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Profile of Haematological Parameters among Radiographers Exposed to Low-Dose X-Rays in Selected Port Harcourt Healthcare Facilities

Wejie-Okachi, Chinunam[1*], Agi, Chukuemeka[2] and Douglas, Kingsley[3]

[1]Centre for Occupational Health, Safety and Environment, University of Port Harcourt, Nigeria.
[2]Department of Radiology, University of Port Harcourt Teaching Hospital, Port Harcourt, Nigeria.
[3]Department of Community Medicine, University of Port Harcourt Teaching Hospital, Port Harcourt, Nigeria.

Authors' contributions

All authors designed the study, managed empirical reviews, performed statistical analysis, read and approved the final manuscript.

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ABSTRACT

X-rays are electromagnetic waves that can traverse the human body due to high energies (≥1.24 keV) and ultra-short wavelengths (≤10^{-10}m). Acute exposures are harmful to human health, affecting hematopoietic systems among others. Workers experience these effects despite use of occupational exposure controls such as Personal Protective Equipment (PPEs). This study spanned May 2018 to February 2019, and was aimed at determining the effects of exposure to low-dose x-rays on haematological parameters of radiographers in Port-Harcourt. Delimitation was to a target population of radiographers who work for ≥ 6-hours daily and ≥ 5-days weekly, over ≥ 12-months, and a corresponding number of control subjects in five healthcare facilities. The cross-sectional retrospective comparative research design method was employed, and consisted of

**Corresponding author: E-mail: drcwejieokachi@yahoo.com;*

administered Questionnaire with a 100% response rate. Two sets of blood samples, collected 120 days apart, underwent clinical laboratory examinations. 30 exposed (case) and 30 unexposed (control) subjects, aged 25-54 years, participated in this study at a ratio of 1:1. Mean annual background x-ray room radiation level was 0.7724mSv (i.e. 0.6088mSv-0.8392mSv), and workers recorded 100% usage of PPEs and 86.7% (n=26) knowledge/awareness to adverse x-ray effects. Mean values for hematocrit, platelet, and mean cell volume, were higher, but White Blood Cells (WBCs) (*P*=0.025, 0.044), Neutrophils (*P*=0.018, 0.042), Lymphocytes (*P*=0.026, 0.025) were significantly lower, in the case vis-à-vis control groups. Haematological parameters showed no statistical differences between values for 1st and 2nd sample sets within each subject group. Normal blood cell morphologies predominated in the unexposed group (76.6% & 86.7%), when compared to the exposed group (53.3% & 50.0%), except for codocytes (z = -1.000, *P*=0.317). WBC values in radiographers inversely correlated with their duration of x-ray exposures (r = -0.431, *P*<0.05).This study showed that chronic exposures to low-dose x-rays affect whole leucocyte parameters, despite implementation of PPEs.

Keywords: Ionizing radiation; haematological parameters; pan-leucopenia; poikilicytosis; anisocytosis; microcytosis; atypical lymphocytes; codocytes.

