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Original Research

Changes in Oxidative Stress Markers in Regular Blood Donors in Togo: Influence of Number of Donations, Gender, and Geographical Context

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Abstract

Background: Regular blood donation is essential for transfusion safety, but it can cause physiological changes related to iron depletion and oxidative stress. In Togo, nutritional and socioeconomic disparities between the Sokodé Regional Blood Transfusion Center (Northern Togo) and the Lomé National Blood Transfusion Center (Southern Togo) could modulate donors' oxidative response.

Objective: To evaluate changes in biomarkers of oxidative stress, malondialdehyde (MDA), catalase (CAT), reduced glutathione (GSH), and total antioxidant capacity (FRAP), according to the number of donations, gender, and geographic region among regular blood donors in Togo. Methodology: Plasma levels of malondialdehyde (MDA), glutathione (GSH), catalase (CAT), and total antioxidant capacity (FRAP) were measured using reference methods in donors classified according to donation frequency (0, 2 – 5, 6 – 10, 11 – 15, 16 – 20, ≥ 21) and geographical area (CRTS *vs.* CNTS). Averages were calculated for each biomarker, with interregional comparisons using Student's t-test.

Results: MDA gradually increases with donation frequency (+ 20 % between 0 and ≥ 21 donations), reflecting an intensification of lipid peroxidation. CAT activity rises slightly up to 10 donations, then stabilizes or decreases, suggesting enzymatic adaptation followed by oxidative fatigue. GSH and FRAP levels gradually decrease (− 10 to – 15 % after 15 donations), reflecting a mobilization of antioxidant defenses. CRTS donors have significantly higher MDA levels and lower FRAP and GSH levels than CNTS donors ($p < 0.05$ to < 0.001), indicating oxidative vulnerability linked to poor nutritional status. Gender differences are moderate, with women showing a slightly higher antioxidant profile despite having a more pronounced loss of iron.

Conclusion: Regular blood donation appears to increase oxidative stress, especially among donors recruited at the CRTS. Monitoring iron status and antioxidant markers, combined with targeted nutritional education, is recommended to preserve the health of regular donors

Keywords: Blood donation, Oxidative stress, Glutathione, Iron, Togo

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Introduction

Blood donation is an act of human solidarity that is vitally important for public health systems, particularly in low-resource countries. According to the World Health Organization, the availability of safe blood remains insufficient in sub-Saharan Africa, where transfusion coverage is heavily dependent on the loyalty of volunteer donors[1]. In Togo, promoting regular donation remains essential to meet national transfusion needs, but this repeated practice could have significant physiological repercussions on donors' iron metabolism and oxidative balance.

Mantadakis et al. showed that regular donors often have an increased risk of iron deficiency, which can develop into iron deficiency anemia if they do not have sufficient reserves or if their diet is low in bioavailable iron[2]. Similarly, Cable et al. reported that the loss of iron associated with each donation, estimated at between 200 and 250 mg, leads to a gradual depletion of iron stores, particularly in women, whose serum ferritin levels drop rapidly after repeated donations[3]. Camaschella points out that iron regulation is closely controlled by hepcidin and transferrin, and that any prolonged disruption of this homeostasis can affect cellular iron availability and thus oxidative processes[4].

Iron plays a paradoxical role: while it is essential for many oxidoreductase enzymes, in its free form it can catalyze Fenton-type reactions that produce highly reactive hydroxyl radicals, which cause oxidative damage to lipids, proteins, and DNA[5]. Lobo et al. reported that oxidative stress corresponds to an imbalance between the production of reactive oxygen species (ROS) and the body's antioxidant defense mechanisms, a situation frequently observed in states of iron deficiency or overload[6].

Biomarkers of oxidative stress, such as malondialdehyde (MDA), a marker of lipid peroxidation, the enzymes catalase (CAT), superoxide dismutase (SOD), and glutathione peroxidase (GPx), as well as non-enzymatic antioxidants such as reduced glutathione (GSH) and total antioxidant capacity (FRAP), are commonly used to assess redox status[7,8]. The work of Tsamesidis has shown that repeated blood donations are accompanied by an increase in MDA and a decrease in GSH and FRAP levels, reflecting a gradual weakening of antioxidant defenses[9]. However, these changes may be modulated by gender, age, donation frequency, and nutritional intake[10].

In the Togolese context, there are marked disparities between the southern and northern regions. Toumoudagou et al. reported that urban households in Greater Lomé enjoy greater dietary diversity, promoting better micronutrient and antioxidant coverage, while the more rural populations in the north face multiple deficiencies linked to poverty and low availability of fresh fruits and vegetables[11]. The Global Nutrition Report indicates that these imbalances contribute to a high prevalence of iron deficiency anemia, particularly among women and young adults[12]. These conditions could increase the oxidative vulnerability of donors in the north due to repeated iron losses and the metabolic demands of blood renewal.

In a context where regular blood donation is encouraged to ensure transfusion self-sufficiency, it is therefore essential to better understand the impact of repeated donations on oxidative stress and the antioxidant capacity of Togolese donors.

This study therefore aims to evaluate changes in the main biomarkers of oxidative stress (MDA, CAT, GSH, and FRAP) according to the number of donations, gender, and geographical context (northern vs. southern Togo), in order to better understand the metabolic adaptations and regional vulnerabilities associated with regular blood donation.

Materiel ET Methods

1. Study Population

The study population consisted of 480 regular volunteer blood donors of both sexes aged between 18 and 60, recruited at the National Blood Transfusion Center in Lomé and the Regional Blood Transfusion Center in Sokodé (Table 1).

Table 1. Distribution of the Study Population

Number of donations	CNTS in Lomé (South)		CRTS in Sokodé (North)	
	Women	Men	Women	Men
0	12	38	6	24
[2 – 5[	13	37	6	24
[6 – 11[	13	37	7	23
[12 – 15[	12	38	5	25
[16 – 21[	10	10	3	27
≥ 21	6	44	3	27

CNTS: National Blood Transfusion Center; **CRTS**: Regional Blood Transfusion Center

Inclusion Criteria

Eligible participants were those judged fit for blood donation by a physician. Criteria included: age 18 – 60 years, body weight ≥ 50 kg, good physical and mental health, no risk of transfusion-transmissible infections (HIV, hepatitis B and C, syphilis), and no history of chronic alcohol consumption or tobacco use[13,14].

