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Haematological Effects of Chronic Exposures to Low-Dose X-Rays among Radiographers in Selected Healthcare Facilities in Port Harcourt

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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 have harmful health effects, affecting hematopoietic systems amongst others. Workers experience these effects despite usage of PPEs. This study was aimed at determining the effects of chronic exposures to low-dose x-rays on basic haematological parameters of radiographers in Port-Harcourt, and 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 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 x-ray room radiation level 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 x-ray effects. Mean values for Hematocrit, and Platelet were marginally higher, but total WBCs (p=0.025, 0.044), Neutrophils (p=0.018, 0.042), Lymphocytes (p=0.026, 0.025) were significantly lower (p≤0.05) in the case vis-à-vis control groups in both sample sets, respectively. Normal blood cell morphologies predominated in the unexposed group (76.6%, 86.7%), vis-à-vis the exposed group (53.3% & 50.0%), except in codocytes (z = -1.000, p=0.317). WBC values in radiographers inversely correlated with duration of exposures (r = -0.431, p<0.05). This study showed that chronic exposures to low-dose x-rays effect haematological parameters, despite usage of PPEs.

Keywords: *Ionizing radiation; Residual 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 (Morris et al., 2004). 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 (ICRP, 1998). Radiation exposure measuring devices include alarm or luminescent dosimeters, film badges, fixed/portable radiation monitors, etc. (NNRA, 2006). Global annual records show that clinical use of x-rays accounts 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/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. 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. (Cotran et al., 1994). The hematopoietic systems control the oxygen-carrying capacity of blood, competent immunological system, and spontaneous control of haemorrhages. Dysfunctions result in degrees of hypoxemia, immuno-suppression, coagulation accidents/disorders, etc., which manifest clinically as anaemia, susceptibility to infections and septicaemia, haemorrhagic 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 exposure effects. 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. These studies did not evaluate the x-ray effects on haematological parameters of radiographers. 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 parameters of radiographers, but their results may not be applicable to Nigeria due to the regional geographical differences. Given increasing global use of radio-imaging procedures (Brenner and Hall, 2007), this study intends to close out this gap, and form the empirical basis for early diagnosis and therapy in affected Nigerian workers. Therefore, this study was aimed at determining the effects of chronic exposures to low-dose x-rays on the basic haematological indices, among radiographers in Port Harcourt.

2. Empirical reviews

Some studies previously conducted on similar topics are briefly presented in this section. Giragn (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 White blood cell (WBC), total Lymphocyte, Monocyte, and Basophil counts, and Mean platelet volume (MPV), were lower in the exposed group. It was concluded that 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. (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. Thus, 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 centres 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) 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. It was concluded that 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 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. it was concluded that FMC-Asaba was radiologically safe, as the ambient radiation value was less than the ICRP recommended limits of 1mSv/year.

3. Materials and methods

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 controls) subjects in the same healthcare facilities, within Port-Harcourt. All participants are Nigerians aged between 25 to 54 years, and resident in Port-Harcourt in the preceding 12-months. 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, encoded as: Healthcare facility-A (HF-A), Healthcare facility-B (HF-B), Healthcare facility-C (HF-C), Healthcare facility-D (HF-D), and Healthcare facility-E (HF-E). HF-A, HF-B and HF-C are public tertiary medical facilities, while HF-D is a premier private specialist hospital, and HF-E is a private specialist radiological outfit. Port Harcourt is the metropolitan capital city of Rivers state in the southern Nigeria, West Africa, 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).

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), 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. 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 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™ 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*™) 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 (Nwaogazie, 2011). A pilot test confirmed statistical reliability of the questionnaire, and content validation was done by radiologists and experts from the Association of Radiographers of Nigeria (ARN).

4. Results

4.1. Presentation of data and analyses

Thirty (30) exposed and 30 unexposed from the same healthcare facilities participated in this study. Medical laboratory technicians were used as control subjects. Sixty (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.

