Available online freely at www.isisn.org

Bioscience Research

Print ISSN: 1811-9506 Online ISSN: 2218-3973

Journal by Innovative Scientific Information & Services Network

RESEARCH ARTICLE BIOSCIENCE RESEARCH, 2022 19(4): 2111-2117. **OPEN ACCESS**

ABO Blood Group and Haematological parameters in relation to the severity of *Plasmodium Falciparum* malaria parasitic infection in Sudan

Yasmeen Gafar[1], Nusaiba Ahmed[1], Duaa Elhadi[1], Wafa saeed[1], Noha Osama[1], Moshtaha Ali[1], Elrashed B. Yasin[2] and Enaam Hussein[1]

[1]Department of Haematology and Immuno haematology, Faculty of Medical Laboratory Sciences, University of Khartoum - **Sudan**
[2]Department of Medical Laboratory Technology (MLT), Faculty of Applied Medical Sciences, King Abdulaziz University (KAU), Rabigh, **Saudi Arabia**

***Correspondence: eyasin@kau.edu.sa, rashed2t@hotmail.com** **Received 15-10-2022, Revised: 18-12-2022, Accepted: 28-12-202 e-Published: 30-12-2022**

Malaria is an infection caused by intracellular protozoan parasites of the genus *Plasmodium*, transmitted by the bite of infected Anopheles mosquitoes. With their ability to invade erythrocytes, infection with malaria parasites can lead to many changes in hematological parameters. Many studies reported an association between malaria and parasitic density with a different ABO blood group. This was a comparative cross-sectional study with a sample size of 240. Haematological parameters, Giemsa-stained thick blood films, and ABO blood groups are determined. The frequency of ABO blood groups among study subjects showed that blood group A is most frequent in cases (50.8%), followed by O (31.7%), B (11.7%), and AB (5.8%). The degree of parasitemia of the 120 patients infected with P. falciparum showed that 71 (59.2%) had low (+) intensity, 29 (24.2%) had mild (++), 13 (10.8 %) had moderate (+++), and 7 (5.8%) had the high intensity of infection. The highest degree of parasitemia was found among group A individuals. There was a significant decrease in Hemoglobin concentration, Total White Blood Cells (TWBCs), and lymphocytes count compared with the control group (P<.001). Also, a significant increase in Neutrophil and Red Cell Distribution Width (RDW) compared with the control (P<.001). Patients with high parasitemia significantly noted a reduction in Hb concentration and platelets number (5.9 ±1.5 mg/dl and 41 ±14 cells/µL, respectively). In conclusion, the most frequent blood group in malaria patients was A, followed by O, B, and eventually AB. There was a significant association between blood group type and susceptibility to malaria, developing anemia, and thrombocytopenia.

Keywords: Malaria, *Plasmodium falciparum*, ABO Blood Group, parasite density, hemoglobin, thrombocytopenia.

INTRODUCTION

Malaria is an infection caused by intracellular protozoan parasites of the genus *Plasmodium,* which is transmitted by the bite of infected Anopheles mosquitoes (WHO 2020, Organization 2021). Generally, four species of malaria parasites infect humans (*Plasmodium falciparum, Plasmodium vivax*, *Plasmodium ovale*, and *Plasmodium malariae*) (Tekeste and Petros 2010). In Africa, *P. falciparum* infection causes the vast majority of malaria-associated mortality and illness because this species is endemic to this area (Haldar, Murphy et al. 2007). P.falciparum is a single-cell eukaryote that undergoes a complex life cycle and is an obligate intracellular parasite of hepatocytes (clinically silent) and erythrocytes (disease-causing). The infection with this Plasmodium can progress into a wide range of pathologies, including severe anemia and cerebral malaria, which can lead to death (Maier, Matuschewski et al. 2019), Occurring almost exclusively in tropical and subtropical regions. In this region, the weather (rainfall, temperature & humidity) is the most obvious cause of seasonality in the malaria transmission (Assafa 2006). For example, in the severe drought and extreme heat of the dry season in semiarid parts of Sudan, female *An. Gambiae* survive up to 11 months of the year by resting in dwelling huts and other sheltered places. Blood feeding continues, so transmission is not interrupted, but the ovaries do not begin to develop eggs until the rains return (Omer and Cloudsley-Thompson 1968). According to the latest World malaria report released in December 2019, there were 228 million cases of malaria in 2018 compared to 231 million cases in 2017 and the estimated number of malaria deaths stood at 405,000 in 2018 compared with 416,000 deaths in 2017. Also, the WHO African Region continues to carry a disproportionately high share of the global malaria burden;