1. INTRODUCTION

X-radiations (x-rays) are ionizing radiological emissions that can traverse organic/inorganic matter, due to their high energy levels - ≥1.24 keV and ultra-short wavelengths - ≤10^{-10}metres [1]. Acceptable annual effective dose limits for human exposures 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), as recommended by the International Commission on Radiological Protection [2]. Radiation exposure measuring devices include; alarm or luminescent dosimeters, film badges, fixed/portable radiation monitors etc. [3]. Global annual records show that clinical use of x-rays accounts for 98% of man-made emissions, i.e. ≈20% of all radioactive emissions [4]. Radiographers are healthcare workers concerned with the handling/operation of radiological materials/procedures in medical facilities, such as plain radiography, mammography, fluoroscopy, angiography, computed axial tomography etc. Therefore they are frequently exposed to low-dose x-rays (also termed residual or 'scatter' radiation). Hematopoietic cells/tissues exhibit high sensitivity to ionizing radiation, and serve as indicators for health effects. Hematological profiling employs empirical methods to evaluate blood constituent parameters, and compare the observed values with normal ranges. Basic haematological indices include; Full blood counts and differentials, cellular morphologies, 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. [5]. The hematopoietic systems control the oxygen-carrying capacity of blood, competent immunological system, and spontaneous control of hemorrhages. Dysfunctions result in degrees of hypoxemia, immuno-suppression, coagulation accidents/disorders, etc., which manifest clinically as anemia, susceptibility to infections and septicemia, hemorrhagic episodes, etc. [6]. 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) [7], highlighted the knowledge, awareness and practice of radiographers in Port-Harcourt, Nigeria, to x-ray exposure effects. Abubakar et al. (2016) [8], assessed the ambient radiation doses at FMC Asaba, Nigeria. Eze et al. (2013) [9], and Usen and Umoh (2014) [10], assessed radiation protection practices among radiographers in Lagos (western), and Maiduguri (northern) Nigeria, respectively. The evaluation of x-ray effects on haematological parameters of radiographers was beyond the scopes of these studies. However Nureddin et al. (2016) [11], in Libya (north), and Giragn (2016) [12], in Ethiopia (east) Africa, respectively, determined the effects of x-rays on the blood parameters of radiographers, but their results may not be applicable to Nigeria due to the regional climatic differences between these countries involved. Given increasing global use of radio-imaging procedures [13], 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 exposure to low-dose x-rays on haematological parameters of 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 six-months.
2. Assess the proper use of radiological Personal Protective Equipment (PPEs) using the availability, accessibility, application and viability as indices.
3. Assess the basic haematological parameters: blood-cell morphologies, blood cell counts and cell-differentials, derived erythrocyte indices, hemoglobin and hematocrit (Hct) levels in the study groups over a period of six months.
4. Establish statistical correlations between the major haematological 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 (control or radiation unexposed) subjects in the same healthcare facilities, within Port-Harcourt. All participants are Nigerians aged between 25 to 54 years, and resident in Port-Harcourt for 12-months prior to the study.

The study consisted of two aspects, namely; the use of validated Questionnaire and Clinical laboratory examinations, preceded by informed subjects' consents.

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 the southern Nigeria, with geographical coordinates of longitude 07º00'48" E - 07º02'01" E and latitude 04º46'38" N - 04º49'27" N, and 16 metres elevation above sea level. Estimated human population is 1,960,000 [14].

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. The Mean corpuscular hemoglobin (MCH), Platelet distribution width (PDW), Platelet large cell ratio (P-LCR), and Atypical lymphocytes were significantly higher, while total White blood cell (WBC), Lymphocyte, Monocyte, and Basophil counts, and Mean platelet volume (MPV), were lower in the exposed group. Conclusion: Low-dose ionizing radiations affect the hematological (especially immunological) system of medical imaging technologists.

A case-control study at Diyala, Iraq, by Mohammed et al. [15], 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. Thus, chronic x-ray exposures may cause atypical alterations to lymphocyte morphology.

Nureddin et al., 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 statistically significant increases ($p<0.01$ and $p<0.05$) in WBC and platelet counts, respectively, vis-a-vis the control population. No significant differences were noted in the other haematological parameters. A conclusion that chronic exposures to low x-rays could cause some degree of hematological changes was reached.

A research paper by Silva et al. (2016) [16] on the toxicogenic biomonitoring of workers to ionizing radiation exposure in Teresina, Brazil, showed no changes in the haematological biomarkers. A significant increase ($P < 0.05$) in the frequency of karyolysis, karyorrhexis, and nuclear aberrations (e.g. micronuclei, sprouts, binucleate cells etc.), was noted. In unprotected workers, significant correlations ($P < 0.05$) were noted in the toxicogenic biomarkers with age, tobacco smoking, alcohol consumption, and duration of work. Conclusion: Ionizing radiation may affect genetic instability in disease conditions.

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.

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 study by Abubakar et al. (2016) at FMC-Asaba, showed 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 1 mSv/year.

2. 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.

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.

Proportionate stratified random sampling method, without ballot replacement, was adopted for the sample selection. According to Gay (2014) [17], and Roscoe (2004) [18], to achieve 80% statistical power and 95% confidence level (or 0.05 risk level), a representative sample size for a large target population (≥ 30 units), should be greater or equal to 10% of the population, i.e.;

$n \geq N \times 10/100$, where n = sample size and N = target population size (2.1)

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 was 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, Pearson's product-moment (bivariate) correlation coefficient (PPMCC), and linear regression analysis. A value of ≤0.05 was used to indicate the level of statistical significance [19].

