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SERUM CADMIUM, COPPER, IRON AND ZINC CONCENTRATIONS AND THEIR ASSOCIATIONS WITH HAEMATOLOGICAL PARAMETERS AMONG APPARENTLY HEALTHY BLOOD DONORS AT ADEOYO TEACHING HOSPITAL, IBADAN, NIGERIA: A CROSS-SECTIONAL STUDY

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ABSTRACT

Background: Routine donor screening concentrates on infectious markers and haemoglobin, leaving environmental toxic-metal exposure and micronutrient status largely unexamined.

Objective: To determine serum cadmium, copper, iron and zinc concentrations and their associations with haematological parameters among blood donors at Adeoyo Teaching Hospital Blood Bank, Ibadan, Nigeria.

Methods: In this descriptive cross-sectional study, 200 apparently healthy donors aged 18–65 years were selected by systematic random sampling. A questionnaire captured socio-demographic, dietary and exposure data. Metals were quantified by atomic absorption spectrophotometry and a full blood count was obtained on a Mindray BC-5000 analyser. Analysis used descriptive statistics, one-sample t-tests and Pearson correlation ($\alpha = 0.05$).

Results: Mean cadmium was 0.64 ± 0.53 µg/L, below the 1.0 µg/L general-population benchmark ($t = -9.61$, $p < 0.001$). Mean copper (125.64 ± 36.54 µg/dL), iron (87.40 ± 43.27 µg/dL) and zinc (82.63 ± 23.92 µg/dL) lay within reference intervals. Mean haemoglobin was 12.79 ± 2.67 g/dL and red cell distribution width (15.62 ± 2.53%) was slightly raised. Cadmium correlated weakly with neutrophil ($r = 0.173$) and lymphocyte percentages ($r = -0.170$), and iron with MCV ($r = 0.165$) and MCH ($r = 0.144$) (all $p < 0.05$, unadjusted); none survived multiple-testing correction. Copper and zinc showed no significant associations.

Conclusion: Donors were largely within reference limits, with low-level cadmium exposure and tentative signals of subtle haematological effects. Targeted metal and iron-status surveillance of repeat donors is recommended.

Keywords: Blood donors; Cadmium; Trace elements; Haematological parameters; Transfusion safety; Nigeria

1 INTRODUCTION

Blood transfusion is a life-saving intervention whose safety depends on the health of the donor as much as on the quality of the donated unit. Donor selection in most centres rests on a medical history, vital signs and a haemoglobin or packed cell volume threshold, while laboratory effort is directed at transfusion-transmissible infections [1]. This approach protects against overt anaemia and infection, but it cannot reveal environmental toxicant burden or sub-clinical micronutrient depletion. Non-infectious donor-related risks therefore remain largely unmeasured, even though they may matter most for neonates and other vulnerable recipients [2].

Cadmium is among the most important of these toxicants. It is released by mining, smelting, fossil-fuel combustion, phosphate fertilisers and tobacco smoke, enters the food chain through crops and water, and accumulates for decades because of its very long biological half-life [3,4]. Cadmium and iron compete for common intestinal transport pathways, so that low iron stores enhance cadmium absorption and cadmium, in turn, may disturb iron homeostasis and erythropoiesis [5]. Experimental and epidemiological work also links cadmium to inflammatory and immune modulation [6]. In rapidly urbanising settings such as Ibadan, where traffic emissions, informal industry and reliance on borehole water are common, low-level cadmium exposure in otherwise healthy adults is therefore plausible [7,8].

Essential trace elements complete the picture. Each whole-blood donation removes a substantial quantity of iron, and iron deficiency is common among frequent donors even when haemoglobin is acceptable [9,10]. Copper is a cofactor in iron mobilisation, and both its deficiency and its excess can produce anaemia and oxidative injury [11,12]. Zinc supports DNA synthesis, cell division and immune function [13]. Because these elements interact with one another and with cadmium, assessing a single element can mislead; an integrated assessment of toxic and essential elements alongside the blood count is more informative [14].

Biomonitoring through blood banks has proved feasible in Israel and Canada, where measurable cadmium, lead and mercury were found in donor blood and varied with age, sex, smoking and place of donation [2,15]. Nigerian studies have reported baseline elemental levels in blood and high metal concentrations among urban residents [16,17]. However, to the best of our knowledge, no study has examined cadmium, copper, iron and zinc together with a full blood count among blood donors in Ibadan, South-West Nigeria. Without such evidence, blood banks cannot judge whether haemoglobin-based screening is adequate or whether targeted metal and micronutrient surveillance is justified.

