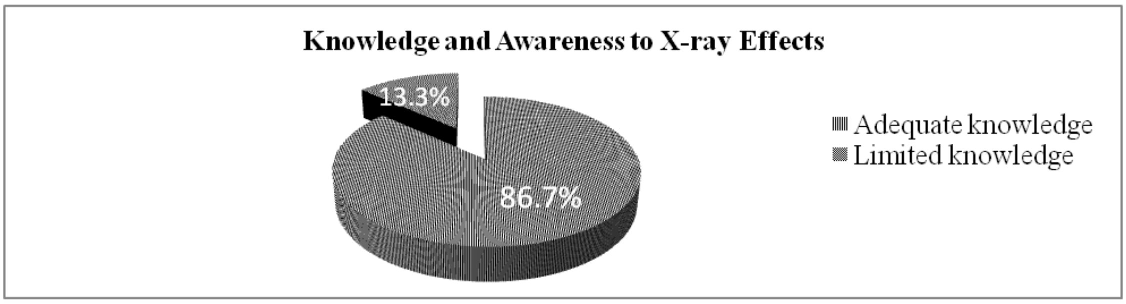

Fig 3.2: Knowledge, awareness and re-training to x-ray effects

3.1.4.1 ***Kendall's coefficient of concordance (w) among raters showing degrees of unanimity to responses on knowledge, awareness and re-training on adverse x-ray effects and prevention.***

On the basis of the respondents' age groups (25-34, 35-44, & 45-54 years), W values of 0.79, 0.77, and 0.81were computed and showed high degrees of unanimity. On the basis of therespondents' years of work experience (≤5years, 6-10years, and >10 years), W values of 0.76, 0.84, and 0.89 showed higher degrees of unanimity of responses.

Table 3.4: Kendall's W of raters on levels of knowledge/awareness/re-training about adverse x-ray effects vis-à-vis their ages and work experience durations

Respondents,	Kendall's W values,	Percentage of concordance
Age (years),	(%)	
25-34,	0.791,	~79
35-44,	0.769,	~77
45-54,	0.811,	~81
Work experience (years),		
≤5,	0.758,	~76
6-10,	0.839,	~84
>10,	0.885,	~89

3.1.5***Peripheral blood cell morphology analysis***

In Fig 3.3a, 53.3% (n=16) of the case subjects, and 76.7% (n=23) of the control subjects, showed normocytic, normochromic blood films; 26.7% (n=8) of the case subjects showed microcytosis, anisocytosis or poikilocytosis, as against 10% (n=3) of the controls; 23.3% (n=7) of the case subjects showed atypical lymphocytes, compared to 10% (n=3) of the controls; while codocytes were observed in 16.7% (n=5) of case, as against 13.3% (n=4) of control subjects. In Fig 3.3b (i.e. second sample set), 50.0% (n=15) of the case subjects, and 86.7% (n=26) of the control subjects, showed normocytic, normochromic blood films; 33.3% (n=10) of the case subjects and 10% (n=3) of the controls showed microcytosis, anisocytosis or poikilocytosis; 23.3% (n=7) of the case subjects and 6.7% (n=2) of the controls showed atypical lymphocytes; while 13.3% (n=4) of case and 10% (n=3) of control subjects had codocytes.

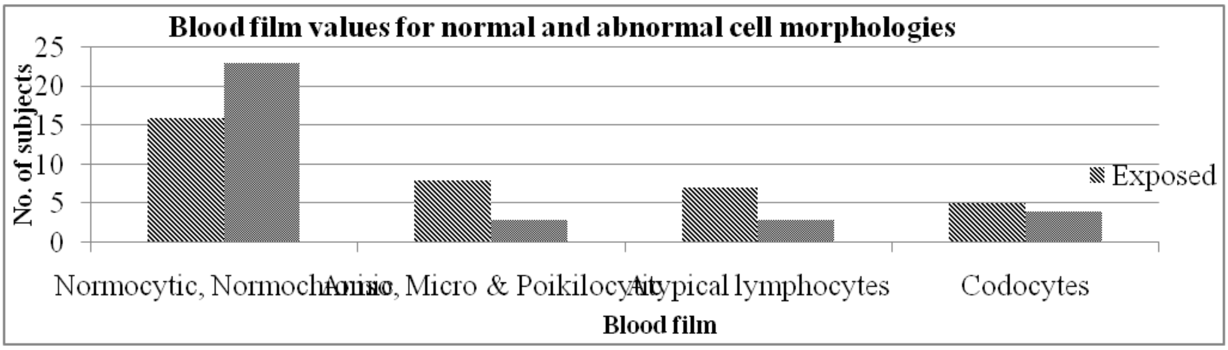

Fig 3.3a: Bar chart of blood film values (baseline set) showing normal and abnormal cell morphologies