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. This is as explained by [19].

Subjects with previous diagnosis with blood or debilitating medical conditions (such as immunesuppressive 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.

3. 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 a 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).

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

20% (n=6) had ≤5 years' experience, 60% (n=18) had 6-10 years, while 20% (n=6) had >10 years' work experience. PPE availability and accessibility was 100% (n=30). 80% (n=24) had proper PPE usage, while 70% confirmed PPE viability inspection.

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)**

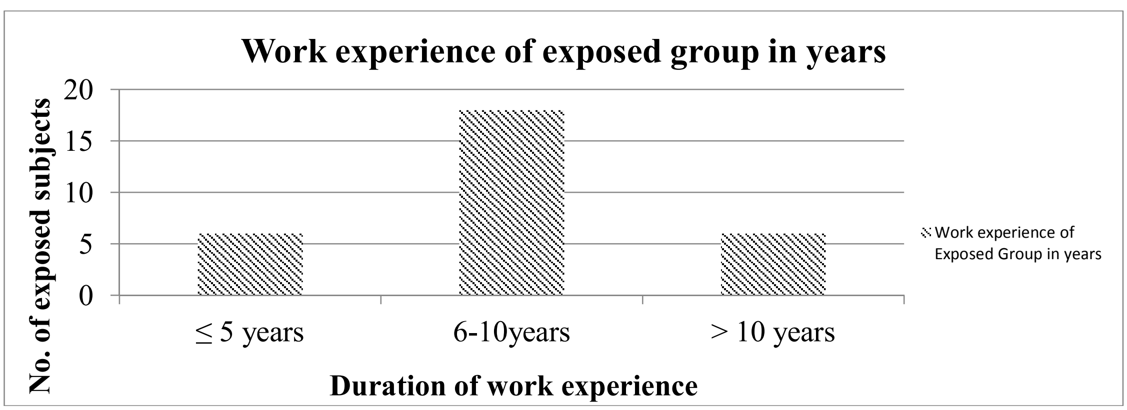

Fig 3.1. Work experience of case subjects

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 in X-ray units of facilities

Annual values ranged from 0.6088mSv/year to 0.8392mSv/year (p≤0.05).

3.1.4 Knowledge, awareness and Re-training on adverse X-ray effects and preventive measures

86.7% (n=26) had regular re-training sessions exhibited adequate knowledge. 13.3% had limited knowledge.

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 their age groups, W values of 0.79, 0.77, and 0.81were computed and showed high degrees of unanimity among subjects of 25-34, 35-44, & 45-54 years, respectively. On the basis of their years of work experience, W values of 0.76, 0.84, and 0.89 showed higher degrees of unanimity between work experience groups of ≤5 years, 6-10 years, and >10 years, respectively.

3.1.5 Full blood count analysis from baseline and second sample sets

Tables 3.5a & b show values for HCT, PLT, and MCV were marginally higher (but no statistically significant differences), while WBC, NEUT and LYMPH were statistically significantly lower in the case group in both sample sets respectively. I.e. WBCs (*P*=0.025, 0.044), NEUTs (*P*=0.018, 0.042) and LYMPHs (*P*=0.026, 0.025), HGB (*P*=0.021, 0.037). Table 3.5c shows T-test of FBC parameters between subjects' baseline and second sample sets. No statistically significant differences were noted.

3.1.6 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 16.7% (n=5) of case, as against 13.3% (n=4) of control subjects, had codocytes. In Fig 3.3b, 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.