in 2018 the region was home to 93% of malaria cases and 94% of malaria deaths (WHO 2020). Malaria in Sudan affected more than two million people in 2005, it is considered the first cause of death around the country, and is endemic to most areas; in fact, about 75% of the population lives daily with the risk of contracting it. Malaria contributes to 30% of hospital admissions and 16% of hospital deaths. Sudan has been known for its long history of wars, poverty, and disease. These multiple factors combine to cause a high incidence of morbidity and mortality, besides the inability of the population to seek and receive medical care (Pardal and Rajiva 2020).

The mechanism by which Malaria parasites enter erythrocytes is a complex, dynamic process. The earliest interactions likely require proteins residing on the invasive parasite surface, which are called merozoite surface proteins (MSPs), this protein, may interact with the major erythrocyte glycoprotein band 3, in addition, parasite ligands and host receptors may contribute to this initial interaction (Haldar, Murphy et al. 2007). Then the invading merozoite subsequently reorients its apical end to direct specialized apical secretory organelles known as the micronemes rhoptries and dense granules toward the junction of invasion. The Initial interaction appears to stimulate a rapid wave of deformation across the erythrocyte membrane, followed by the formation of a stable parasite-host cell junction. Invagination of the erythrocyte bilayer then results in the engulfment of the parasite and establishment of the intracellular ring-stage parasite surrounded by a vacuolar membrane (Bannister, Hopkins et al. 2000). As their ability to invade erythrocytes, the infection with malaria parasites can lead to many changes in hematological parameters of the host body (Motchan, Subashchandrabose et al. 2019). These changes involve all major cell lines including red blood cells (RBC), leukocytes, and thrombocytes that can predispose to infection, anemia, thrombocytopenia, and Leukocytosis or leucopenia which are well recognized in patients. These alterations vary with the level of malarial endemicity, background hemoglobinopathy, nutritional status, demographic factors, and also malaria immunity. Hyperparasitemia has been listed as one of the criteria of severe falciparum malaria by the World Health Organization (WHO) for more than two decades (Kotepui, Piwkham et al. 2015), and many previous studies have shown that there is a correlation between parasite density and severity of malarial infections (Tangpukdee, Krudsood et al. 2012).

ABO blood group system consists of A, B and H antigens (Zerihun, Degarege et al. 2011). A, B antigens are trisaccharide structures [A, GalNAcα1–3(Fucα1–2) Galβ1; and B, Galα1–3(Fucα1–2) Galβ1] attached to a variety of glycolipids and glycoproteins on the erythrocyte surface**.** Group O individuals lack the terminal glycosyltransferases necessary to produce the A or B antigens and carry the disaccharide H antigen (Fucα1–2Galβ1) (Rowe, Opi et al. 2009). Several studies were conducted to investigate the association between the ABO blood group system and some disease conditions (Zerihun, Degarege et al. 2011).

Malaria parasites spend a substantial part of their life cycle invading red blood cells (RBCs) and growing within them they have evolved specific receptor-ligand interactions to facilitate RBC binding, some of which involve blood group antigens (Chotivanich, Udomsangpetch et al. 1998). Rosetting, defined as the binding of two or more uninfected red blood cells (RBC) to an infected RBC, occurs when malarial parasites mature, to trophozoites and schizonts, in the second half of their asexual development. Rosetting is believed to be an important factor in the development of cerebral malaria. In a series of studies to examine the characteristics of the uninfected RBC which contribute to rosetting, the ability of RBC from healthy donors to form rosettes was found to be greater in the cells of groups A and B than in those of group O (Rowe, Handel et al. 2007).

These trisaccharides of the blood group antigens are thought to act as receptors for rosetting on uninfected erythrocytes and bind to parasite rosetting ligands such as PfEMP-1 and sequestration (Tekeste and Petros 2010). Cyto-adherence and rosetting are important components of several possible pathogenic mechanisms attributed to the cause of severe infection (Assafa 2006). An association between the 'O' blood group and lower rosetting capacity has been demonstrated (Uneke 2007).

This study aims to assess the distribution of the ABO blood group and hematological characteristics in relation to severity and parasite density among malaria patients infected with P. falciparum and compared it to healthy control. The study was conducted in Khartoum state, Sudan.