4.1.1. Age and gender distribution of subjects

As shown in Table 1, 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 aged 45-54 years. Male subjects consisted 80% (n=48), while the females consisted 20% (n=12).

Table 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)**

4.1.2. Duration of work experience and use of PPEs by case subjects

Figure 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 2 shows that PPE availability and accessibility was 100% (n=30). 80% (n=24) had proper PPE usage, while 70% confirmed PPE viability inspection.

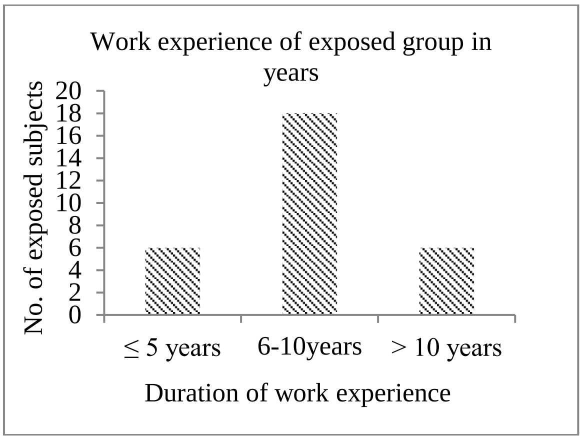

Fig. 1: Work experience of case subjects

Table 2: Assessment of use of PPEs

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

4.1.3. Ambient (Background) Radiation Levels in X-ray Units of Facilities

As shown in Table 3, annual values ranged from 0.6088mSv/year to 0.8392mSv/year ($p \leq 0.05$).

Table 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		
HF-A	0.0510	0.0880	0.06950±0.02616	0.6088
HF-B	0.0771	0.1040	0.09055±0.01902	0.7932
HF-C	0.0822	0.1094	0.09580±0.01923	0.8392
HF-D	0.0814	0.1072	0.09430±0.01824	0.8261
HF-E	0.0789	0.1025	0.09070±0.01669	0.7945

4.1.4 Knowledge, awareness and re-training on adverse x-ray effects and preventive measures

Figure 2 shows that 86.7% (n=26) had regular re-training sessions exhibited adequate knowledge. 13.3% had limited knowledge.

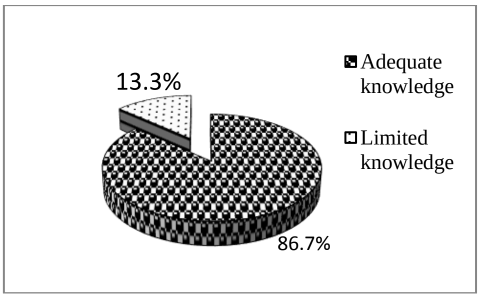

Fig 2: Knowledge, awareness and re-training to x-ray effects

Table 4 shows the 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. Based on 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. Based on years of work experience, W values of 0.76, 0.84, and 0.89 showed higher degrees of unanimity between work experience groups of ≤5years, 6-10years, and >10 years, respectively.

Table 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

4.1.5. Full blood count analysis from baseline and second sample sets

Tables 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 at $p \leq 0.05$ in the case group in both sample sets respectively. That is 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 5c shows t-test of FBC parameters between subjects' baseline and second sample sets. No statistically significant differences were noted at $p \leq 0.05$.

Table 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 5a(ii): Mean values of full blood counts in the 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	6.13355
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

Table 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 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

3.5c: T-test to compare mean values of FBCs between the baseline and second sample sets

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

4.1.6. Peripheral blood cell morphology analysis

In Fig. 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. 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.