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

Facility	Dose rate (µSv/hr)		Mean ±Std dev.	Annual doserate(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

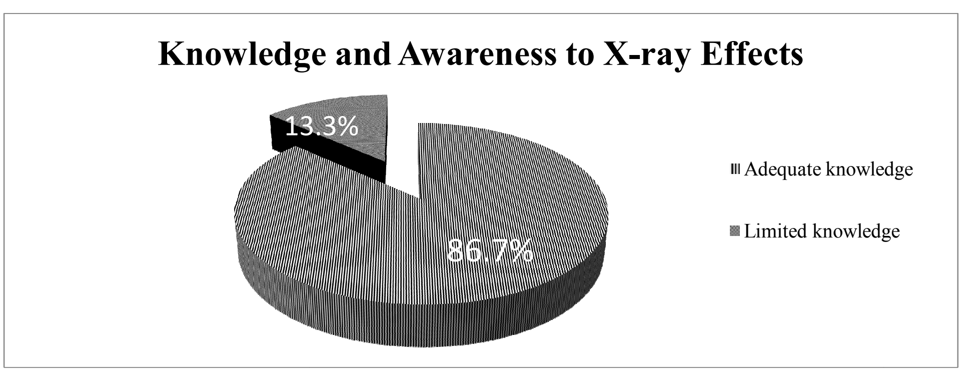

Fig 3.2.Knowledge, awareness and re-training to x-ray effects

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

Table 3.5a(i). Mean values of full blood counts in exposed and unexposed using baseline sample set

Parameter	Mean (exposed workers; n=30)	Standard deviation	Mean (unexposed workers; n=30)	Standard deviation
RBC (10^6 /μL),	4.8660 ±0.09344,	0.51180,	4.6517 ±0.06739,	0.36911
HGB (g/dL),	12.6833 ±0.14312,	0.78393,	12.2233 ±0.13014,	0.71278
HCT (%),	41.8867 ±0.47398,	2.59612,	40.7267 ±0.50893,	2.78753
PLT (10^3/μL),	265.1000 ±9.78109,	53.57325,	251.8333 ±11.02412,	60.38159
MCV (fL),	85.3133 ±1.01388,	5.55324,	84.4067 ±1.12343,	6.15327
WBC (10^3/μL),	6.8167 ±0.35347,	1.93606,	7.9600 ±0.34884,	1.91070
NEUT (%),	45.6667 ±0.89228,	4.88723,	49.1000 ±1.09161,	5.97899
LYMPH (%),	41.9667 ±0.94380,	5.16943,	46.7000 ±1.82385,	9.99017
MON (%),	7.943 ±0.7347,	4.0239,	7.020 ±0.7948,	4.3535
EOSN (%),	7.903 ±0.7497,	4.0336,	7.028 ±0.7967,	4.3222

Table 3.5a (ii). Mean values of Full Blood Counts in exposed and unexposed using second sample set

Parameter	Mean (exposed workers; n=30)	Standard deviation	Mean (unexposed workers; n=30)	Standard Deviation
RBC (10^6/μL),	4.8700 ±0.08891,	0.48695,	4.7007 ±0.06977,	0.38217
HGB (g/dL),	12.7000 ±0.14400,	0.78871,	12.2967 ±0.12163,	0.66671
HCT (%),	42.0700 ±0.59355,	3.25101,	40.3333 ±0.51013,	2.79412
PLT (10^3/μL),	265.1667 ±9.78905,	53.61683,	252.2000±11.08332,	60.70585
MCV (fL),	85.2967 ±1.01318,	5.54943,	84.4400 ±1.11983,	
WBC (10^3/μL),	6.8133 ±0.34789,	1.90548,	7.8167 ±0.34160,	1.87103
NEUT (%),	45.8667 ±0.86932,	4.76144,	48.9000 ±1.17982,	6.42382
LYMPH (%),	42.0333 ±0.92169,	5.04793,	46.9333 ±1.89369,	10.3721
MON (%),	8.1533 ±0.73676,	4.03542,	7.1533 ±0.76010,	4.16325
EOSN (%),	8.1970 ±0.72943,	4.01071,	8.0672 ±0.74491,	4.09345

3.1.7 Correlation between categorical variables and WBC counts

Coefficient values of 0.056 for age (*P*>0.05, i.e. *P*=0.770), and 0.184 for gender (*P*>0.05, i.e. *P*=0.331) indicated negligible strengths of association with WBC count. Correlation coefficient values of -0.431 (*P*<0.05, i.e. *P*=0.017) for duration of work exposure indicated moderately inverse association with WBC count. In the scatter plot diagram, moderately negative correlation is highlighted by the line of fit.