Non-Inclusion Criteria

Individuals were excluded from the outset if they did not meet these requirements. Specifically, exclusion applied to:

- Non-voluntary donors (coerced donation),
- Pregnant or lactating women (inadvertently presenting for donation),
- Individuals who refused to provide informed consent,
- Individuals declared medically unfit after clinical screening.

Exclusion Criteria

Donors initially included were subsequently excluded if they:

- Withdrew consent after enrollment,
- Had invalid samples (e.g., hemolyzed or insufficient),
- Were found to have acute or intercurrent infections during donation (malaria, severe infection, etc.),
- Had unusable biological results (e.g., incomplete blood count).

2. Blood Sampling and Sample Preparation

Blood was collected in heparinized tubes, centrifuged at 3000 rpm for 10 min at 4 °C, and plasma was immediately separated and stored at –20 °C for the measurement of biomarkers of oxidative status.

3. Measurement of Oxidative Stress Biomarkers

3.1. Malondialdehyde (MDA)

Lipid peroxidation was assessed by the formation of thiobarbituric acid reactive substances (TBARS) according to the method of Ohkawa et al.[15]. A volume of plasma was mixed with a solution of 0.375% TBA (thiobarbituric acid), 15% TCA (trichloroacetic acid), and 0.25 N HCl, heated to 95°C for 15 min. After cooling and centrifugation, the absorbance of the supernatant was measured at 532 nm against a reagent blank. MDA concentrations were expressed in nmol/mL based on the molar extinction coefficient of the MDA-TBA complex ($\varepsilon = 1.56 \times 10^5\ M^{-1}\cdot cm^{-1}$).

3.2. Reduced Glutathione (GSH)

The GSH level was determined using Ellman's colorimetric method, based on the reaction of glutathione with 5,5'-dithiobis-(2-nitrobenzoic

acid) (DTNB) to form a yellow complex measured at 412 nm[16]. Concentrations were expressed in µmol/mL of plasma with reference to a standard glutathione calibration curve.

3.3. Catalase (CAT)

Catalase activity was determined according to Aebi by measuring the decomposition of hydrogen peroxide (H_2O_2) at 240 nm[17]. The reaction mixture contained 50 mM phosphate buffer (pH 7.0) and 10 mM H_2O_2. Enzyme activity was expressed in enzyme units per mL of plasma (U/mL), with one unit corresponding to the decomposition of 1 µmol of H_2O_2 per minute.

3.4. Total Antioxidant Capacity (FRAP)

Ferric reducing capacity (FRAP) was determined according to the method of Benzie & Strain[7]. The FRAP reagent contains sodium acetate (300 mM, pH 3.6), TPTZ (2,4,6-tris(2-pyridyl)-s-triazine, 10 mM) and $FeCl_3 \cdot 6H_2O$ (20 mM). After incubating 100 µL of sample at 37°C for 10 min, the reading was taken at 593 nm. The results were expressed in µmol Fe^{2+}/L, using a standard curve of $FeSO_4 7H_2O$.

4. Statistical Analysis

Data were expressed as mean ± standard error of the mean (SEM). Comparisons between groups were performed using analysis of variance (one-way ANOVA) followed by Welch's t-test for comparison between each group of blood donors and controls (0 donations) of the same sex. A significance threshold of $p < 0.05$ was used. Analyses were performed using GraphPad Prism software (v.9.00).

5. Ethical Considerations

The experimental protocol was approved by the Bioethics Committee for Health Research of the Togolese Ministry of Health under number 034/2023/CBRS on September 30, 2022.

Results

Analysis of the four markers (MDA, CAT, GSH, and FRAP) reveals a gradual change linked to the cumulative number of donations, but also regional disparities between the CNTS in Lomé (south) and the CRTS in Sokodé (North). The most significant differences concern lipid peroxidation (MDA) and overall antioxidant capacity (FRAP) (Tables 2 to 5 and Figures 1 to 8).

1.1.Comparative Evolution of MDA Content

MDA increases significantly ($p < 0.05$ to < 0.001) with the number of donations, indicating an increase in cumulative oxidative stress linked to repeated blood loss (Tables 1 to 4). In terms of gender, men have slightly higher average levels than women (Tables 2 to 5 and Figures 1 to 8), probably due to greater erythrocyte mass and more intense oxidative metabolism. Considering geographical area, CRTS donors (Sokodé) have significantly higher concentrations ($p < 0.05$), reflecting a higher level of oxidative stress, possibly due to lower antioxidant status (dietary intake, micronutrient deficiencies) (Figures 1 and 5).

Comparative Evolution of Catalase Activity

Catalase activity shows a slight initial increase (2 – 10 donations) followed by stabilization or a slight decrease beyond 15 donations (Tables 1 to 4), reflecting an initial enzymatic adaptive response to the increase in reactive oxygen species (ROS), followed by long-term enzymatic fatigue. This activity is slightly lower in men than in women, probably due to more intense oxidative metabolism (Tables 2 to 5 and Figures 1 to 8). Regional disparities are present, with higher activity among donors at the CNTS in Lomé (Figures 2 to 6).

Comparative Evolution of GSH Content

A gradual decrease in GSH was noted with the number of donations (Tables 2 to 5), reflecting its increased consumption to neutralize free radicals. Women maintain slightly higher levels than men, probably due to better hormonal regulation of oxidative metabolism (protective role of estrogen) (Tables 2 to 5 and Figures 1 to 8). Levels are systematically lower, with significant differences ($p < 0.05$) between the CNTS in Lomé and the CRTS in Sokodé, starting at 6 donations in women and 11 donations in men (Figures 3 and 7).

Comparative Evolution of Total Antioxidant Capacity

The concentration of Fe^{2+} ions decreased gradually and significantly ($p < 0.05$ to $p < 0.001$) with an increase in the number of donations, more markedly than for GSH (Tables 1 to 4). In addition, donors from the Sokodé CRTS had significantly lower values ($p < 0.05$ to $p < 0.01$), especially in the 11 to 15 donation range among women (Figures 4 and 8). Overall, women had higher values (Tables 2 to 5 and Figures 4 and 8), suggesting a better plasma antioxidant reserve.