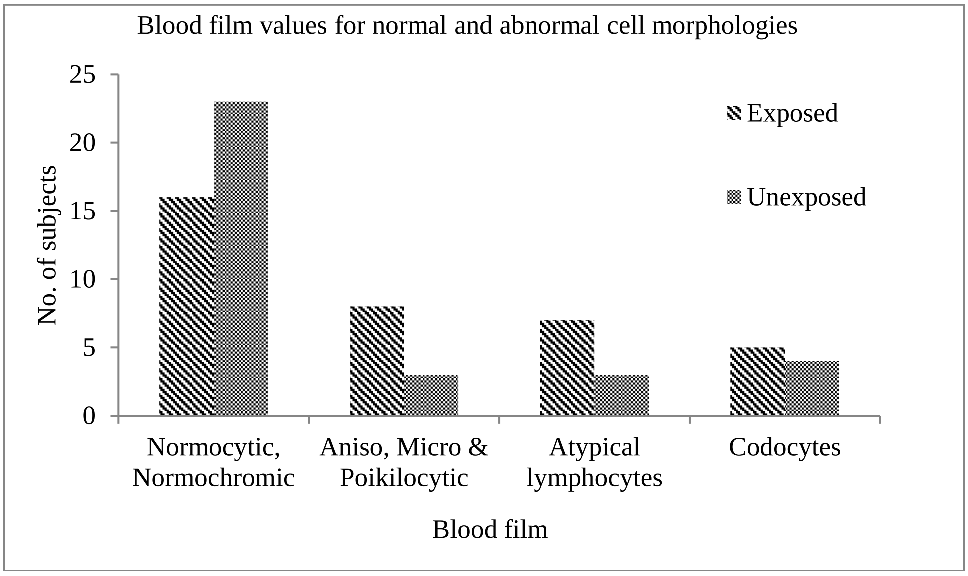

Fig 3a: Bar chart of blood film values (baseline set) showing normal and abnormal cell morphologies

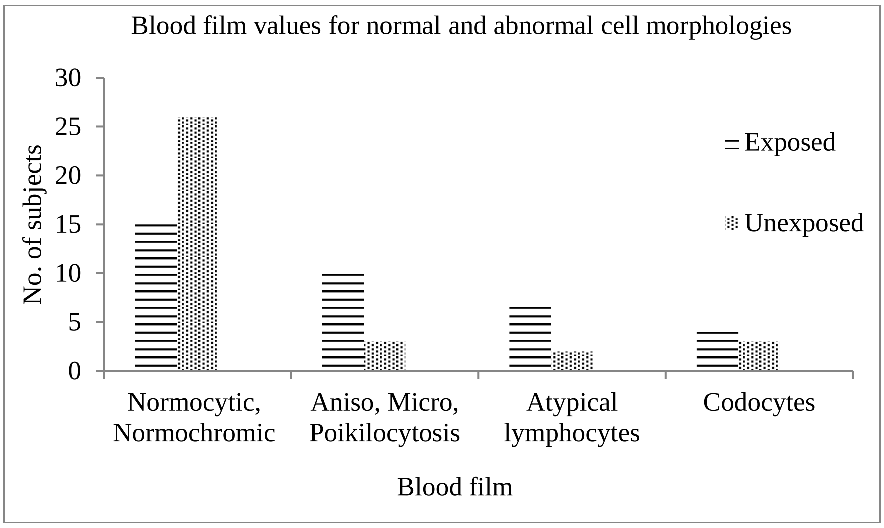

Fig. 3b: Bar chart of blood film values (second sample set) showing normal and abnormal cell morphologies

4.1.7. Correlation between categorical variables and WBC counts

From Table 6, 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 (Fig. 4), moderately negative correlation is highlighted by the line of fit.

Table 6: Pearson correlation coefficient for associations between WBC counts, age, gender, and duration of work exposure of case subjects

	Pearson Coeff.	**p-value**
WBC	1	<0.0001
Age	0.056	0.770
Gender	0.184	0.331
Work exposure	-0.431	0.017