MATERIALS AND METHODS

This was a comparative cross-sectional study. The samples were collected at some private laboratories in Khartoum state, Sudan in the period from June 2020 to March 2021. The practical work was conducted at the Faculty of Medical Laboratory Sciences, University of Khartoum. All participants were Sudanese. 5 mLs of blood were collected from each participant and transferred to E.D.T.A. tubes by trained medical laboratory technologist. Sterile techniques and disposable, single-use materials were used at all times. The hematological parameters of each participant were determined using a Semi-automated haematology analyzer (Sysmex KX-21N). Giemsa-stained thick blood films were prepared for each collected sample, from which parasite density and *plasmodium* species were identified. Species confirmation of the malaria parasite was done by using immunochromatography test (ICT), thereafter, the stained thick blood film was examined using a light microscope by a 100×oil immersion lens. The parasitemia was estimated by counting the number of parasites per 200 white blood cells in thick blood film and then the parasite count/µl was calculated from the total

white blood cells count. The percentage of parasitaemia determined the severity of the infection. The control group were apparently healthy individuals who were not suffering from malaria. Determination of ABO blood groups were typed by the agglutination method using commercial antisera.

Ethics approval

This study complied with the Declaration of Helsinki and was reviewed and approved by Faculty of Medical Laboratory Sciences, University of Khartoum. All Peripheral blood samples were collected following an informed consent.

Statistical analysis

Statistical analysis was performed using the Statistical Package for Social Science (SPSS) version 23 software. Evaluation of the patient´s quantitative data was performed using the t-test. A comparison of frequency distribution between groups was made by the X2 test. All tests are two-sided and P value less than 0.05 have been considered statistically significant.

RESULTS

The study included 120 patients with different degree of parasitemia as cases and 120 healthy individuals as control matched in age (18-50) and sex. The most frequent ABO blood group among cases is blood group A (50.8%) followed by O (31.7%), B (11.7%), and AB (5.8%), while blood group O (51.7%) was the most frequent among control group followed by A (25%), B (20.8%), and AB (2.5%) which indicate that blood group A is highly affected by malaria infection (Table1).

The results of the degree of parasitemia of the 120 patients infected with *P. falciparum* showed that 71 (59.2%) had a low intensity of infection (1+ (1–10/100 fields), 29 (24.2%) had a mild intensity of infection 2+ (11–100/100 fields), 13 (10.8 %) had the moderate intensity of infection 3+(1–10/one field), and 7 (5.8%) had a high intensity of infection 4+ (>10/one field) (Table 2). The distribution of different blood groups according to the degree of parasitemia is described in Table 3.

Table1: distribution of ABO blood groups among cases and controls

Blood Group	Patients		Control		*P*. value
	Frequency	Percentage %	Frequency	Percentage %	
Group A	61	50.8%	30	25%	.000
Group B	14	11.7%	25	20.8%	.000
Group O	38	31.7%	62	51.7%	.000
Group AB	7	5.8%	3	2.5%	.047

Table2: Degree of parasitaemia among malaria patients

Malaria parasitemia	Frequency	Percentage%
(+)	71	59.2%
(++)	29	24.2%
(+++)	13	10.8%
(++++)	7	5.8%

The results of haematological parameters revealed that the mean values for TWBCs, Hb, and lymphocytes were significantly lower in cases compared to controls (*P* = 0.00, 0.00, 0.001, respectively). While mean values for neutrophils and RDW were significantly higher in patients than in controls (*P* = 0.001, 0.00, respectively). The mean of the platelets count was lower in cases compared to controls but without statistically significant difference (*P*=0.456, Table 4).

Our results also showed that some hematological parameters were affected by degrees of parasitaemia, the mean value of TWBCs and RDW was significantly increased with the degree of parasitaemia (*P* = 0.020, 0.000, respectively), while Hb level and platelets count were significantly reduced with a degree of parasitaemia (*P* = 0.001, 0.000, respectively). This indicated that severe infection affects both Hb concentration and platelets (Table5).