This study therefore determined serum cadmium, copper, iron and zinc concentrations and a panel of haematological parameters among apparently healthy donors at Adeoyo Teaching Hospital Blood Bank, Ibadan, compared the values with reference limits, and examined the relationships between the elements and the blood count. Guided by a metal–haematopoiesis interaction framework, in which toxic and essential elements jointly influence erythropoiesis and leukocyte distribution, we tested five null hypotheses: no difference from reference values for cadmium (H_{01}), copper (H_{02}) and haematological parameters (H_{05}), and no relationship between cadmium and copper (H_{03}) or iron and zinc (H_{04}) and haematological parameters. We discuss the findings in terms of donor management and transfusion safety.

2 MATERIAL AND METHODS

2.1 Study design, setting and reporting

A descriptive cross-sectional design was used [18], and the report follows the STROBE statement for observational studies [19]. The study was conducted at the Blood Bank of Adeoyo Teaching Hospital, Yemetu, Ibadan, Oyo State, a major healthcare facility offering emergency, maternity, surgical, diagnostic and transfusion services. The blood bank receives voluntary and replacement donors from diverse socio-economic backgrounds across Ibadan and surrounding semi-urban communities.

2.2 Study population, sample size and sampling

The population comprised apparently healthy voluntary and replacement donors who passed routine pre-donation screening. The sample size was calculated with the Yamane formula, $n = N/[1 + N(e)^2]$ [20], where N is the accessible donor population and e the precision (0.05). For an estimated 400 eligible donors in the study period (from hospital registry records), $n = 400/[1 + 400(0.0025)] = 200$. Donors were numbered sequentially on arrival and selected at a fixed sampling interval (systematic random sampling) across different days and donation sessions; those who declined were replaced by the same procedure.

Eligible participants were adults aged 18–65 years who met the blood bank's eligibility requirements, had acceptable pre-donation haemoglobin and gave written informed consent. Donors were excluded if they failed routine screening; reported chronic kidney or liver disease, a haematological disorder or malignancy; were taking mineral supplements,

chelating agents or drugs known to alter metal metabolism; had recently been transfused or had donated within the deferral period; or withdrew consent.

2.3 Questionnaire

An interviewer-administered structured questionnaire, completed before blood collection, captured age, sex, marital status, education, employment, length of residence, donation history, environmental and occupational exposure, diet, lifestyle, medical history and perceived health. No personal identifiers were recorded, and responses were checked for completeness and coded numerically.

2.4 Sample collection and processing

Ten millilitres of venous blood were collected aseptically by trained personnel: 5 mL into ethylenediaminetetraacetic acid (EDTA) tubes for the full blood count and 5 mL into plain tubes for metal and trace-element analysis. Tubes carried anonymous codes. Plain-tube samples were allowed to clot and centrifuged, and serum was stored in trace-element-free containers until analysis.

2.5 Laboratory analysis

Cadmium, copper, iron and zinc were determined by atomic absorption spectrophotometry (AAS). Serum was equilibrated to room temperature; for cadmium and copper, samples were digested with analytical-grade acids to remove organic matter and reduce matrix interference, then diluted with deionised water. Iron and zinc samples were diluted to fall within the linear range. Calibration curves were constructed from certified stock standards or reference materials, and the instrument was calibrated at element-specific wavelengths. Reagent blanks and quality-control standards were run with each batch, every sample was analysed in duplicate, and the mean was used [21]. Copper, iron and zinc are reported in μg/dL and cadmium in μg/L.

The full blood count (haemoglobin, packed cell volume, red cell count, red cell indices, red cell distribution width, total and differential white cell counts and platelets) was measured on a Mindray BC-5000 automated analyser, calibrated with manufacturer controls and checked against internal quality control before each run; results were reviewed for plausibility.