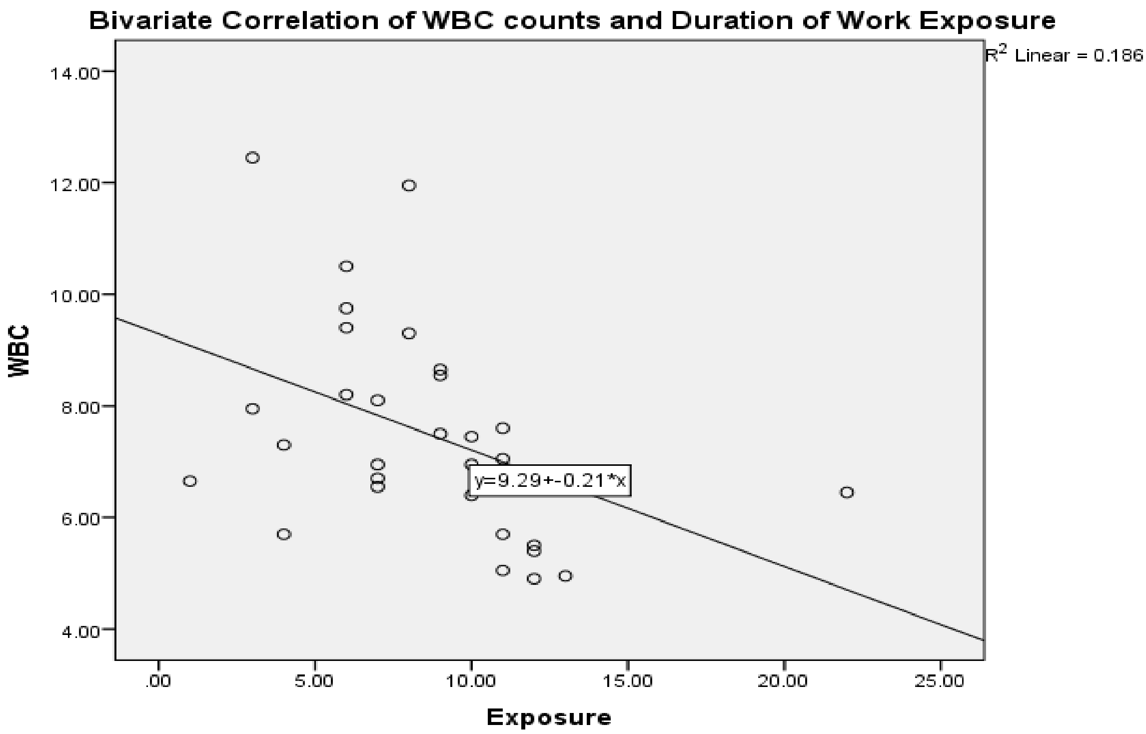

Fig 4: Scatter plot of bivariate correlation between WBC counts and duration of work exposure

4.1.8. Prediction of WBC Counts vis-à-vis AAED using simple linear regression

In Table 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=<0.0001, 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 (Fig. 5), the moderately inverse relationship is highlighted by the regression line.

Table 7: Simple linear regression model between AAEDs (predictor) and WBC count (response) variables

Regression statistic	Output value	p-value
R^2	0.716	<0.0001
Unstandardized coefficient B (Constant)	20.975	<0.0001
Unstandardized coefficient B (AAED)	-17.810	<0.0001
Beta (β)	- 0.846	<0.0001
T-test	8.400	<0.0001
Durbin-Watson	1.797	<0.0001