Table3: Malaria parasitemia frequency according to ABO blood group

Blood group	Malaria parasitemia			
	(+)	(++)	(+++)	(++++)
Group A	35 (49.3%)	12 (41.4%)	7 (53.8%)	7 (100%)
Group B	11 (15.5%)	3 (10.3%)	0	0
Group O	21 (29.6%)	12 (41.4%)	5 (38.5%)	0
Group AB	4 (5.6%)	2 (6.9%)	1 (7.7%)	0
Total	71	29	13	7

Table4: Haematological parameters in patients compared with controls

CBC parameters	patients	Controls	*P*.value

	Mean ±STD	Mean ±STD	
WBC (cells/ ul)	6.4 ±2.9	6.8 ±1.5	.000
Hb (g/dl)	12.2 ±2.6	13.7 ±0.9	.000
Neu (%)	62.5 ±16	58.1 ±9	.001
Lym (%)	27 ±15	33 ±8	.001
RDW (%)	14.3 ±2.9	13 ±0.8	.000
PLT (cells/ul)	168 ±78	284 ±68	.456

Table5: Mean of Haematological parameters according to Malaria parasitemia

CBC parameters	(+)	(++)	(+++)	(++++)	*P*.value
WBC (cells/ ul)	5.8 ±2.5	7.1 ±3.0	7.4 ±3.0	8.3 ±4.3	.020
Hb (g/dl)	13.6 ±1.7	11.3 ±1.5	9.8 ±1.8	5.9 ±1.5	.001
Neu (%)	64 ±12	61 ±18	58.7 ±19	58.9 ±32	.481
Lym (%)	25.8 ±12	27.7 ±15	31 ±18	30 ±26	.599
RDW (%)	13 ±1.6	14.6 ±1.8	16.9 ±4	20.6 ±3.8	.000
PLT (cells/ul)	210 ±66	129 ±48	93 ±18	41 ±14	.000

DISCUSSION

The relationship between ABO blood types and malaria was first suggested over 50 years ago (Zhang, Yang et al. 2017). We designed this study to evaluate the association between the ABO blood group and malaria parasitic infection and to assess the effect on hematological parameters in malaria patients of Khartoum state, Sudan. To achieve this aim, 120 patient samples and 120 controls matched in age (18-50) and sex were analyzed.

In the present study, a significant association between blood group and malaria was found ($P< 0.05$). This agrees with some previous studies done by Zerihun et.al. Muawia et al and Rowe et.al. (Rowe, Handel et al. 2007, Rowe, Handel et al. 2007, Zerihun, Degarege et al. 2011, Muawia and Abdalla 2017). On the other hand, disagreement with the finding of Burhan et al and Onanuga et al. (Burhan, Hasan et al. 2016, Onanuga and Lamikanra 2016). A high percentage of A blood group (50.8%) phenotype was observed among the study participants followed by O (31.7 %), B (11.7 %), and AB (5.8 %), respectively. In healthy controls, blood group O was the dominant blood type (51.7 %). This agrees with some previous studies, which reported a high frequency of blood group A in tropical regions with rampant malaria and high frequency of blood group O among healthy control (Fry, Griffiths et al. 2008, Tekeste and Petros 2010, Muawia and Abdalla 2017). On the other hand, our study disagree with the finding of highest prevalence of blood group O of patients, presented by Zerihun et.al. (Zerihun, Degarege et al. 2011) and Zhang et.al. (Zhang, Yang et al. 2017). Another study reported no association between the ABO blood group and malaria (Bayoumi, Bashir et al. 1986, Montoya, Restrepo et al. 1994). Parasitaemia is relatively high across all blood groups with group A recording the highest parasitic density in the current study suggested that patients with blood group 'A' have an increased risk of developing a severe infection, this agrees with Zerihun *et.al.* and Muawia et.al. (Zerihun, Degarege et al. 2011, Muawia and Abdalla 2017) disagrees with Panda et al who reported that the frequency of blood group 'B' was significantly higher in patients with severe malaria (Panda, Panda et al. 2011). We suppose that the difference was induced by the different distributions of ABO blood types in various races and geographical distribution has an important role in blood groups and their effect on the *plasmodium falciparum* malaria parasite.

Haematological abnormalities are considered a hallmark of malaria and statistical analyses have shown that many of these haematological values may lead to increased clinical suspicion of malaria.