2.6 Statistical analysis

Data were analysed in the Statistical Package for the Social Sciences (SPSS). Categorical variables are presented as frequencies and percentages, and continuous variables as mean ± standard deviation (SD) with 95% confidence intervals (CI). Observed means were compared with reference values by one-sample t-tests: cadmium against 1.0 μg/L, copper against the midpoint of its reference interval (105 μg/dL), and haemoglobin (15.0 g/dL), packed cell volume (45%), red cell count (5.0×10^{12}/L), white cell count (7.5×10^{9}/L) and platelets (300×10^{9}/L) against single benchmark values. Relationships between each element and 14 haematological variables were assessed by Pearson's correlation, with magnitude interpreted by conventional benchmarks [22]. Significance was set at a two-sided $p < 0.05$. Because 56 correlations were examined, Bonferroni ($\alpha = 0.05/56 = 0.0009$) and Benjamini–Hochberg false-discovery-rate procedures [23] were applied post hoc to the reported p-values to guide interpretation.

2.7 Ethical considerations

Ethical approval was obtained from the Oyo State Ministry of Health Research Ethics Committee AD 13/479/118c and permission was granted by the management of Adeoyo Teaching Hospital and its Blood Bank Unit. Participants received information on objectives, procedures, risks and benefits and gave written informed consent; participation was voluntary, withdrawal was possible at any stage, and confidentiality and anonymity were maintained.

3 RESULTS AND DISCUSSION

3.1 Characteristics of the donors

The 200 donors were spread across all age bands, with the largest share aged 46–55 years (23.5%) and a slight male predominance (55.0% men, 45.0% women) (Table 1). Most were married (54.0%), had tertiary education (59.0%) and were employed or self-employed (75.0%), and 43.0% had lived at their present address for more than ten years. This describes a stable, relatively educated urban donor pool with prolonged residential exposure to local environmental conditions, a feature that matters for cumulative cadmium uptake [3,8]. It also means that the results apply most directly to similar urban and semi-urban donor populations.

Table 1: Socio-demographic characteristics of the donors (*n* = 200)

Variable	Category	n	%
Age (years)	18–25	32	16.0
	26–35	40	20.0
	36–45	41	20.5
	46–55	47	23.5
	56–65	40	20.0
Sex	Male	110	55.0
	Female	90	45.0
Marital status	Single	72	36.0
	Married	108	54.0
	Divorced	12	6.0
	Widowed	8	4.0
Education	Primary	18	9.0
	Secondary	64	32.0
	Tertiary	118	59.0
Employment	Employed	92	46.0
	Self-employed	58	29.0
	Unemployed	22	11.0
	Student	20	10.0
	Retired	8	4.0
Length of residence (years)	< 5	46	23.0
	5–10	68	34.0
	> 10	86	43.0

Questionnaire responses (Table 2) showed that two-thirds of donors (66.0%) were repeat donors and 35.0% had donated more than five times. Substantial proportions reported living in heavy-traffic or industrial areas (62.0%), exposure to dust, fumes or smoke (58.5%), borehole or well water use (64.5%) and pesticide exposure (39.0%), whereas only 12.0% smoked often. Dietary iron and zinc sources were consumed often by about half of donors, but 59.0% rarely or never took iron or zinc supplements and 61.5% often drank tea or coffee after meals. Nearly one in four (24.5%) reported a previous diagnosis of anaemia. Taken together, these data indicate several plausible environmental routes of metal exposure and dietary and donation-related risks for iron depletion. Because exposure and diet were self-reported, they inform the interpretation of laboratory findings but cannot confirm sources.

Table 2: Selected donation, exposure, dietary and health characteristics (*n* = 200)

Characteristic	% of donors
First-time donor	34.0
More than five previous donations	35.0
Previously deferred from donation	19.0
Lives in heavy-traffic or industrial area*	62.0
Exposure to dust, fumes or smoke*	58.5
Occupational exposure to metals*	41.0

Uses borehole or well water*	64.5
Eats roadside-grown food*	44.0
Pesticide exposure*	39.0
Smokes cigarettes often or very often	12.0
Consumes alcohol often or very often	41.0
Tea or coffee after meals often or very often	61.5
Iron or zinc supplements often or very often	22.0
Iron or zinc supplements never or rarely	59.0
Previous diagnosis of anaemia*	24.5
Self-reported chronic medical condition*	18.0

*Proportion answering "agree" or "strongly agree".