Table 3.5b(i). Independent samples T-test to compare mean values in FBCs between exposed and unexposed workers using baseline samples

Parameter,	T,	*P*-Value,	95% confidence interval of the difference	
			Lower	**Upper**
RBC (10^6/µL),	1.866,	0.067,	-0.01561,	0.44561
HGB (g/dL),	2.378,	0.021,	0.07278,	0.84722
HCT (%)	1.668,	0.101,	-0.23212,	2.55212
PLT (10^3/µL),	0.900,	0.372,	-16.23413,	42.76746
MCV (fL),	0.599,	0.551,	-2.12251,	3.93584
WBC (10^3/µL),	-2.302,	0.025,	-2.13744,	-0.14923
NEUT(%),	-2.435,	0.018,	-6.25553,	-0.61114
LYMPH (%),	-2.305,	0.026,	-8.87360,	-0.59307
MON (%),	0.853,	0.397,	-1.24324,	3.08991
EOSN (%),	0.849,	0.410,	-1.23397,	3.07442

Table 3.5b(ii). Independent samples T-test to compare mean values in FBCs between exposed and unexposed workers using second sample set

Parameter,	T,	*P*-Value,	95% confidence interval of the difference	
			Lower	**Upper**
RBC (10^6/µL),	1.498,	0.139,	-0.05689,	0.39556
HGB (g/dL),	2.140,	0.037,	0.02603,	0.78064
HCT (%),	1.708,	0.093,	-0.22998,	2.90331
PLT (10^3/µL),	0.877,	0.384,	-16.63341,	42.56675
MCV (fL),	0.567,	0.573,	-2.16623,	3.87956
WBC (10^3/µL),	-2.058,	0.044,	-1.97930,	-0.02737
NEUT (%),	-2.078,	0.042,	-5.95558,	-0.11108
LYMPH (%),	-2.327,	0.025,	-9.15015,	-0.6498
MON (%),	0.964,	0.339,	-1.09896,	3.13896
EOSN(%),	0.923,	0.331,	-1.09644,	3.13888

Table 3.5c. T-test to compare mean values of FBCs between the baseline and second sample sets within each subject group

Parameter,	T,	F-value,	*P*-Value,	95% confidence interval of the difference	
				Lower	**Upper**
Exposed(1 & 2),					
RBC,	-0.026,	0.069,	0.979,	-0.26151,	0.25485
HGB,	-0.082,	0.015 ,	0.935,	-0.42307,	0.38974
HCT,	-0.241,	1.058,	0.810,	-1.70380,	1.33713
PLT,	-0.005,	0.000,	0.996,	-27.76680,	27.63346
WBC,	0.007,	0.026,	0.995,	-0.98943,	0.99610
NEUT,	-0.161,	0.075,	0.873,	-2.69363,	2.29363
LYMPH,	-0.051,	0.071,	0.960,	-2.70723,	2.57390
MON,	-0.215,	0.033,	0.831,	-2.30250,	1.85583
EOSN,	-0.202,	0.033,	0.841,	-2.29269,	1.87269
Unexposed (1&2),					
RBC,	-0.505,	0.141,	0.615,	-0.24318,	0.14518
HGB,	-0.412,	0.015,	0.682,	-0.42989,	0.28322
HCT,	-0.009,	0.000,	0.993,	-1.44908,	1.43575
PLT,	-0.023,	0.001,	0.981,	-31.65827,	30.92494
WBC,	0.294,	0.136,	0.770,	-0.83400,	1.12066
NEUT,	0.125,	0.096,	0.901,	-3.00720,	3.40720
LYMPH,	-0.089,	0.030,	0.930,	-5.49630,	5.02964
MON,	-0.100,	0.003,	0.921,	-2.31115,	2.09115
EOSN,	-0.103,	0.003,	0.918,	-2.31480,	2.08813

