

The Rhesus ABO Blood Group Distribution among Malaria Patients: A Case Study of Nasarawa State, Nigeria

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Abstract

Malaria is transmitted throughout Nigeria, with majority of the population being at risk of being infected with the disease. This study investigated the relationship between the ABO/Rhesus blood group types and malaria susceptibility in Nasarawa State, Nigeria. A hospital-based cross-sectional study was conducted from January 13, 2025, to May 22, 2025 in Nasarawa State. Convenient sampling was used for selecting the study individuals. A total of 384 malaria patients, diagnosed by microscopy were enrolled, and their blood group types were determined using the tile method. The results showed a higher prevalence of malaria in females (59.9%) than males (40.1%). The age group 21-30 years had the highest prevalence (38.5%). The ABO/Rhesus blood group types revealed the following pattern of distribution for malaria positive individuals: ORh+ > BRh+ > ARh+ > ORh- > ARh- > ABRh+ > BRh- > ABRh- with the following distribution 46.9%, 25.3%, 16.1%, 4.9%, 3.1%, 2.9%, 0.5% and 0.3% respectively. Though it was statistically insignificant, the results showed that individuals with ORh+ had the highest prevalence of malaria in the study area, followed by BRh+ and ARh+. The findings suggest that blood group may not be the sole significant predictor of malaria susceptibility in this population. Further studies are needed to confirm these findings and explore other biological markers that may influence susceptibility to malaria infection. These findings have implications for public health strategies, particularly in high-transmission areas, and underscore the need for expanded multi-regional studies to further elucidate the complex relationships between blood group types and malaria susceptibility. This could inform personalized medicine and contribute to understanding malaria susceptibility in similar populations.

Keywords: Malaria Parasite, Rhesus Blood Group, Susceptibility, Prevalence, ABO Blood Group, Nasarawa State.

Introduction

Malaria is a common life-threatening disease transmitted to humans by some types of mosquitoes. It is mostly found in the tropical countries. It is preventable and curable. The infection is caused by a parasite and does not spread from person to person. The symptoms can be mild or life-threatening. Mild symptoms are fever, chills and headache. Severe symptoms include fatigue, confusion, seizures, and difficulty breathing (WHO, 2024). According to the World Health Organization (WHO), the African region bore a disproportionate burden of malaria cases and deaths in 2022, accounting for 94% of cases and 96% of fatalities (WHO, 2023). Globally, malaria resulted in an estimated 627,000 deaths in 2021 (WHO, 2022), despite representing a fraction of the over 200 million clinical cases reported annually.

Recent data from the WHO (2024) indicate that approximately 263 million malaria cases and 597,000 malaria-related deaths occurred worldwide in 2023. This represents an increase of around 11 million cases compared to 2022, with a relatively stable mortality rate (WHO, 2023). Nigeria carries the largest malaria burden globally, with an estimated 66.7 million cases in 2022, accounting for 27% of global cases and 31% of deaths (WHO, 2023). The severe form of the disease resulted in 189,321 deaths in Nigeria in 2022, with approximately 80% of these fatalities occurring in children under 5 years of age, contributing to 39% of global malaria deaths in this age group (WHO, 2023). The persistent burden of malaria, particularly in Nigeria's growing population, underscores the need for sustained efforts to address this major public health concern.

Among the *Plasmodium* species that infect humans, *Plasmodium falciparum* remains the most virulent, followed by *P. vivax*, with *P. ovale*, *P. malariae*, and *P. knowlesi* contributing to a lesser extent (Okagu *et al.*, 2022). Upon entering the human host, *Plasmodium* parasites circulate through the bloodstream and invade hepatocytes in the liver, where they develop into schizonts. These schizonts then rupture, releasing merozoites into the bloodstream, which subsequently infect erythrocytes. The erythrocytic stage of the parasite's life cycle is primarily responsible for the pathological effects of malaria (Chandley *et al.*, 2023).

Despite the fact that previous studies have indicated varying associations between ABO phenotypes and malaria prevalence in Nigeria (Gajida *et al.*, 2010; Ibekwe *et al.*, 2009; Nmadu *et al.*, 2015; Onyiri, 2015), there remains a knowledge gap regarding the disease's prevalence in certain regions, particularly among individuals in Nasarawa State. Research has suggested a link between blood group type and malaria susceptibility, especially in endemic populations.

The ABO blood group system is comprised of complex carbohydrate moieties on the red blood cell (RBC) membrane surface (Storry and Olsson, 2009; Yamamoto *et al.*, 2010), and is crucial among human blood group systems. This system categorizes individuals into four main blood types: A, B, AB, and O (Reid *et al.*, 2012). The A and B alleles encode glycosyltransferase activities that convert the precursor H antigen into A or B determinants

by adding a saccharide unit. In contrast, individuals with blood group O lack these transferase enzymes, expressing the unmodified H antigen (Lowe, 2011).