3.2 Serum cadmium, copper, iron and zinc

Table 3: Serum elements and haematological parameters of donors (*n* = 200) compared with reference values

Parameter	Mean ± SD	95% CI	Reference range	Interpretation
Cadmium (µg/L)	0.64 ± 0.53	0.57–0.71	< 1.0 (non-exposed); < 5.0 (occupational)	Below limits
Copper (µg/dL)	125.64 ± 36.54	120.55–130.73	70–140	Within range
Iron (µg/dL)	87.40 ± 43.27	81.37–93.43	60–170	Within range
Zinc (µg/dL)	82.63 ± 23.92	79.30–85.96	70–120	Within range
Haemoglobin (g/dL)	12.79 ± 2.67	12.42–13.16	M 13.5–17.5; F 12.0–15.5	Below male range; within female range
PCV (%)	38.34 ± 8.07	37.22–39.46	M 41–53; F 36–46	Within overall range
RBC ($\times 10^{12}$/L)	4.54 ± 1.02	4.40–4.68	M 4.5–5.9; F 4.1–5.1	Within range
MCV (fL)	89.65 ± 30.66	85.40–93.90†	80–100	Within range
MCH (pg)	29.69 ± 9.46	28.38–31.00†	27–33	Within range
MCHC (g/dL)	34.77 ± 10.02	33.38–36.16†	32–36	Within range
RDW (%)	15.62 ± 2.53	15.27–15.97†	11.5–14.5	Slightly above range
WBC ($\times 10^{9}$/L)	8.34 ± 3.10	7.91–8.77	4.0–11.0	Within range
Platelets ($\times 10^{9}$/L)	319.64 ± 147.19	299.12–340.16	150–450	Within range

PCV, packed cell volume; RBC, red blood cell count; MCV, mean corpuscular volume; MCH, mean corpuscular haemoglobin; MCHC, mean corpuscular haemoglobin concentration; RDW, red cell distribution width; WBC, white blood cell count; M, male; F, female. †95% CI calculated from the mean, SD and *n* = 200. Reference ranges follow standard clinical references [21].

Mean serum cadmium was 0.64 ± 0.53 µg/L (95% CI 0.57–0.71), copper 125.64 ± 36.54 µg/dL (120.55–130.73), iron 87.40 ± 43.27 µg/dL (81.37–93.43) and zinc 82.63 ± 23.92 µg/dL (79.30–85.96) (Table 3). All four means fell inside their reference intervals, and mean cadmium was below both the 1.0 µg/L benchmark commonly applied to non-occupationally exposed adults and the 5.0 µg/L occupational limit [24,25]. The narrow confidence intervals show that the group means were estimated precisely, whereas the wide SDs (a coefficient of variation near 50% for iron) show

marked donor-to-donor variation. Donors as a group were therefore neither overloaded with these elements nor deficient in them, yet individual donors may lie at the extremes, which is the level at which donor management operates.

Low but detectable cadmium in healthy donors agrees with biomonitoring from other settings. In Canada, cadmium was measurable in donor blood, was higher in women and rose with donor age [2]; in Israel, donor cadmium varied with age, sex and smoking and was not higher in donors from the industrialised Haifa Bay area than elsewhere [15]. These studies show that detectable cadmium is a general feature of modern populations through diet and tobacco and does not by itself signal industrial exposure. In our donors, where only 12.0% smoked often, residence near traffic and industry (62.0%) and borehole water use (64.5%) are plausible but unverified contributors. Direct numerical comparison with those studies is inappropriate because they measured whole blood by mass spectrometry, whereas we measured serum by AAS. Reports of high blood metal concentrations in an urban Nigerian population [17] also suggest that donors, who are screened and generally well, may under-represent the most exposed residents, so our estimates could understate exposure in the wider community (healthy-donor effect).

For copper, iron and zinc, adequate group means are consistent with baseline elemental data from Nigerian subjects, which compared well with values from other regions [16]. This is expected, because donor screening excludes overt deficiency. The wide iron variation nevertheless matters when set beside the donation and dietary profile: 66.0% were repeat donors, 59.0% rarely took supplements, 61.5% often took tea or coffee with meals and 24.5% reported previous anaemia. Frequent donation depletes iron stores despite acceptable haemoglobin [9,10], so a normal group mean may conceal a depleted subgroup, which could not be identified here because ferritin was not measured.