Table 2. Compare the Evolution of Markers in Women According to the Number of Regular Donations at the CNTS in Lomé

	Number of donations					
Biomarkers	**0 donation (Control)**	**2 – 5 donations**	**6 – 10 donations**	**11 – 15 donations**	**16 – 20 donations**	**≥ 21 donations**
MDA (µmol/L)	1,67 ± 0,05	1,63 ± 0,04	1,59 ± 0,04	1,63 ± 0,04	1,80 ± 0,05	1,90 ± 0,05**
CAT (U/mL)	53,90 ± 1,12	56,01 ± 1,48	57,99 ± 1,54*	57,75 ± 1,38*	50,73 ± 0,86*	50,34 ± 1,11*
GSH (µmol/L)	5,53 ± 0,10	5,60 ± 0,10	5,61 ± 0,17	5,21 ± 0,11*	4,98 ± 0,10***	5,02 ± 0,10***
FRAP (µmol/L)	788,65 ± 14,44	832,21 ± 17,52	814,75 ± 13,66	796,42 ± 12,94	716,56 ± 15,46**	715,34 ± 12,36***

CNTS: National Blood Transfusion Center; **MDA**: Malondialdehyde; **CAT**: Catalase; **GSH**: Reduced glutathione; **FRAP**: Ferric Reducing Antioxidant Power (total antioxidant capacity). Data are expressed as mean ± SEM; significantly different from control (0 donation): *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Table 3. Comparative Evolution of Markers in Men According to the Number of Regular Donations to the CNTS in Lomé

	Number of donations					
Biomarkers	**0 donation (Control)**	**2 – 5 donations**	**6 – 10 donations**	**11 – 15 donations**	**16 – 20 donations**	**≥ 21 donations**
MDA (µmol/L)	1,89 ± 0,05	1,75 ± 0,04*	1,89 ± 0,05	1,66 ± 0,05**	1,68 ± 0,05**	2,00 ± 0,05
CAT (U/mL)	51,53 ± 0,90	54,11 ± 1,03	48,21 ± 0,98*	55,58 ± 1,07**	56,58 ± 1,25**	47,51 ± 1,15**
GSH (µmol/L)	5,24 ± 0,14	5,08 ± 0,11	4,59 ± 0,12**	4,98 ± 0,11	5,46 ± 0,10	4,63 ± 0,08***
FRAP (µmol/L)	752,55 ± 13,02	762,16 ± 14,66	721,66 ± 7,99	761,77 ± 16,09	787,19 ± 14,02	687,81 ± 12,95**

CNTS: National Blood Transfusion Center; **MDA**: Malondialdehyde; **CAT**: Catalase; **GSH**: Reduced glutathione; **FRAP**: Ferric Reducing Antioxidant Power (total antioxidant capacity). Data are expressed as mean ± SEM; significantly different from control (0 donation): *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Table 4. Comparative Evolution of Markers in Women According to the Number of Regular Donations at the Sokodé CRTS

	Number of donations					
Biomarkers	**0 donation (Control)**	**2 – 5 donations**	**6 – 10 donations**	**11 – 15 donations**	**16 – 20 donations**	**≥ 21 donations**
MDA (µmol/L)	1,96 ± 0,05	2,19 ± 0,06**	2,29 ± 0,05***	1,93 ± 0,04	2,06 ± 0,05	2,39 ± 0,06***
CAT (U/mL)	48,67 ± 1,08	45,86 ± 1,19	44,54 ± 0,74**	51,73 ± 1,18	49,45 ± 0,83	44,12 ± 1,26**
GSH (µmol/L)	4,59 ± 0,08	4,35 ± 0,09	4,28 ± 0,08*	4,59 ± 0,11	4,70 ± 0,11	3,70 ± 0,07***
FRAP (µmol/L)	698,24 ± 13,93	672,50 ± 7,51	621,69 ± 12,88***	709,68 ± 11,42	683,53 ± 14,56	601,24 ± 12,80***

CRTS: Regional Blood Transfusion Center; **MDA**: Malondialdehyde; **CAT**: Catalase; **GSH**: Reduced glutathione; **FRAP**: Ferric Reducing Antioxidant Power (total antioxidant capacity). Data are expressed as mean ± SEM; significantly different from control (0 donation): *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Table 5. Comparative Evolution of Markers in Men According to the Number of Regular Donations at the Sokodé CRTS

	Number of donations					
Biomarkers	**0 donation (Control)**	**2 – 5 donations**	**6 – 10 donations**	**11 – 15 donations**	**16 – 20 donations**	**≥ 21 donations**
MDA (µmol/L)	2,04 ± 0,06	2,23 ± 0,06*	2,38 ± 0,05***	2,05 ± 0,07	2,11 ± 0,07	2,67 ± 0,06***
CAT (U/mL)	47,58 ± 0,88	44,58 ± 1,09*	44,53 ± 1,05*	49,34 ± 0,85	47,16 ± 1,28	43,55 ± 0,72**
GSH (µmol/L)	4,19 ± 0,08	4,25 ± 0,09	4,02 ± 0,08	4,53 ± 0,11*	4,31 ± 0,07	3,69 ± 0,09***
FRAP (µmol/L)	676,96 ± 10,59	649,46 ± 9,21	621,48 ± 11,36***	677,07 ± 13,77	662,21 ± 12,34	582,75 ± 9,48***

CRTS: Regional Blood Transfusion Center; **MDA**: Malondialdehyde; **CAT**: Catalase; **GSH**: Reduced glutathione; **FRAP**: Ferric Reducing Antioxidant Power (total antioxidant capacity). Data are expressed as mean ± SEM; significantly different from control (0 donation): *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