The present study demonstrates that low mean Hb (12.2 ± 2.6 g/dl) is a statistically significant variable (P= 0.000) when compared with control (13.7 ± 0.9 g⁄dl). This agrees with the result of Motchan, Subashch and rabose et al. 2019). In high parasitaemia, we found the lowest mean of Hb concentration (5.9 ±1.5 g/dl) and this was statistically significant association (P= .001). This agrees with earlier studies that reported a significant reduction in hemoglobin concentration in patients with high malaria parasitaemia (Kotepui, Piwkham et al. 2015, Al-Salahy, Shnawa et al. 2016). The pathogenesis of anaemia during malaria infection is not clearly understood. It is often thought to result from a combination of hemolysis of parasitized red blood cells, accelerated removal of both parasitized and unparasitized red blood cells, depression as well as ineffective erythropoiesis, anemia of chronic disease (Perrin, Mackey et al. 1982, Bashawri, Mandil et al. 2002), and the level of parasitemia (Kotepui, Phunphuech et al. 2014).

Leucopenia is a common finding in malaria cases although leukocytosis is also seen. Our study related leucopenia as a statistically significant variable in malaria, although leukocytosis was seen in some cases with the

highest TWBCs value of 15.9 × 10^3 cells/μL. The mean of TWBCs in patients was 6.4 ± 2.9 × 10^3 cells/μL, compared with healthy control (6.8 ± 1.5× 10^3 cells/μL). This is in agreement with Jairajpuri *et.al.* and Ahamed *et.al.* (Jairajpuri, Rana et al. 2014, Ahamed, Modawe et al. 2019) and contrasts with another study that had to demonstrate leukocytosis Maina *et.al.* (Maina, Walsh et al. 2010). In our study, leukocyte count was also significantly higher in patients with high parasitemia compared to those with low and moderate parasitemia (*P* = 0.020) and we agree with Kotepui (Kotepui, Piwkham et al. 2015).

Leukocyte components were also significantly affected. Neutrophil and lymphocyte counts were the most important leukocytic changes associated with malaria infection. Neutrophil was significantly increase by 62.5 ±16 % when compared with control (58.1±9 % (*P*= 0.001), this agrees with Al-Salahy *et.al.* (Al-Salahy, Shnawa et al. 2016) who reported an increase of neutrophil and it could be a representation of the early release of neutrophil from the bone in response to the infection. We are in contrast with Kotepui (Kotepui, Phunphuech et al. 2014).

lymphocytes were significantly decrease when we compare patient's result with control (27 ±15% and 33 ± 8%, *P*= 0.001) and this agrees with Al-Salahy et.al. (Al-Salahy, Shnawa et al. 2016). The decrease in lymphocyte counts associated with malaria may be due to reflecting redistribution of lymphocytes with sequestration in the spleen (Wickramasinghe and Abdalla 2000). This study disagrees with Kotepui et.al. (Kotepui, Phunphuech et al. 2014) according to parasitemia neutrophil and lymphocyte show no significant association (*P* > .05).

Malaria infection was also significantly associated with elevated RDW. In this study when comparing patients with the healthy control sample (14.3 ±2.9%, 13 ±0.8% , respectively) (*P*= 0.000), increase parasite density lead to a significant increase in RDW (20.6 ±3.9%) (*P*= 0.000) which has also been noted by another study by Motchan et.al. (Motchan, Subashch and rabose et al. 2019) who suppose elevated RDW may arise from RBCs enlarged due to infection with malarial parasites.

Reduction in the number of platelets is another one of the more well-known hematologic changes observed in patients with malaria. This study supported that lower platelet counts were associated with increased parasite density with a significant statistical association (*P*= .000). Previous studies reported a low number of the platelet (Jairajpuri, Rana et al. 2014, Kotepui, Phunphuech et al. 2014, Burhan, Hasan et al. 2016). This association may result from sensitization induced by parasitized RBCs in platelets, with a consequent increase in platelet sensitivity to adenosine diphosphate (ADP) and higher dense-granule secretion. These alterations could promote platelet aggregation on the endothelium, such as in the cerebral malaria (Kotepui, Phunphuech et al. 2014). According to blood group, A was the dominant blood group affected with hematological change than other blood group types, the exact mechanism behind the relative protection offered by the "O" blood group as opposed to the "A" blood group is not yet properly understood. Many different studies have come up with varying hypotheses. Some of these include rosette formation, which has been observed more in "A" blood group individuals infected with malaria when compared with those with "O" blood group (Rowe, Handel et al. 2007).

CONCLUSION

This study concluded that blood group A is the most prevalent blood group type in the area and there is a significant association between the ABO blood group and malaria infection. Interestingly, blood group A is also more susceptible to a higher level of malaria parasitemia and hematological change. Proposing a need for further evaluation to establish a more reliable conclusion. Efforts should be made to diagnose and treat the disease promptly before severe symptoms develop.