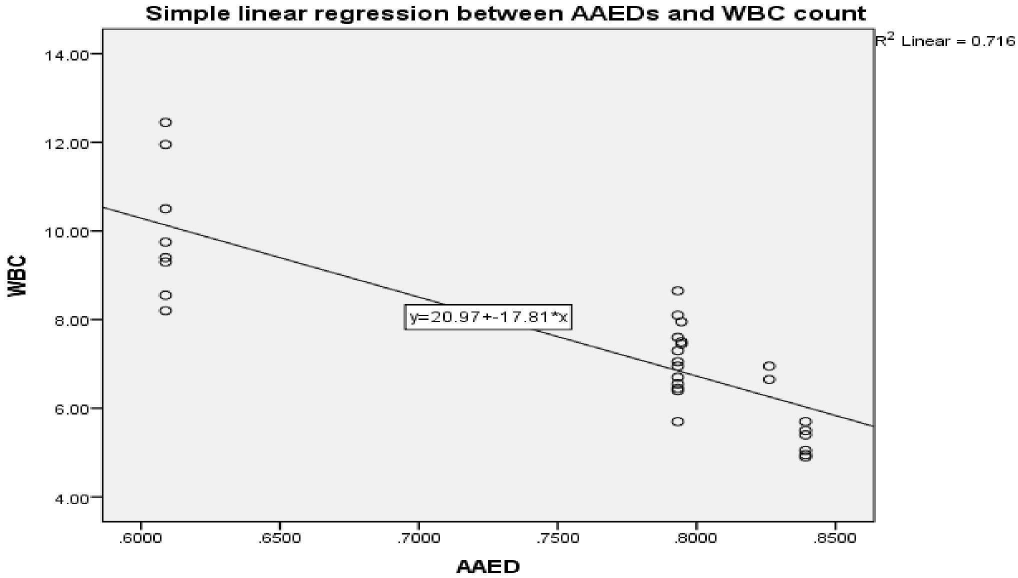

Fig 5: Scatter plot of simple linear regression between values for AAEDs and WBC counts

4.2. Discussion

Studies have demonstrated that ionizing radiation has acute or chronic adverse effects on human beings. No threshold level exists below which harmful effects do not occur. Hematopoietic cells/tissues exhibit high sensitivities and haematological parameters were shown to be affected in exposed subjects in this study. Annual radiation levels recorded in the respective radiology rooms did not exceed the ICRP recommended limit of 1.0 mSv/year. 100% availability and accessibility to PPEs was noted in the facilities. The number of anisocytic/microcytic/poikilocytic cells, and atypical lymphocytes (abnormal cell morphologies) were higher in the exposed, while normocytic/normochromic cells predominated in the unexposed group indicating that x-rays may enhance cellular anomalies. The findings were similar to the Iraqi, Libyan and Ethiopian studies conducted by Mohammed et al. (2013), Nurredin et al. (2016) and Giragn (2016), respectively. Hemoglobin levels, RBC and Platelet counts were marginally higher, while WBC, Neutrophil and Lymphocyte counts were significantly lower in exposed subjects. These findings were similar to those by Shahid et al. (2014) in Lahore-Pakistan, and Silva et al. (2016) in Teresina-Brazil. However, they differed from the findings by Nurredin et al. (2016). The significantly lower WBCs, NEUTs and LYMPHs in the radiation exposed group was a confounding factor, as these affected both neutrophils and lymphocytes which are medically known to increase in acute and chronic inflammatory conditions, respectively. Clinically, this could be attributed to some degree of chronic suppression of immunological cells, though further studies will be required before confirmation. Bivariate correlations were not noted between WBC counts and biographical data of radiographers, a finding similar to those in the study conducted by Giragn (2016) in Addis Ababa-Ethiopia**.** However, the test showed significantly moderate inverse correlations between the WBC counts and the annual average exposure dose (AAED), a finding similar to those in the study by Silva et al. (2016) in Teresina- Brazil.

5. Conclusions

A study to determine the haematological effects of chronic exposure to x-rays on radiographers in Port-Harcourt has been conducted. Based on the data obtained and the analysis carried out, the following conclusions were drawn:

1. Radiation levels in the facilities were within the ICRP recommended limit of 1.0mSv/year.
2. Lower mean values of WBCs, involving both NEUTs and LYMPHs, were noted in the radiographers.
3. Higher ranges of abnormal blood cell morphologies (such as poikilocytes, anisocytes, microcytes, and atypical lymphocytes) occurred in radiation exposed subjects.
4. WBC counts showed marginal inverse proportionality to the duration of x-ray work exposure.

5. WBC counts vis-à-vis AAEDs can be roughly computed using: $\hat{Y}_{WBCcount}$=20.975-17.810(AAED) + e.

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