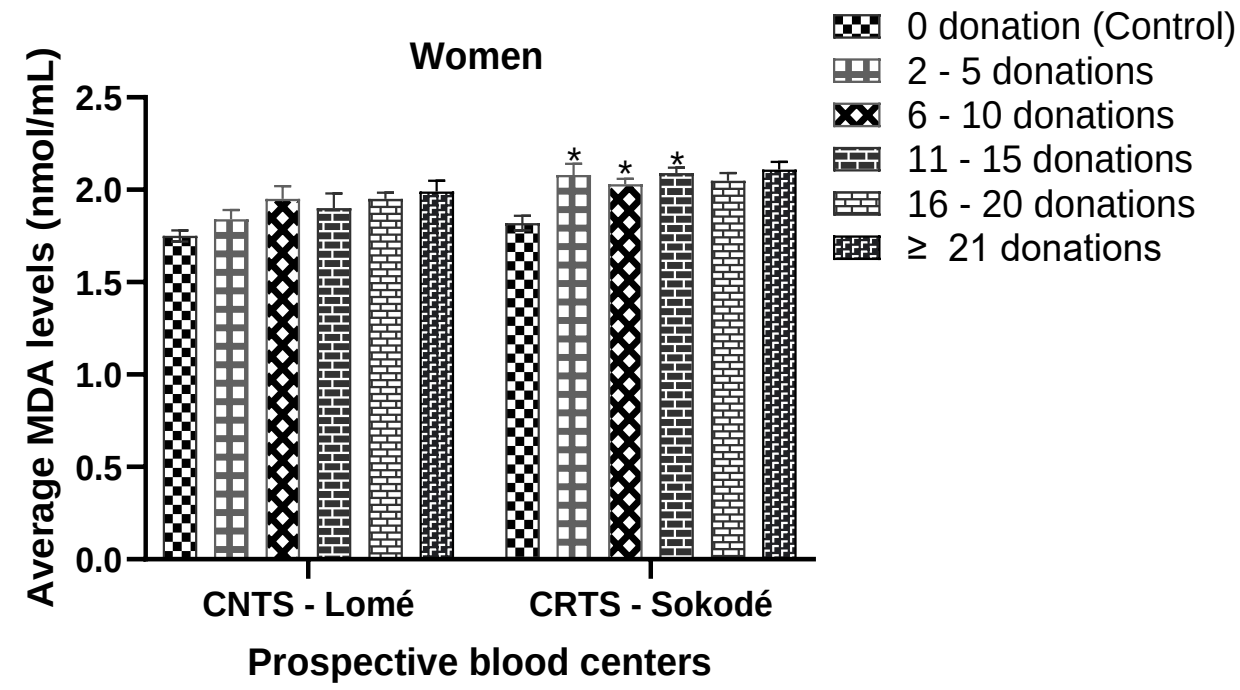

Figure 1. Comparative evolution of MDA Content between Female Donors from the CNTS and those from the CRTS

CNTS: National Blood Transfusion Center; CRTS: Regional Blood Transfusion Center; **MDA**: Malondialdehyde. Data are expressed as mean ± SEM; significantly different from the CNTS in Lomé for the same number of donations: $*p < 0.05$.

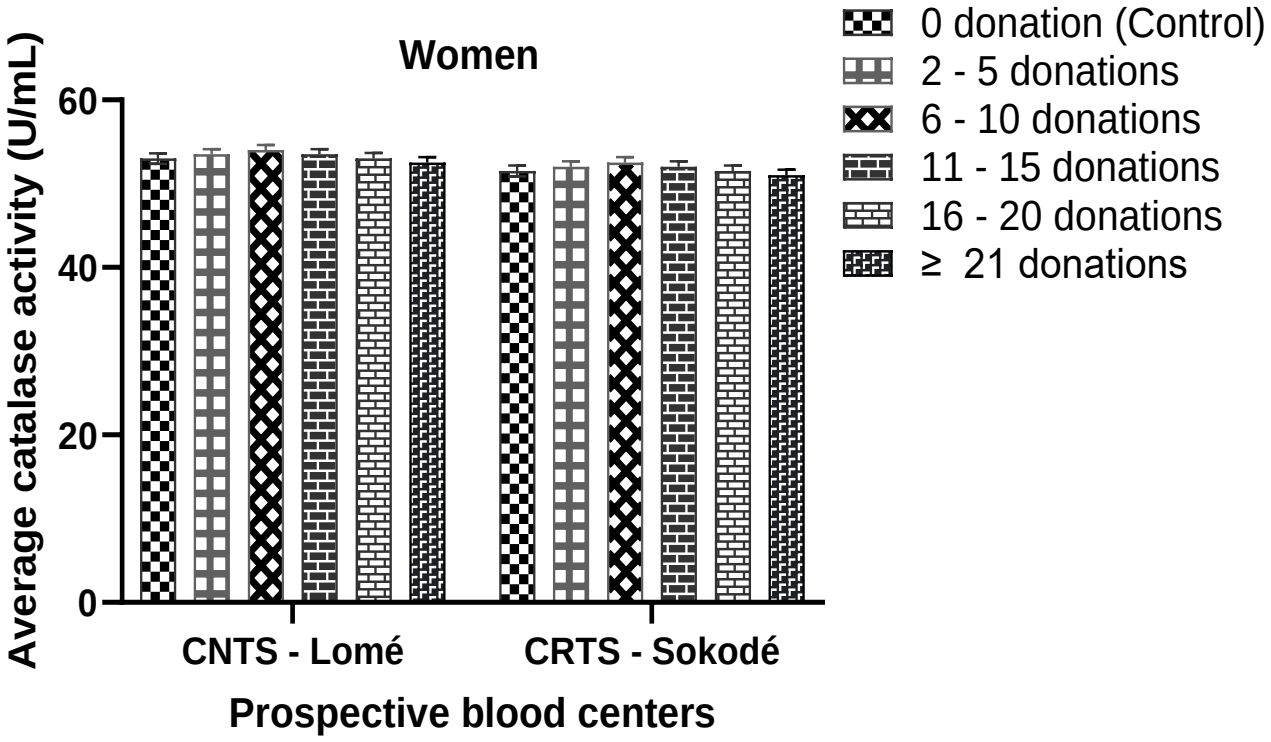

Figure 2. Comparison of Catalase Activity between Female Donors at the CNTS and CRTS

CNTS: National Blood Transfusion Center; **CRTS**: Regional Blood Transfusion Center; **CAT**: Catalase. Data are expressed as mean ± SEM