CONFLICT OF INTEREST

The authors declared that present study was performed in absence of any conflict of interest.

ACKNOWLEDGEMENT

We would like to thank the management and staff of the Department of haematology, the Faculty of the Medical Laboratory Sciences for their support, and thank all the participants who were enrolled in this study.

AUTHOR CONTRIBUTIONS

Enaam Hussein has designed, performed, and drafted the manuscript and did critical editing of the study. Yasmeen Gafar, Nusaiba Ahmed, Duaa Elhadi, Wafa saeed, Noha Osama, and Moshtaha Ali have supported and assisted in sample collection and analysis with statistics. Elrashed B. Yasin has supervised this manuscript's writing and preparation.

REFERENCES

Ahamed, A., G. Modawe and M. Elsammani (2019). "Hematological Changes in Sudanese Patients with Falciparum Malaria Attending Elnihoud Teaching Hospital." Sudan Journal of Medical Sciences 14: 24.

Al-Salahy, M., B. Shnawa, G. Abed, A. Mandour and A. Al-Ezzi (2016). "Parasitaemia and Its Relation to

Hematological Parameters and Liver Function among Patients Malaria in Abs, Hajjah, Northwest Yemen." Interdisciplinary Perspectives on Infectious Diseases 2016: 5954394.

Assafa, D. (2006). Medical Parasitology, Dawit Assafa.

Bannister, L., J. Hopkins, R. Fowler, S. Krishna and G. Mitchell (2000). "A brief illustrated guide to the ultrastructure of Plasmodium falciparum asexual blood stages." Parasitology today 16(10): 427-433.

Bashawri, L., A. Mandil, A. Bahnassy and M. Ahmed (2002). "Malaria: Hematological Aspects." Annals of Saudi medicine 22: 372-376.

Bayoumi, R., A. Bashir and N. Abdul-hadi (1986). "Resistance to falciparum malaria among adults in central Sudan." The American journal of tropical medicine and hygiene 35 1: 45-55.

Burhan, H., A. S. Hasan, S. Mansur-Ul-Haque, G. Zaidi, T. Shaikh and A. Zia (2016). "Association between blood group and susceptibility to malaria and its effects on platelets, TLC, and Hb." J Infect Dev Ctries 10(10): 1124-1128.

Chotivanich, K., R. Udomsangpetch, B. Pipitaporn, B. Angus, Y. Suputtamongkol, S. Pukrittayakamee and N. White (1998). "Rosetting characteristics of uninfected erythrocytes from healthy individuals and malaria patients." Annals of Tropical Medicine & Parasitology 92(1): 45-56.

Fry, A. E., M. J. Griffiths, S. Auburn, M. Diakite, J. T. Forton, A. Green, A. Richardson, J. Wilson, M. Jallow, F. Sisay-Joof, M. Pinder, N. Peshu, T. N. Williams, K. Marsh, M. E. Molyneux, T. E. Taylor, K. A. Rockett and D. P. Kwiatkowski (2008). "Common variation in the ABO glycosyltransferase is associated with susceptibility to severe Plasmodium falciparum malaria." Human molecular genetics 17(4): 567-576.

Haldar, K., S. C. Murphy, J. Dan A. Milner and T. E. Taylor (2007). "Malaria: Mechanisms of Erythrocytic Infection and Pathological Correlates of Severe Disease." Annual Review of Pathology: Mechanisms of Disease 2(1): 217-249.

Jairajpuri, Z. S., S. Rana, M. J. Hassan, F. Nabi and S. Jetley (2014). "An Analysis of Hematological Parameters as a Diagnostic test for Malaria in Patients with Acute Febrile Illness: An Institutional Experience." Oman medical journal 29(1): 12-17.

Kotepui, M., B. Phunphuech, N. Phiwklam, C. Chupeerach and S. Duangmano (2014). "Effect of malarial infection on haematological parameters in population near Thailand-Myanmar border." Malaria Journal 13(1): 218.

Kotepui, M., D. Piwkham, B. PhunPhuech, N. Phiwklam, C. Chupeerach and S. Duangmano (2015). "Effects of malaria parasite density on blood cell parameters." PLoS One 10(3): e0121057.