3.3 Haematological profile

Mean haemoglobin was 12.79 ± 2.67 g/dL, packed cell volume 38.34 ± 8.07%, red cell count 4.54 ± 1.02 × 10^{12}/L, white cell count 8.34 ± 3.10 × 10^{9}/L and platelet count 319.64 ± 147.19 × 10^{9}/L (Table 3). Packed cell volume, red cell count, red cell indices, white cell count and platelets were within their reference ranges, but mean haemoglobin was below the lower limit for men and mean red cell distribution width (15.62 ± 2.53%) exceeded the upper reference limit. Because 55.0% of donors were men, a mean below the male limit implies that a sizeable fraction of male donors had low haemoglobin on analyser measurement, and a raised RDW indicates increased variation in red cell size that often accompanies early or mixed nutritional deficiency [26]. These observations point to suboptimal erythropoietic reserve in a subgroup despite generally normal indices.

A haemoglobin mean near the lower margin is plausible in this donor setting. Nigerian data comparing donors with non-donors have emphasised monitoring of haematocrit and transferrin because donation imposes physiological demands [27], and iron deficiency without anaemia is common in frequent donors elsewhere [9]. Haemoglobin thresholds also differ by sex, and population differences in the lower limit of normal have been described [28], so deviations should be read against sex-specific criteria [29]. The large SD (2.67 g/dL) indicates that some donors fell well below conventional thresholds, which may reflect differences between the analyser and the point-of-care method used at screening, and this deserves verification in the donor workflow.

3.4 Comparison with reference values and hypothesis testing

Table 4: One-sample t-tests of observed means against reference values (*n* = 200)

Parameter	Mean ± SD	Test value	t	p	Direction
Cadmium (µg/L)	0.64 ± 0.53	1.00	−9.61	< 0.001	Lower
Copper (µg/dL)	125.64 ± 36.54	105.00 (midpoint)	7.98	< 0.001	Higher (within range)
Haemoglobin (g/dL)	12.79 ± 2.67	15.00	−11.71	< 0.001	Lower
PCV (%)	38.34 ± 8.07	45.00	−11.67	< 0.001	Lower
RBC (×10^{12}/L)	4.54 ± 1.02	5.00	−6.38	< 0.001	Lower
WBC (×10^{9}/L)	8.34 ± 3.10	7.50	3.83	< 0.001	Higher (within range)
Platelets (×10^{9}/L)	319.64 ± 147.19	300.00	1.89	0.060	No difference

Two-sided one-sample t-tests, df = 199.

Mean cadmium was significantly lower than the 1.0 µg/L benchmark (t = −9.61, p < 0.001), so H_{01} was rejected in a favourable direction (Table 4). Mean copper differed significantly from the reference-interval midpoint of 105 µg/dL (t = 7.98, p < 0.001) while remaining inside the 70–140 µg/dL interval, so H_{02} was rejected statistically but without clinical abnormality. For haematological parameters, means were significantly lower than the benchmark values for

haemoglobin (t = −11.71), packed cell volume (t = −11.67) and red cell count (t = −6.38) and higher for white cell count (t = 3.83) (all $p < 0.001$), whereas platelets did not differ (t = 1.89, p = 0.060); H_{05} was therefore rejected for several parameters. A significant t-test shows only that a mean differs from the chosen value, and the size of the test statistic reflects the large sample as much as the biological distance. The single benchmarks for haemoglobin, packed cell volume and red cell count are close to male values, so a sample that is 45.0% female will necessarily fall below them. Clinical interpretation should therefore rest on the sex-specific reference intervals in Table 3, which is why we regard the copper and white-cell findings as statistically but not clinically significant.

3.5 Associations between elements and haematological parameters

Cadmium was weakly and positively correlated with neutrophil percentage (r = 0.173, p = 0.014) and weakly and negatively with lymphocyte percentage (r = −0.170, p = 0.016), but not with haemoglobin, red cell indices, total white cell count or platelets (Table 5; Figure 1). Iron correlated weakly and positively with MCV (r = 0.165, p = 0.020) and MCH (r = 0.144, p = 0.042), with a borderline inverse link to red cell count (r = −0.133, p = 0.061). Copper and zinc showed no significant correlations with any parameter (all $p > 0.05$, $|r| \leq 0.12$). The significant coefficients explain only about 2–3% of the variance (r^2 = 0.021–0.030) and are small by conventional benchmarks [22]. Of the 56 correlations, four were nominally significant, close to the 2.8 expected by chance at $\alpha = 0.05$, and none remained significant after Bonferroni or Benjamini–Hochberg adjustment. On this basis H_{03} and H_{04} are rejected only nominally, and the results are best regarded as exploratory signals.