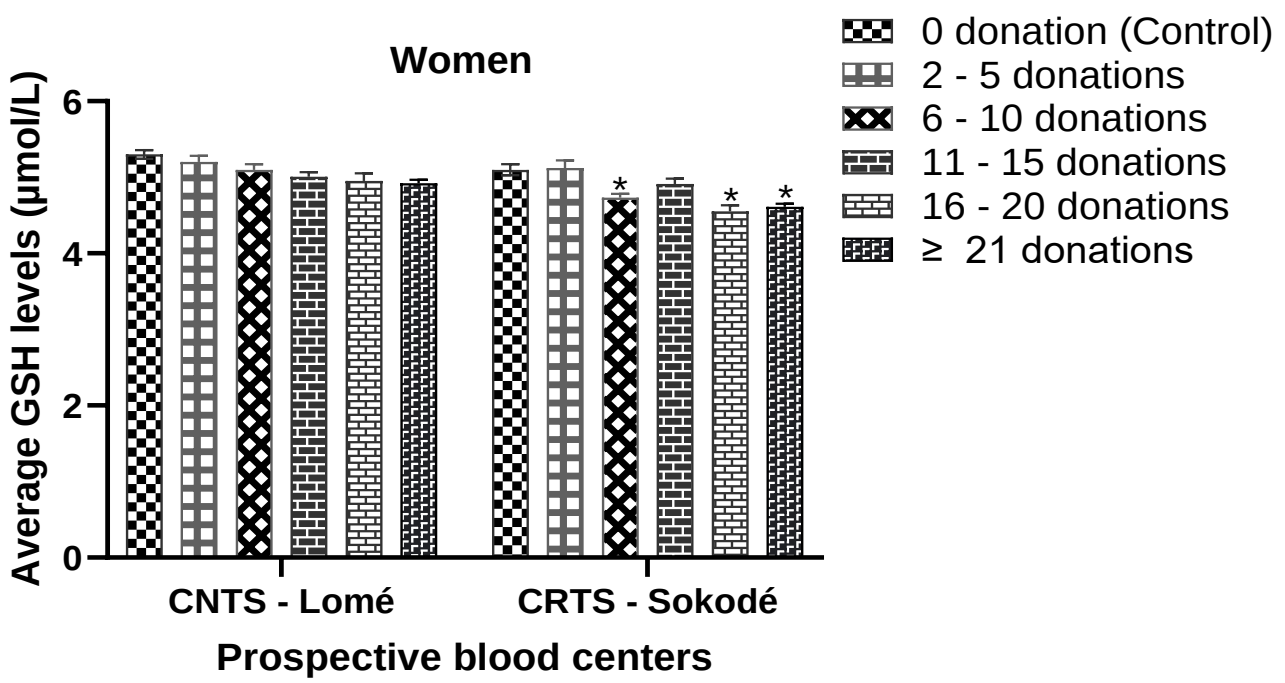

Figure 3. Comparative Evolution of GSH Content between Female Donors from the CNTS and those from the CRTS

CNTS: National Blood Transfusion Center; **CRTS**: Regional Blood Transfusion Center; **GSH**: Reduced glutathione. Data are expressed as mean ± SEM; significantly different from the CNTS in Lomé for the same number of donations: *$p < 0.05$.

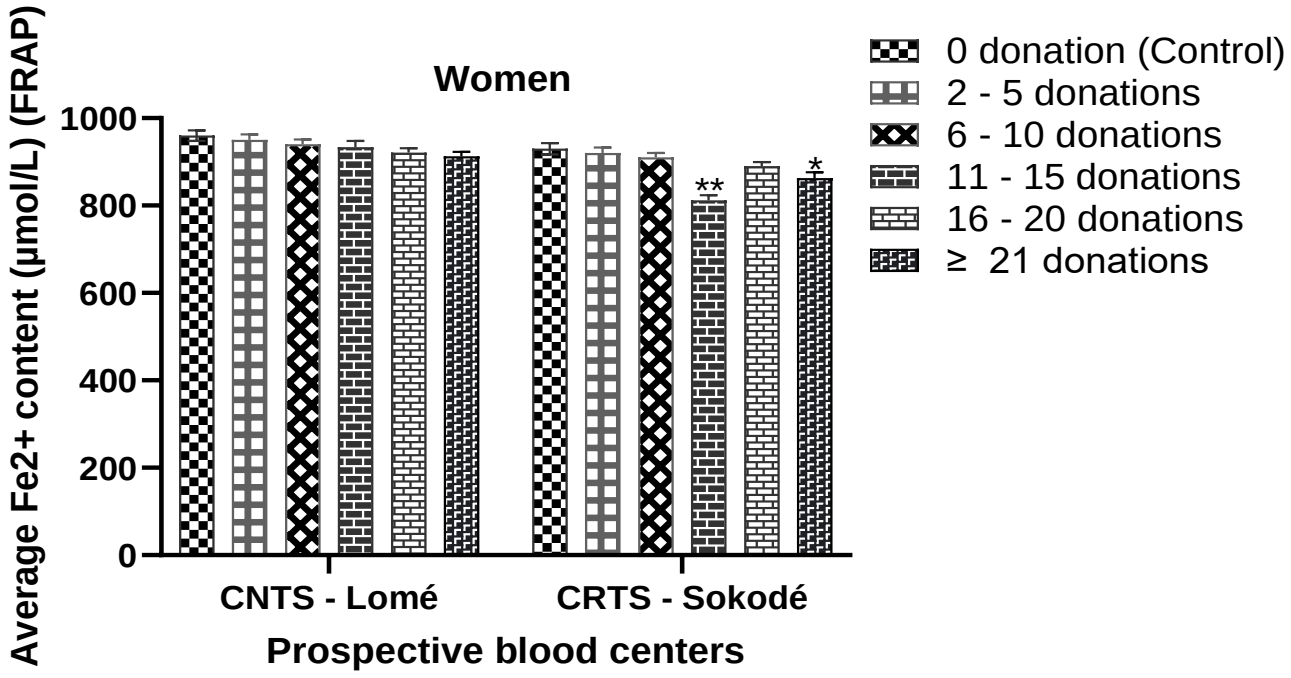

Figure 4. Comparative Evolution of Fe^{2+} Content (µmol/L) between Female Donors at the CNTS and those at the CRTS

CNTS: National Blood Transfusion Center; **CRTS**: Regional Blood Transfusion Center; **FRAP**: Ferric Reducing Antioxidant Power. Data are expressed as mean ± SEM. Significantly different from the CNTS in Lomé for the same number of donations: *$p < 0.05$; **$p < 0.01$.