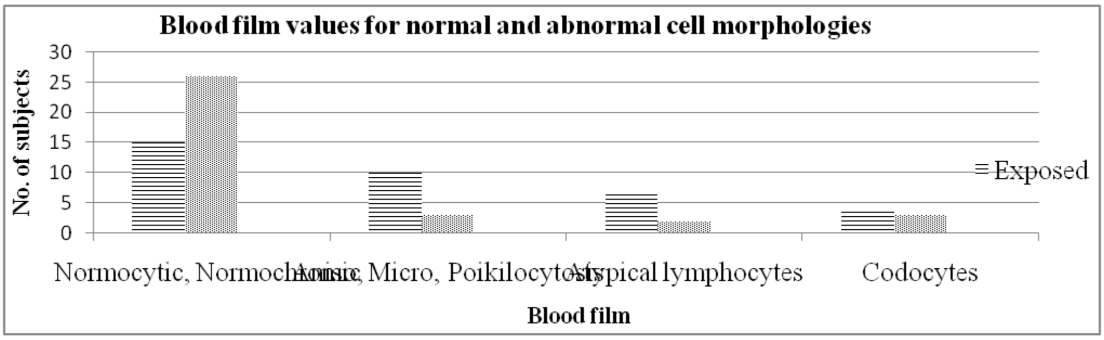

Fig 3.3b: Bar chart of blood film values (second sample set) showing normal and abnormal cell morphologies

Tables 3.5(a)&(b), for baseline and second sample sets respectively, depict the number of case subjects exhibiting predominantly normal or abnormal cell morphologies within the categorical parameters using baseline and second sample sets, respectively.34.5%(a) & 33%(b)of the males showed predominantlyabnormal cell morphologies, as against 33%(a) & 25%(b) of females. 30.7%(a) & 38.5%(b) of case subjects in the 25-34 years age range showed predominantlyabnormal cell morphologies, as against 36.6%(a) & 36.5%(b)in the 35-44years range, and 33.3%(a) &50%(b)in the 45-54 years range.16.6%(a) &…(b)of case subjects with ≤5 years work experience showed predominantlyabnormal cell morphologies, as against 66.7%(a) &61.1%(b)in the 6-10 years range, and 83.3%(a) & 100%(b)in the >10years'work experience range

Table 3.5a: Number of Subjects Exhibiting Normal or Abnormal Cell Morphologies within the Categorical Parameters using baseline samples

Categorical Parameters		Total Number	Normal Morphology	Abnormal Morphology
Gender	Male	48	31	17
	Female	12	8	4
	25-34 years	13	9	4
Age group	35-44 years	41	26	15
	45-54 years	6	4	2
	≤ 5 years	6	5	1
Work experience	6-10 years 18	6		12
group>10 years6	1		5	

Table 3.5b: Number of Subjects Exhibiting Normal or Abnormal Cell Morphologies within the Categorical Parameters using second sample set

Categorical Parameters		Total Number	Normal Morphology	Abnormal Morphology
Gender	Male	48	32	16
	Female	12	9	3
Age group	25-34 years	13	8	5
	35-44 years	41	26	15
	45-54 years	6	3	3
Work duration group	≤ 5 years	6	5	1
	6-10 years	18	7	11
	>10 years	6	0	6

Table 3.6a: Wilcoxon's signed rank test of blood film values for normal and abnormal cell morphologies in exposed and unexposed groups, using the baseline samples

Blood cell morphology	Exposed number (%)	Unexposed number (%)	p-Value	Z-test
Normocytic/ Normochromic	16 (53.3)	23 (76.7)	0.008	-2.646
Anisocytic/ Microcytic/ Poikilocytic	8 (26.7)	3 (10.0)	0.025	-2.236
Atypical lymphocytes	7 (23.3)	3 (10.0)	0.046	-2.000
Codocytes	5 (16.7)	4 (13.3)	0.317	-1.000