Key: 1 & 2 - Baseline and second sample sets

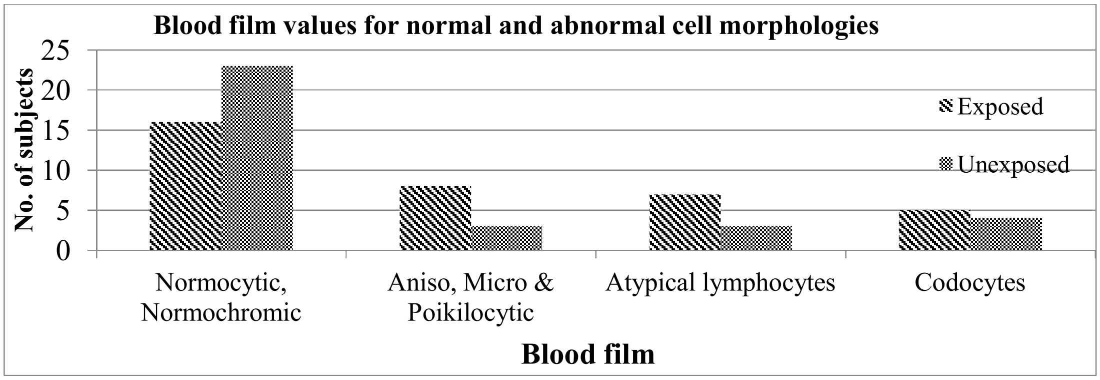

Fig. 3.3a. Bar chart of blood film values (baseline set) showing normal and abnormal cell morphologies

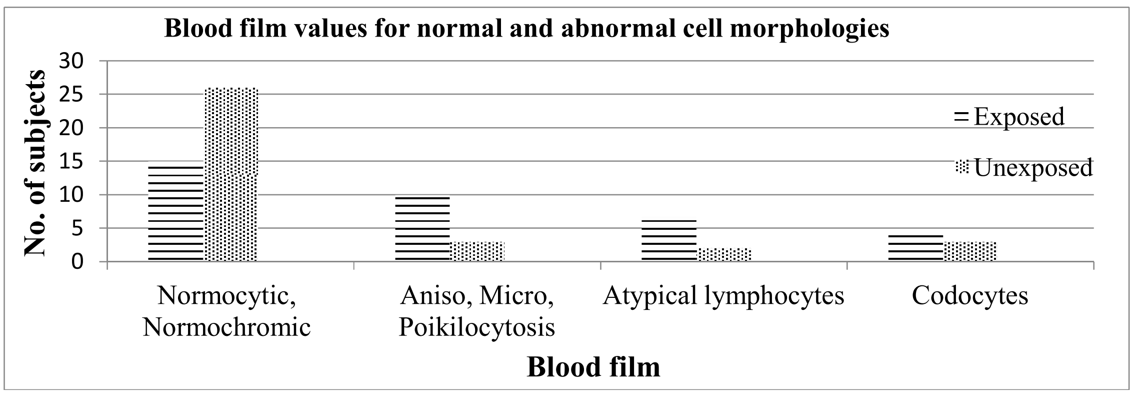

Fig. 3.3b. Bar chart of blood film values (second sample set) showing normal and abnormal cell morphologies

Table 3.6. Pearson correlation coefficient for associations between WBC counts, age, gender, and duration of work exposure of case subjects, respectively

	Pearson coefficient,	*P*-value
WBC,	1,	<0.001
Age,	0.056,	0.770
Gender,	0.184,	0.331
Work exposure,	-0.431,	0.017

3.1.8 Prediction of WBC counts vis-à-vis AAED using linear regression

In Table 3.7, the AAED was a moderate-high predictor of WBC count in exposed subjects because it explained 71.6% of the variations in the WBC count as shown in the coefficients table; β=-0.846, t(1,28) = -8.400, P=<0.001, R^2=0.716, Durbin-Watson=1.797. Therefore within margins of statistical error, the regression equation was computed as: $\hat{Y}_{WBC\ count} = 20.975 - 17.810(AAED) + e$ In the scatter plot diagram, the moderately inverse relationship is highlighted by the regression line.

4. DISCUSSION

Exposures to ionizing radiations have been demonstrated to have various degrees of harmful effects on different parts of the human body which may be acute or chronic. The effects of chronic exposures are usually gradual; therefore periodic examinations of haemato-logical parameters would serve as internal indicators of adverse health conditions because of the high sensitivities to radiation exhibited by hematopoietic cells. Some haematological parameters were shown to be affected in the blood samples obtained from radiation exposed subjects in this study.