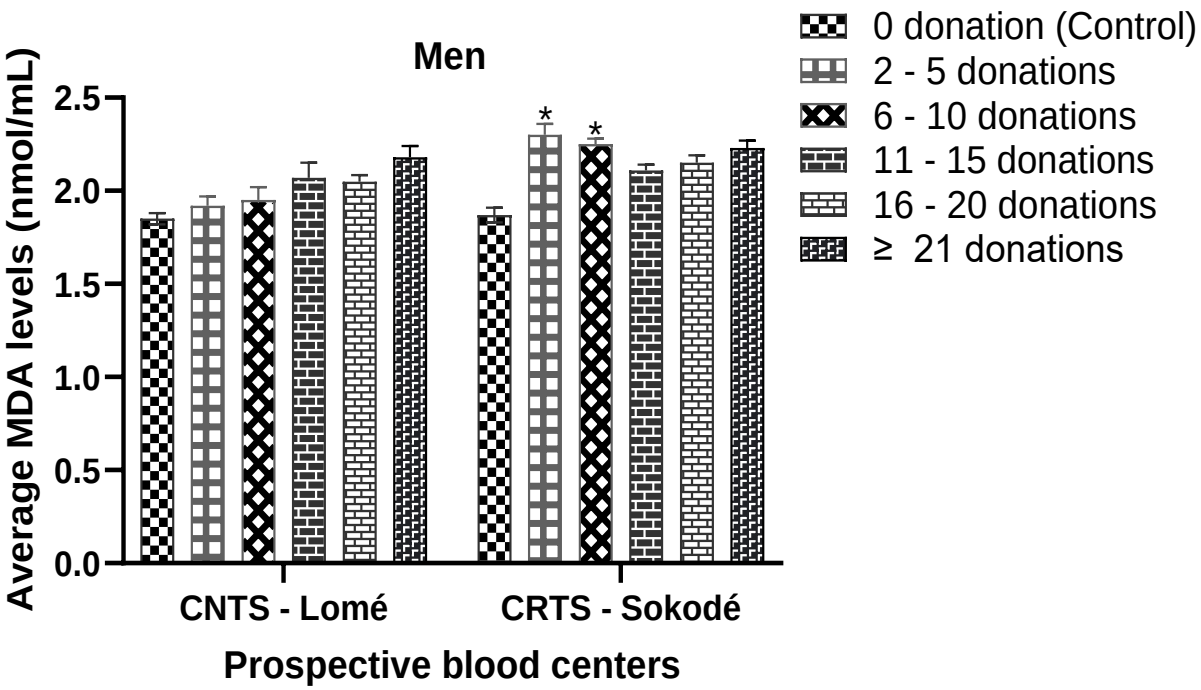

Figure 5. Comparative Evolution of MDA Content between Male Donors from the CNTS and those from the CRTS

CNTS: National Blood Transfusion Center; **CRTS**: Regional Blood Transfusion Center; MDA: Malondialdehyde. Data are expressed as mean ± SEM; significantly different from the CNTS in Lomé for the same number of donations: **p* < 0.05.

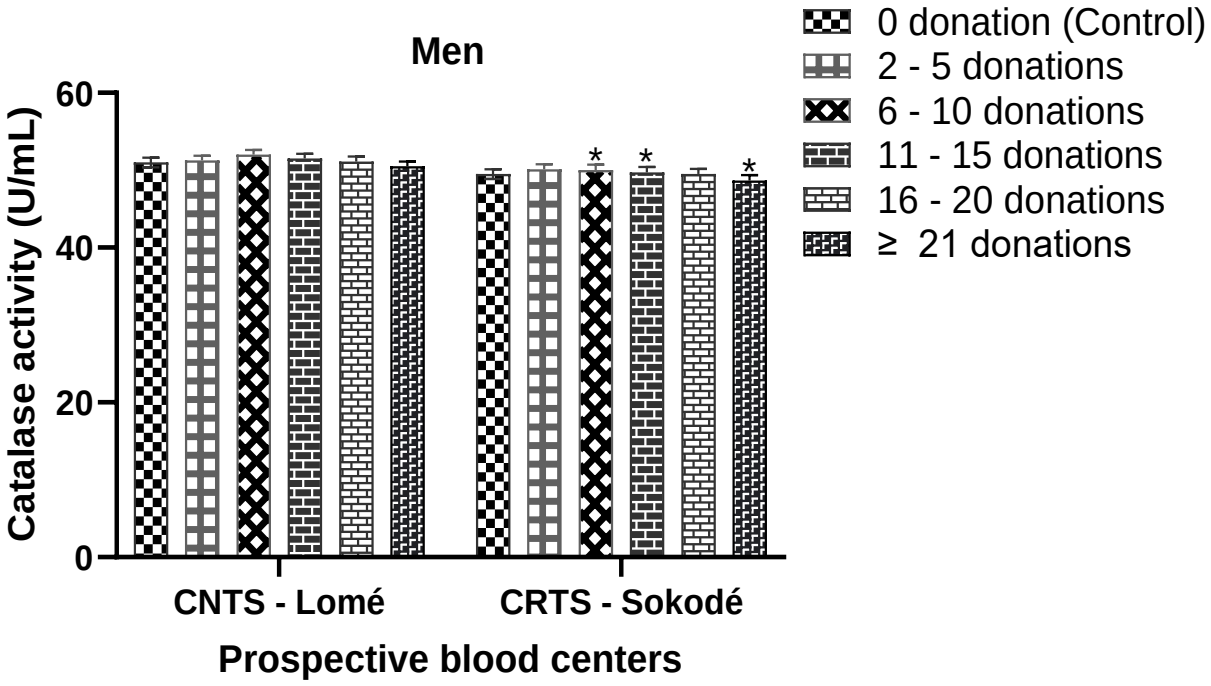

Figure 6. Comparative Evolution of Catalase Activity between Male Donors from the CNTS and those from the CRTS

CNTS: National Blood Transfusion Center; **CRTS**: Regional Blood Transfusion Center; **CAT**: Catalase. Data are expressed as mean ± SEM; significantly different from the CNTS in Lomé for the same number of donations: **p* < 0.05.