Table 3.6b: Wilcoxon's signed rank test of blood film values for normal and abnormal cell morphologies in exposed and unexposed groups, using the second sample set

Blood cell morphology	Exposed number (%)	Unexposed number (%)	p-Value	Z-test
Normocytic/ Normochromic	15 (50.0)	26 (86.7)	0.001	-3.317
Anisocytic/ Microcytic/ Poikilocytic	10 (33.3)	3 (10.0)	0.008	-2.646
Atypical lymphocytes	7 (23.3)	2 (6.7)	0.025	-2.236
Codocytes	4 (13.3)	3 (10.0)	0.317	-1.000

3.1.6 Correlation between abnormal morphologies other categorical variables (age, gender, and work duration)

Using data from the baseline sampleset (Table 3.6a),Pearson Chi Square test values for the subjects' age group and gender were$X^2(2, N{=}60) = 0.155$, $p>0.05$; and $X^2(1, N{=}60) = 0.018$,$p>0.05$, respectively. This indicatesthat no significant strengths of association exits between these parameters and abnormal cellular morphologies. Test values of $X^2(2, N{=}60) = 6.389$, $p<0.05$ for duration of work exposure, indicated statistically significant association between abnormal cellular morphologies and duration of work exposure.

Using data from the second sample set (Table 3.6b), Pearson Chi Square test values for the subjects' age group and gender were$X^2(2, N{=}60) = 0.399$,$p>0.05$; and $X^2(1, N{=}60) = 0.308$, $p>0.05$, respectively, indicating no significant association between the parameters and abnormal cellular morphologies. Test values of $X^2(2, N{=}60) = 8.704$, $p<0.05$indicated statistically significant association between abnormal cellular morphologies and duration of work exposure.

Table 3.7a: Pearson Chi Square test for associations between Abnormal morphologies versus age, gender, and duration of work exposure of case subjects, respectively, using baseline sample set.

	Pearson Chi square	**p-value**
Abnormal morphology,	1,	<0.001
Age,	0.155	0.925
Gender,	0.018,	0.892
Work exposure,	6.389,	0.041

Table 3.7b: Pearson Chi Square test for associations between Abnormal morphologies versus age, gender, and duration of work exposure of case subjects, respectively, using second sample set.

	Pearson Chi square	**p-value**
Abnormal morphology,	1,	<0.001
Age,	0.399	0.819
Gender,	0.308	0.579
Work exposure,	8.704,	0.013

Despite variations in the recorded mean ambient radiation levels between the radiology units of the respective healthcare facilities, no statistically significant differences were noted. Also, the obtained annual radiation levels in the radiology units of the respective facilities ranged from 0.6088mSv/year to 0.8392mSv/year and did not exceed the ICRP recommended limit of 1.0 mSv/year. Complete (100%) availability and accessibility to PPEs by radiographers was recorded in the healthcare facilities. Annual equipment/materials viability tests by regulatory bodies were confirmed by 70% of the case respondents. These observations implied that the risks of unnecessary exposures of radiographers to x-rays were considered minimal (though not eliminated) at these Port Harcourt premier healthcare facilities, given that the recorded background radiation values did not exceed the ICRP recommended limits, and their usage of radiological PPEs were adequate. Though the radiological equipment at the facilities were viable, the frequency/regularity of equipment viability testing by regulatory bodies was less than optimal. Briggs-Kamara et al. (2013), showed that 97% of radiographers in Port Harcourt exhibit a form of adverse health condition especially during their active years of occupational radiation exposure. The chronicity of the radiographers' exposure to low-dose x-rays may have accounted for the observed changes in their basic haematological parameters.

Eighty six percent of radiographers (n=26) exhibited adequate knowledge to adverse biological effects of x-ray exposures. Thirteen percent (n=4) showed less than optimal knowledge of the subject matter. Kendall's W values for extent of unanimity of responses among radiographers regarding their levels of knowledge/awareness/re-training about adverse effects of x-rays vis-à-vis their chronological ages and years of work experience varied between 0.79, 0.77, 0.81 (based on age groups), and 0.76, 0.84, and 0.89 (based on years of work experience groups), respectively. This indicated high levels of response agreements among raters.