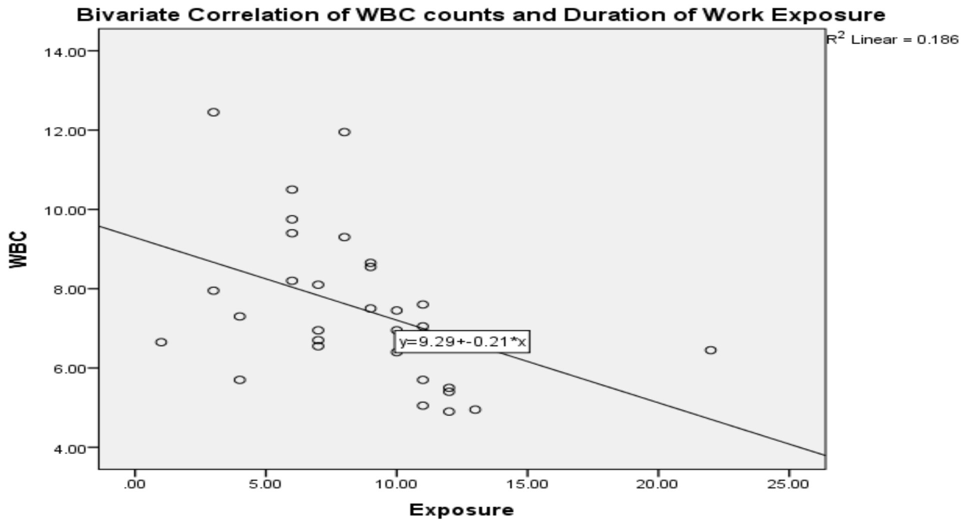

Fig 3.4. Scatter plot of bivariate correlation between WBC counts and duration of work exposure.
Key: Shows the general trajectory of the inverse association between WBC counts of radiographers and their duration of work exposure

Table 3.7 Linear regression model between AAEDs (predictor) and WBC count (response) variables

Regression statistic,	Output value,	*P*-value
R^2,	0.716,	<0.001
Unstandardized coefficient B (Constant),	20.975,	<0.001
Unstandardized coefficient B (AAED),	-17.810,	<0.001
Beta (β),	- 0.846,	<0.001
T-test,	8.400,	<0.001
Durbin-Watson,	1.797,	<0.001

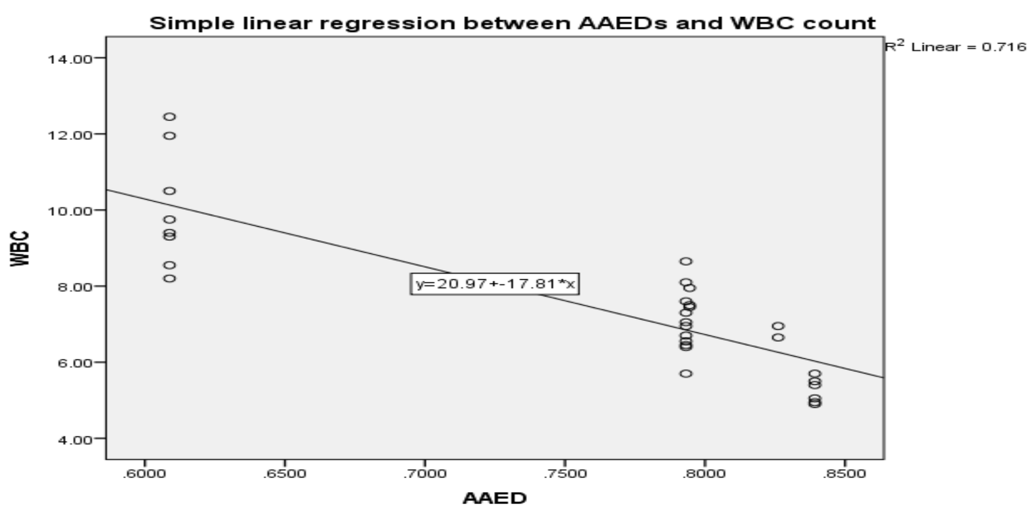

Fig. 3.5. Scatter plot of linear regression between values for AAEDs and WBC counts
Key: Shows the general trajectory of the negative proportionality effect of AAED values on the WBC counts of radiographers

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. Sixty percent of the radiographers studied, had 6-10 year work duration experience. 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 years of active 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 had limited knowledge of the subject matter.