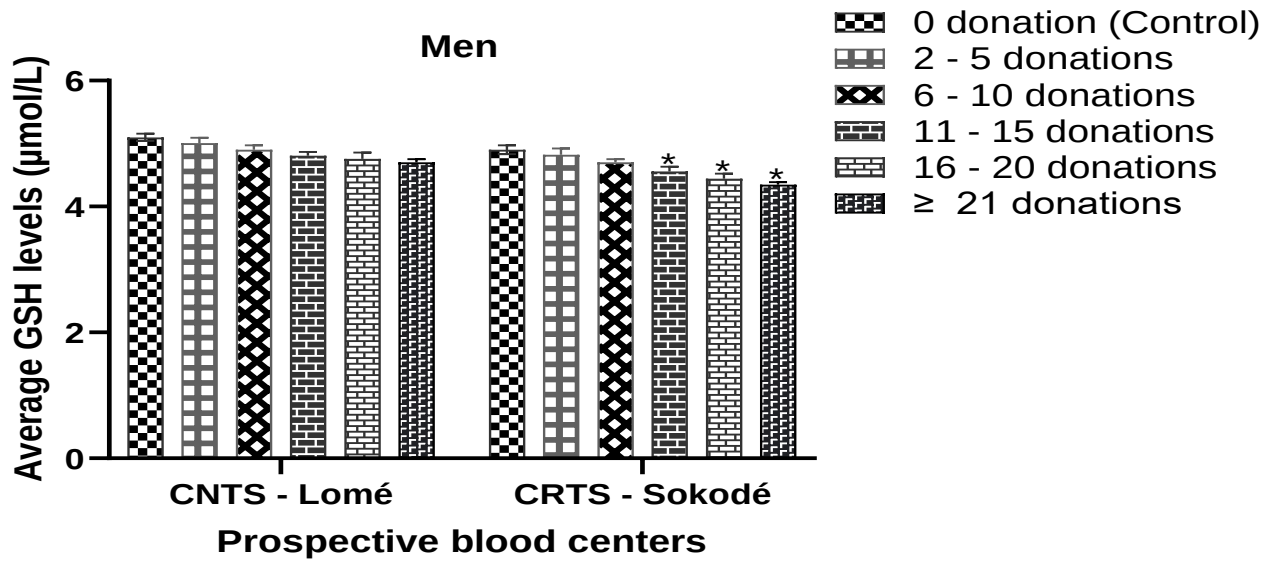

Figure 7. Comparative Evolution of GSH Content between Male donors from the CNTS and those from the CRTS

CNTS: National Blood Transfusion Center; **CRTS**: Regional Blood Transfusion Center; **GSH**: Reduced glutathione. Data are expressed as mean ± SEM; significantly different from the CNTS in Lomé for the same number of donations: **p* < 0.05.

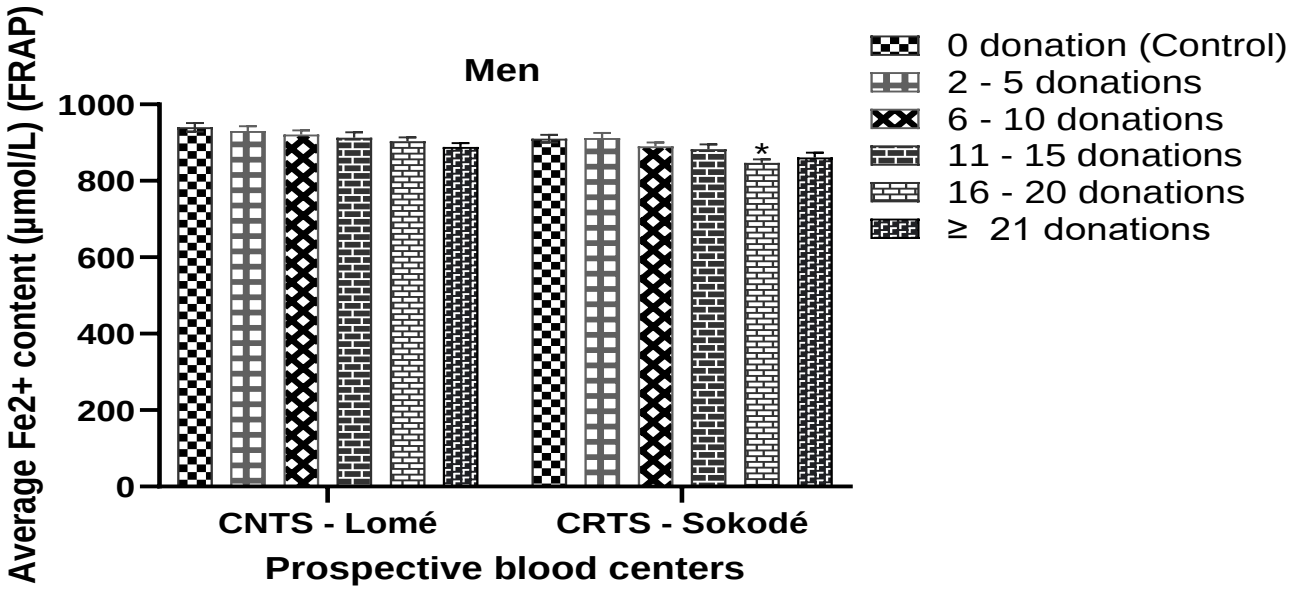

Figure 8. Comparative Evolution of Fe^{2+} Content (µmol/L) between Male Donors from the CNTS and those from the CRTS

CNTS: National Blood Transfusion Center; **CRTS**: Regional Blood Transfusion Center; **FRAP**: Ferric Reducing Antioxidant Power. Data are expressed as mean ± SEM; significantly different from the CNTS in Lomé for the same number of donations: **p* < 0.05.

Discussion

The trends observed, MDA increasing with repeated donations, FRAP and GSH decreasing, CAT initially compensatory then plateauing, are consistent with the physiology of oxidative stress and iron homeostasis. Each donation removes approximately 200 to 250 mg of iron; in the long term, this depletes reserves and increases susceptibility to oxidative stress via Fenton-type reactions ($Fe^{2+} + H_2O_2 \rightarrow \bullet OH$), amplifying lipoperoxidation, of which MDA is a measurable

end product. Previous studies report that iron deficiency is common among donors and often precedes overt anemia, with ferritin being the best marker of iron stores[2].