Statistically significant variations in the blood cell morphologies were observed between the radiation-exposed and unexposed groups using Wilcoxon's signed rank testing. The number of anisocytic/microcytic/poikilocytic cells, and atypical lymphocytes were noted to be higher than normal in the exposed, while normocytic/normochromic cells predominated in the unexposed group. However, the number of case subjects with these findings did not significantly change between both laboratory sample sets within each subject group. These findings connoted that protracted exposures to latent doses of x-rays by radiographers have some degrees of adverse effects on the morphologies of their blood cells. The biochemical alterations of the anatomical structures of their cell constituents by free radical ions (released during irradiation procedures), could have caused micro-damages to the haematological cells, and resulted in the higher numbers of abnormal cellular morphologies. Blood cells with normal (normocytes) and abnormal (poikilocytes, anisocytes, codocytes, atypical lymphocytes, etc.) morphologies can occur simultaneously in normal blood films, however, the abnormal cells usually comprise ≤5% of the film cellular volume. Blood cell defects occur due to abnormal hemoglobin contents, altered membrane volumes, altered cellular shapes or sizes which then result in cell malformations and inability to carry out their physiological functions effectively (cellular functional deficiencies). These findings were similar to the Iraqi, Libyan and Ethiopian studies conducted by Mohammed et al. (2013), Nurredin et al. (2016), and Giragn (2016), respectively.

Statistical testfor association of categorical variables (Pearson's Chi Square test)did not indicate significant relationship between the major study finding (i.e. higher abnormal blood cell morphology values) and biographical data of radiographers. The tests were performed between the abnormal morphologyvalues versus the ages, and genders of the radiographers, respectively. Marital status and geographical locations were exempted because these characteristics were common to all the study subjects. This indicated that the higher abnormal blood cell morphology values observed in the blood samples from the radiographers were neither due to their different ages nor genders. These findings were similar to those in the study conducted by Giragn (2016) in Addis Ababa-Ethiopia, but differed in the index dependent variable since only atypical lymphocyte counts were correlated with exposure duration instead, in that study**.** However, statistically significant relationships were noted between the abnormal blood cell morphology and the duration of work exposure to x-rays among radiographers. The implication of this finding was that the longer the duration of exposure to latent x-rays, the more the occurrence of higher abnormal blood cell morphologies in the radiographers studied. This could be attributed to the cumulative adverse effects of the free radicals on the haematological cells of the radiographers. These findings were similar to those in the study by Silva et al. (2016) in Teresina-Brazil. The durations of work experience among the radiographers ranged from 1 year to 22 years.

IV. Conclusion

Uncontrolled exposures to x-rays have deleterious effects on the human body, due to their capacity to penetrate living cells and cause abnormal biochemical changes. This research was aimed at determining the effects of exposures to low-dose x-rays onbasic blood cell morphologies of radiographers in Port-Harcourt.

The study employed the cross-sectional retrospective comparative analytical method and involved 60 subjects. Proportionate stratified random sampling was adopted in the selection of the sample size, and the study involved the use of validated Questionnaire copies and clinical examinations at the same tertiary medical laboratory. The data were analyzed using Microsoft excel and the Statistical package social sciences (SPSS version 22).

Annual ambient radiation levels recorded in the facilities did not exceed the ICRP recommended limit of 1.0mSv/year.

Statistically higher values of abnormal blood cell morphologies (such as poikilocytes, anisocytes, microcytes, and atypical lymphocytes), were observed in the radiation-exposed (radiographers) vis-á-vis unexposed (medical laboratory technologists) study subjects.

Statistical correlations were noted between abnormal blood cell morphology valuesand duration of x-ray exposures.

PARTICIPANTS' CONSENT

The authors declare that 'written informed consents were obtained from the subjects for publication of this research.

COMPETING INTERESTS:

Authors have declared that no competing interests exist in this study.

ETHICAL ISSUES

The study had ethical considerations because it involved invasive procedures on human subjects. Approval for the study was obtained from the Research Ethics Committee of the University, with the assigned reference number: UPH/CEREMAD/REC/04. The authors declare that all experiments have been examined and approved by the appropriate ethics committee and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

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