Maier, A. G., K. Matuschewski, M. Zhang and M. Rug (2019). "Plasmodium falciparum." Trends in Parasitology 35(6): 481-482.

Maina, R. N., D. Walsh, C. Gaddy, G. Hongo, J. Waitumbi, L. Otieno, D. Jones and B. R. Ogutu (2010). "Impact of Plasmodium falciparum infection on haematological parameters in children living in Western Kenya." Malaria Journal 9(3): S4.

Montoya, F., M. Restrepo, A. E. Montoya and W. Rojas (1994). "Blood groups and malaria." Revista do Instituto de Medicina Tropical de São Paulo 36: 33-38.

Motchan, P. A., P. Subashchandrabose, M. Basavegowda and A. Suryanarayan (2019). "Hematological features in malarial infection and their variations with parasite density: A retrospective analysis of 6-year data in an Indian city." International Journal of Health & Allied Sciences 8(1): 53.

Muawia, S. and M. Abdalla (2017). "Association of ABO Blood Group and Malaria Parasitic Infection in Eiedbabkier, Sudan." IOSR Journal of Dental and Medical Sciences 16: 135-138.

Omer, S. M. and J. Cloudsley-Thompson (1968). "Dry season biology of Anopheles gambiae Giles in the Sudan." Nature 217(5131): 879-880.

Onanuga, A. and A. Lamikanra (2016). "Association of ABO blood group and Plasmodium falciparum malaria among Children in Federal Capital Territory, Nigeria." African Journal Biomedical Research 19: 24-29.

Organization, W. H. (2021). WHO guidelines for malaria, 16 February 2021, World Health Organization.

Panda, A. K., S. K. Panda, A. N. Sahu, R. Tripathy, B. Ravindran and B. K. Das (2011). "Association of ABO blood group with severe falciparum malaria in adults: case control study and meta-analysis." Malaria journal 10: 309-309.

Pardal, M. P. S. and G. O. Rajiva (2020). "Overview of malaria situation in Sudan." International Journal of Community Medicine and Public Health 7(5): 1721.

Perrin, L. H., L. J. Mackey and P. A. Miescher (1982). "The hematology of malaria in man." Semin Hematol 19(2): 70-82.

Rowe, J. A., I. G. Handel, M. A. Thera, A.-M. Deans, K. E. Lyke, A. Koné, D. A. Diallo, A. Raza, O. Kai and K. Marsh (2007). "Blood group O protects against severe Plasmodium falciparum malaria through the mechanism of reduced rosetting." Proceedings of the National Academy of Sciences 104(44): 17471-17476.

Rowe, J. A., I. G. Handel, M. A. Thera, A.-M. Deans, K. E. Lyke, A. Koné, D. A. Diallo, A. Raza, O. Kai, K. Marsh, C. V. Plowe, O. K. Doumbo and J. M. Moulds (2007). "Blood group O protects against severe Plasmodium falciparum malaria through the mechanism of reduced rosetting." Proceedings of the National Academy of Sciences 104(44): 17471-17476.

Rowe, J. A., D. H. Opi and T. N. Williams (2009). "Blood

groups and malaria: fresh insights into pathogenesis and identification of targets for intervention." Current opinion in hematology 16(6): 480.

Tangpukdee, N., S. Krudsood, S. Kano and P. Wilairatana (2012). "Falciparum malaria parasitemia index for predicting severe malaria." International journal of laboratory hematology 34(3): 320-327.

Tekeste, Z. and B. Petros (2010). "The ABO blood group and Plasmodium falciparum malaria in Awash, Metehara and Ziway areas, Ethiopia." Malaria Journal 9(1): 280.

Uneke, C. (2007). "Plasmodium falciparum malaria and ABO blood group: is there any relationship?" Parasitology research 100(4): 759-765.

WHO (2020) "malaria."

Wickramasinghe, S. N. and S. H. Abdalla (2000). "Blood and bone marrow changes in malaria." Baillieres Best Pract Res Clin Haematol 13(2): 277-299.

Zerihun, T., A. Degarege and B. Erko (2011). "Association of ABO blood group and Plasmodium falciparum malaria in Dore Bafeno Area, Southern Ethiopia." Asian Pacific Journal of Tropical Biomedicine 1(4): 289-294.

Zhang, X., M. Yang, H. Zhao, J. Hu and L. Li (2017). "Relationship between Malaria and ABO Blood Types in East China." BioMed Research International 2017: 8163762.