Table 5: Pearson correlation coefficients, r (p-value), between serum elements and haematological parameters (n = 200)

Parameter	Cadmium	Copper	Iron	Zinc
Haemoglobin	−0.015 (0.829)	0.076 (0.287)	0.061 (0.390)	−0.024 (0.739)
PCV	0.059 (0.404)	0.004 (0.959)	0.104 (0.143)	0.033 (0.640)
RBC	−0.022 (0.754)	0.016 (0.826)	−0.133 (0.061)	−0.060 (0.401)
MCV	0.055 (0.438)	−0.015 (0.831)	0.165 (0.020)*	0.067 (0.343)
MCH	−0.025 (0.722)	0.002 (0.974)	0.144 (0.042)*	0.044 (0.537)
MCHC	−0.041 (0.568)	0.056 (0.431)	−0.057 (0.425)	−0.018 (0.798)
RDW	0.082 (0.248)	0.035 (0.622)	0.011 (0.873)	−0.084 (0.238)
WBC	0.102 (0.149)	0.004 (0.957)	−0.019 (0.789)	0.092 (0.197)
Neutrophils (%)	0.173 (0.014)*	0.025 (0.726)	0.037 (0.599)	0.073 (0.307)
Lymphocytes (%)	−0.170 (0.016)*	0.002 (0.976)	−0.009 (0.901)	−0.092 (0.193)
Monocytes (%)	−0.007 (0.923)	−0.099 (0.163)	−0.106 (0.136)	0.053 (0.455)
Eosinophils (%)	−0.050 (0.480)	0.034 (0.637)	0.085 (0.232)	0.037 (0.598)
Basophils (%)	−0.032 (0.650)	−0.019 (0.794)	−0.090 (0.203)	−0.013 (0.850)
Platelets	−0.006 (0.928)	−0.028 (0.692)	−0.023 (0.742)	−0.056 (0.432)

*Nominally significant ($p < 0.05$, unadjusted); none remained significant after Bonferroni or Benjamini–Hochberg correction for 56 tests. Abbreviations as in Table 3.

The cadmium–leukocyte pattern is biologically coherent but must be read cautiously. Cadmium has been linked to inflammatory and immune modulation [6], and a shift towards neutrophils with fewer lymphocytes is the direction that would be expected if low-level exposure nudged leukocyte distribution. Nevertheless, the coefficients are small, were not corrected for smoking, infection or age, and did not survive correction for multiplicity, so they generate a hypothesis for longitudinal and immunophenotyping studies rather than evidence of harm. The absence of any cadmium association with haemoglobin and red cell indices is consistent with the low mean exposure and with the view that overt erythropoietic effects require higher body burdens [3,7].

The positive links between iron and both MCV and MCH are physiologically expected, because iron availability governs haemoglobin content per cell and cell size, and iron deficiency classically produces microcytic, hypochromic cells [26]. The finding supports the idea that red cell indices reflect iron status in donors more sensitively than haemoglobin concentration, which did not correlate with iron (r = 0.061, p = 0.390). It also fits the raised RDW, the donation history and the dietary profile described above [9,10]. The null results for copper and zinc suggest that, within their normal

ranges, these elements are not major determinants of the blood count in healthy donors, although a single serum zinc or copper measurement is a limited index of status [11,13].