Kendall's W values for extent of unanimity of responses among radiographers on 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 ages groups), and 0.76, 0.84, and 0.89 (based on years of work experience groups), respectively.

Statistically significant variations in the blood cell morphologies were observed between the radiation-exposed and unexposed groups. 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 observed. Blood cells with normal (normocytes) and abnormal (poikilocytes, anisocytes, codocytes, atypical lymphocytes, etc.) morphologies can occur simultaneously in a normal blood film, 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). The findings in this study were similar to those of the Iraqi, Libyan and Ethiopian studies conducted by Mohammed et al. (2013), Nurredin et al. (2016), and Giragn (2016), respectively.

Statistically significant differences were noted in the values obtained between the exposed and unexposed subjects in some indices such as Hemoglobin levels (which were observed to be higher in the radiation exposed), total White blood cell (WBC), Neutrophil and Lymphocyte counts, which were much lower in the same group of subjects. RBC and Platelet counts, and Hematocrit levels were recorded to be marginally higher in the exposed vis-à-vis the unexposed group. The significantly lower values recorded for WBCs and differentials implied that prolonged exposures to minimal x-ray doses (as occurred in these radiographers) resulted in some harmful effects which majorly affected the leucocyte component of their basic haematological parameters. Relative to values obtained from the radiation-unexposed subjects, the total WBCs and differential values were recorded to be statistically significantly lower in the radiation-exposed (radiographers) in samples from both sets of laboratory analyses spaced 120 days apart. This observation indicated that free radical ions due to irradiation procedures may have resulted in increased destruction (or consumption) of leucocytes in the radiographers.

The determination of the exact pathway for cellular destruction/consumption is beyond the scope of this study, however, the significantly lower mean values of WBCs, neutrophils and lymphocytes in the radiation-exposed group was considered a confounding factor in this study, as the values for neutrophils and lymphocytes, which are medically known to increase in acute and chronic inflammatory conditions respectively, were both affected. Clinically, the occurrence could be attributed to some degree of chronic suppression of immunological blood cells or pan-leucopenia, though this would only be confirmed after conducting further studies. Also, there seemed to be a deviation from the pattern of most of the other parameters. However, within each study group, no statistically significant differences were noted between the baseline and second sample sets in all the haematological parameters. These findings were similar to those by Shahid et al. (2014) [20], in Lahore-Pakistan, and Silva et al. (2016) in Teresina-Brazil. However, they differed from the findings by Nurredin et al. (2016).

Statistical tests for association of variables did not yield significant correlations between the major haematological finding (i.e. lower WBC count) and biographical data of radiographers. The bivariate correlation tests were performed between the WBC values versus the ages, and genders of the radiographers, respectively. Marital status and geographical locations were exempted because all the subjects were married and resident in Port Harcourt. The correlation values showed negligible strengths of association which were not statistically significant. This indicated that the lower WBC values observed in the blood samples from the radiographers were neither due to the different ages nor genders of the radiographers. 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 atypical lymphocyte counts were correlated with exposure duration instead, in that study. However, statistically significant moderate inverse correlations were noted between the WBCs 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 lowered WBCs 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 while their WBC counts varied from WBC (10^3/μL) 6.8167 ±0.35347 to 4.4582 ±0.30845 correspondingly.

5. CONCLUSIONS

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 exposure to low-dose x-rays on haematological parameters 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 a 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.

Significantly lower counts for WBCs, Neutrophils and Lymphocytes, and higher ranges of abnormal blood cell morphologies (such as poikilocytes, anisocytes, microcytes, and atypical lymphocytes), were observed in the radiation-exposed (radiographers) vis-á-vis unexposed (laboratory technologists) study subjects.

Negative statistical correlations (inverse proportionality) were noted between the WBC counts and the duration of work exposure in radiographers, but not with their biographical data. Also, a mathematical model to predict the values of WBCs vis-à-vis AAEDs, was computed using:

$\hat{Y}_{WBCcount}$=20.975- 17.810(AAED) + e.

PARTICIPANTS' CONSENT

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

ETHICAL APPROVAL

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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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