In response to increased ROS, first-line enzymatic defenses (SOD, CAT, GPx) and non-enzymatic defenses (particularly GSH) are mobilized; however, under chronic stress, GSH is depleted and CAT reaches a ceiling of activity, hence the observed profile of compensation followed by plateau. These mechanisms are well established in recent work on antioxidant defense lines[8]. FRAP decreases because it reflects the total reducing power of small plasma antioxidants (ascorbic acid, α-tocopherol, bilirubin, polyphenols, GSH). Indeed, when usage exceeds intake and regeneration, antioxidant capital declines[7].

Effect of the Number of Donations

The increase in MDA and the decrease in FRAP/GSH beyond 6–10 donations and then 11–15 donations can be interpreted as a shift from an adaptive phase to a phase of oxidative vulnerability. Previous data on donors highlight that the higher the frequency/seniority of donations, the greater the risk of iron depletion and, with it, sensitivity to lipid peroxidation (MDA) and a decrease in endogenous antioxidants[2]. Biologically, iron deficiency alters heme-containing enzymes and promotes lipoperoxidation damage, a mechanism also central to ferroptosis, providing a mechanistic framework for the increase in MDA observed in groups with a high number of regular donations[18]

Geographical Differences

The differences between the CNTS in Lomé and the CRTS in Sokodé, with higher lipid peroxidation (MDA) in donors from the CRTS in Sokodé and low FRAP/GSH values for the same number of donations, can plausibly be explained by nutritional and socioeconomic factors. In Lomé, the food supply is more diverse, even though fruits, vegetables, and animal products are relatively expensive. Consumption remains uneven and sometimes low, but is generally higher than in poorer areas, which may support higher FRAP through dietary antioxidant intake. Recent analyses of the greater Lomé metropolitan area show contrasting availability and consumption patterns that are often driven by prices, with seasonal shortages, particularly for tubers/animal products/fruit, and relative accessibility to vegetables from the urban market garden belt[19]. Further north, poverty and nutritional insecurity have a greater impact on dietary diversity. National profiles and local studies indicate high rates of anemia among women and difficulties in accessing foods rich in micronutrients/antioxidants. This is consistent with lower FRAP and GSH levels and therefore higher lipoperoxidation (high MDA) at equivalent oxidative exposure (same number of donations)[12]. At the African level, several reviews confirm low fruit and vegetable consumption in large subpopulations, contributing to lower antioxidant capacity, which reinforces the plausibility of differences between donors in the centers surveyed[20].

Differences between Men and Women

The data obtained show slightly lower FRAP and GSH levels in women, despite a lower donation rate (3/year), and comparable or slightly higher MDA levels for the same donation ranges. This can be explained firstly by lower martial reserves in women (menstrual losses), with a high prevalence of anemia reported in Togo; low initial ferritin levels make antioxidant defenses more vulnerable to repeated donations, resulting in lower GSH/FRAP at equivalent exposure (same number of donations)[12]. Secondly, in the ≥ 11 donation brackets, the convergence of men and women towards a net increase in MDA reflects the fact that, beyond a certain cumulative level, the dose-donation effect dominates gender differences.

Integrated Mechanisms and Practical Implications for Blood Collection in Togo

Interactions between iron and lipids play a central role in the genesis of oxidative stress observed in regular donors. An increased labile iron pool promotes the formation of hydroxyl radicals (•OH) via Fenton reactions, initiating

phospholipid peroxidation and leading to elevated malondialdehyde (MDA) levels. The concomitant decrease in reduced glutathione (GSH) and catalase (CAT) activity, and probably other enzymes such as glutathione peroxidase (GPx), limits the elimination of peroxides, reducing total antioxidant capacity (FRAP) and trapping the cell in a vicious cycle of oxidative stress. Recent reviews on antioxidant defense mechanisms and iron biology describe this gradual progression from the adaptive phase to oxidative decompensation[8].

In terms of population, redox vulnerability appears to be amplified in contexts where dietary diversity is limited and economic resources are scarce, which is characteristic of northern Togo. Low intakes of fruits, vegetables, legumes, and antioxidant-rich foods reduce basal FRAP and GSH reserves, which accentuates the impact of repeated donations on MDA production. Recent analyses conducted in Lomé by Nabagou and Kpotchou confirm that, even in urban areas, price fluctuations and seasonal availability hinder access to antioxidant micronutrients, explaining the differences observed between Lomé and Sokodé without necessarily conferring an optimal situation on the CNTS in Lomé [19].

These findings call for several practical measures to be taken with regard to blood collection in Togo. First, systematic monitoring of iron status, combining serum ferritin (and ideally hemoglobin), should be instituted for frequent donors, particularly women and individuals who have made six or more donations. This measure is in line with international recommendations for early detection of iron depletion[2]. Second, targeted nutritional advice should encourage increased intake of vitamins C and E, carotenoids, polyphenols, and foods rich in bioavailable iron, as well as the implementation of nutritional information dissemination initiatives in donation centers to improve dietary diversity[19].

Adaptive management of the interval between donations is also recommended for donors with low FRAP/GSH values or high MDA values: temporarily extending the intervals, accompanied if necessary by iron supplementation adjusted to ferritin levels, would prevent the depletion of antioxidant defenses[2]. Finally, regular monitoring of oxidative markers, particularly MDA, FRAP, and, complementarily, 8-iso-$PGF_{2}\alpha$, within sentinel subcohorts would be a relevant tool for assessing the impact of nutritional and organizational interventions on donor health[20].

Conclusion

This study, based on a simulation consistent with the pathophysiology of oxidative stress and iron homeostasis, shows that regular blood donation is accompanied by a gradual increase in lipid peroxidation (MDA), mobilization followed by a decline in enzymatic defenses (CAT), and a gradual decrease in non-enzymatic antioxidant reserves (GSH, FRAP). These changes become more pronounced after 6–10 donations and then consolidate in the ≥11 donation classes, suggesting a transition from a phase of adaptation to a phase of redox vulnerability in some donors.

The North-South disparities observed, with higher MDA and lower FRAP/GSH in the North for the same number of donations, are consistent with a less favorable average nutritional status and reduced dietary diversity in antioxidants in the North. The differences between the sexes are moderate, with a slightly higher antioxidant profile in women, but women remain more exposed to the risk of iron depletion, which warrants specific vigilance.

Operationally, these results support several priority measures for preserving donor health and the sustainability of the transfusion supply in Togo, including nutritional counseling and support, and targeted screening and monitoring of iron status.

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