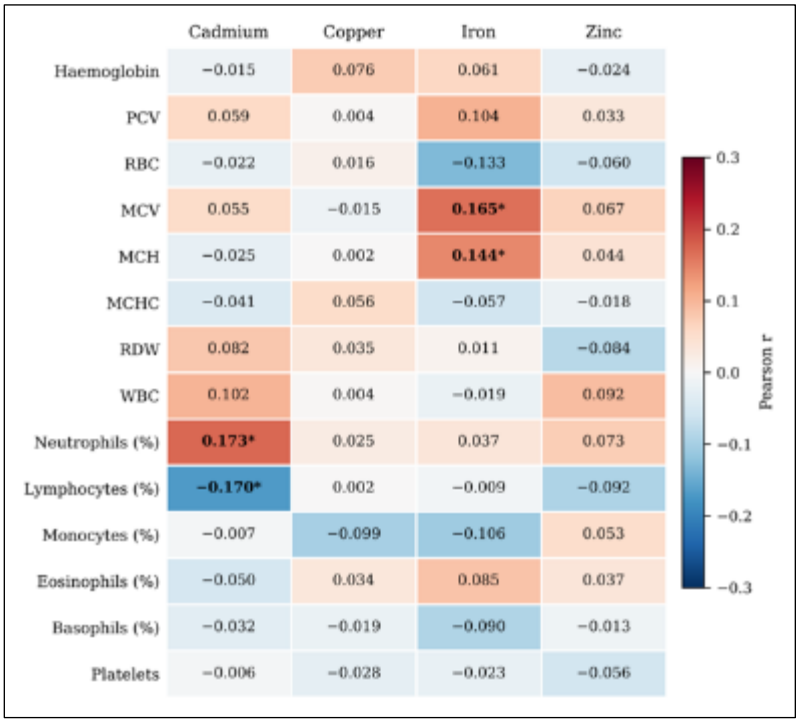


Figure 1: Heat map of Pearson correlation coefficients between serum elements and haematological parameters (*n* = 200).

*Nominally significant ($p < 0.05$, unadjusted).

3.6 Implications for donor health and transfusion safety

Mean cadmium was low, so on current evidence these donors do not present a population-level hazard to recipients through cadmium. However, cadmium was detectable in the donor group, donors with higher metal burdens may exist, and vulnerable recipients such as neonates are the group for which donor-metal thresholds have been proposed [2]. A proportionate response is targeted surveillance of donors with exposure risk factors, rather than routine metal screening of every donor, together with health education on environmental sources. The iron-related findings carry the more immediate practical message: haemoglobin alone cannot detect early iron depletion, repeat donors should be monitored at suitable intervals with iron indices such as ferritin where resources permit, and nutritional counselling should address iron-rich foods and the timing of tea or coffee [9,10,27]. Integrating these measures into donor management would extend blood safety from the unit to the donor, and the findings provide baseline data for such a programme in Ibadan.

3.7 Strengths and limitations

Strengths include the integrated assessment of toxic metals, essential trace elements and a full blood count in one donor population, systematic random sampling, duplicate analysis with blanks and quality-control standards, and transparent reporting of exact correlation coefficients and p-values. Limitations should be acknowledged. The cross-sectional design precludes causal inference, and a single hospital limits generalisability. Cadmium and the other elements were measured in serum, whereas most cadmium circulates in erythrocytes and reference values are usually derived from whole blood, so comparison with whole-blood benchmarks should be cautious. Iron status was inferred from serum iron and red cell indices without ferritin or transferrin saturation. Exposure, diet and supplement use were self-reported; for instance, 22.0% reported frequent supplement use and 18.0% a chronic condition despite exclusion criteria, which may reflect past rather than current use or conditions outside the excluded categories. The wide SDs of the red cell indices (for example MCV, 30.66 fL) suggest heterogeneity or outlying values, for which medians and interquartile ranges would be more robust. Finally, benchmark t-tests used single reference values and 56 correlations were tested, so the nominally significant associations need confirmation in larger, adjusted analyses.

4 CONCLUSION

Blood donors at Adeoyo Teaching Hospital Blood Bank were, as a group, within reference limits for serum cadmium, copper, iron and zinc and for most haematological parameters, and mean cadmium (0.64 ± 0.53 µg/L) indicated low-level exposure. Weak associations of cadmium with neutrophil and lymphocyte percentages and of iron with MCV and MCH were observed, but they did not survive multiplicity correction and are hypothesis-generating. Mean haemoglobin below the male reference limit and a raised RDW, set against frequent repeat donation, point to subclinical iron vulnerability that haemoglobin screening alone may miss. We recommend targeted heavy-metal and iron-status assessment for repeat donors and those with identifiable exposure risks, nutritional counselling at the blood bank, donor health education on environmental sources of metals, and stronger environmental monitoring of urban metal pollution. Future work should use longitudinal designs, whole-blood cadmium, ferritin and transferrin saturation, larger multi-centre samples and adjustment for smoking, age and sex.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

Statement of ethical approval

Ethical approval was obtained from the Oyo State Ministry of Health Research Ethics Committee AD 13/479/118cbefore the study began.

Statement of informed consent

Written informed consent was obtained from all participants.

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