The ABO blood grouping system includes the A, B, and H carbohydrate antigens, along with antibodies against these antigens, while the Rhesus system is defined by the presence of the D antigen (Tadesse and Tadesse, 2013). Consequently, Rhesus blood grouping is determined by the presence or absence of the D antigen on the surface of red blood cells (RBCs), while ABO blood grouping is based on the presence or absence of the A and B antigens (Gylmiyarova *et al.*, 2018; Mandefro *et al.*, 2014).

The Rhesus blood group system is the next most clinically significant after the ABO blood group system. There are 5 antigens of the Rhesus blood group system (C, D, E, c and e). The most immunogenic of the antigens of Rhesus D blood group system is the D antigen. These antigens are inherited from biological parents. If the D antigen is present on the red cell surface, the Rhesus D blood type is considered Rh- D positive. Conversely, if the protein is absent, the blood type is Rh- D negative. It is important to note that most people, approximately 85%, are Rh- D positive (Urbaniak and Greiss, 2000).

The ABO blood type system is genetically determined, and the proportions of the various ABO group vary greatly between populations and ethnic groupings. Blood group antigens have polymorphic features acquired by individuals and groups (Harmening *et al.*, 2012). Differences in blood group antigen expression can make the host more or less susceptible to a variety of diseases. Blood types can directly influence infection by acting as receptors and/or coreceptors. Polymorphisms in blood types can alter the innate immune response to infection. Several different phenotypes linked with improved host resistance to malaria have been identified in populations living in malaria-endemic areas, as a result of evolutionary forces (Cooling, 2015).

The associations between ABO phenotypes and malaria are linked to the disease's pathogenesis, and a deeper understanding of these interactions is essential for exploring the glycobiology of malaria. Typically, individuals with a high parasite density in their peripheral blood are at greater risk of developing severe malaria. However, some individuals can experience severe or even critical malaria with very low peripheral parasitemia due to the sequestration of parasites in deep tissue capillaries (Maria-Pax *et al.*, 2007).

Numerous research studies have been conducted to assess how an individual's ABO blood type influences distinct kinds of malaria. However, contradictory outcomes have been discovered (Alemu and Mama, 2016; Cserti and Dzik, 2007). Some research indicated the lack of a substantial connection between malaria and ABO antigens (Cserti and Dzik, 2007; Uneke *et al.*, 2006). However, several researchers have found that malaria is more frequent in those with blood groups A, B, and AB compared to those with blood group O (Degarege *et al.*, 2019). Conversely, other research and reports revealed that persons with blood type O are more vulnerable to malaria infection especially in endemic locations (Singh *et al.*, 2015). These studies have indeed shown that people with the blood group O have a selective evolutionary advantage over malaria compared to people with non- O blood groups (A, B

and AB) (Uneke *et al.*, 2006). The mechanism by which blood group O confers selective resistance to malaria, while individuals with non O blood groups show selective vulnerability, has been attributed to rosette formation (Dumbo *et al.*, 2009). Rosetting is a mechanism in which an infected erythrocyte with *Plasmodium falciparum* adheres to non-infected erythrocytes (Juillerat *et al.*, 2011). Therefore, in patients with malaria with the non-O blood group, invasion of uninfected red blood cells is enhanced, compared to the other red cell polymorphs. Rosetting may be mediated by a membrane protein, including PfEMP1 (Moll *et al.*, 2015), RIFIN and STEVOR (Dumbo *et al.*, 2009), which are expressed on the surface of the infected host cell. Rosettes formed by non-O blood groups are resilient to disruption (Hedberg *et al.*, 2021). However, there are several unanswered questions and unclear links about how the various blood groups contribute to clinical malaria manifestations. Furthermore, the role of Rhesus (Rh) types in *P. falciparum* infection remains unanswered, since available information on this subject are equivocal (Yeda *et al.*, 2022). Till date, it remains unknown how the different blood group types plays a role in the observed differences in similar levels of parasitaemia. This gap merits further study. This study is therefore aimed to determine the association between ABO/Rhesus blood group types and malaria susceptibility among confirmed malaria patients in Nasarawa State, Nigeria.

Materials and Methods

Methods

A cross-sectional study was carried out from January 13, 2025, to May 22, 2025 on 384 malaria confirmed individuals who were attending major hospitals in Nasarawa State, Nigeria.

Study design

The study site was Nasarawa State. Nasarawa State with 13 local government areas is one of the 36 states in Nigeria and is situated in the North-Central geopolitical zone of Nigeria, bordering the Federal Capital Territory (FCT) to the north, Kaduna State to the northwest, Plateau State to the northeast, Taraba State to the east, and Benue State to the South. The state capital is Lafia, which is also the largest city. The state has an area of 26256km² and a population of about 1,826883 at the 2006 census (Wikipedia, 2015), though is currently projected to be about 2,886,000 (Projection, 2022).

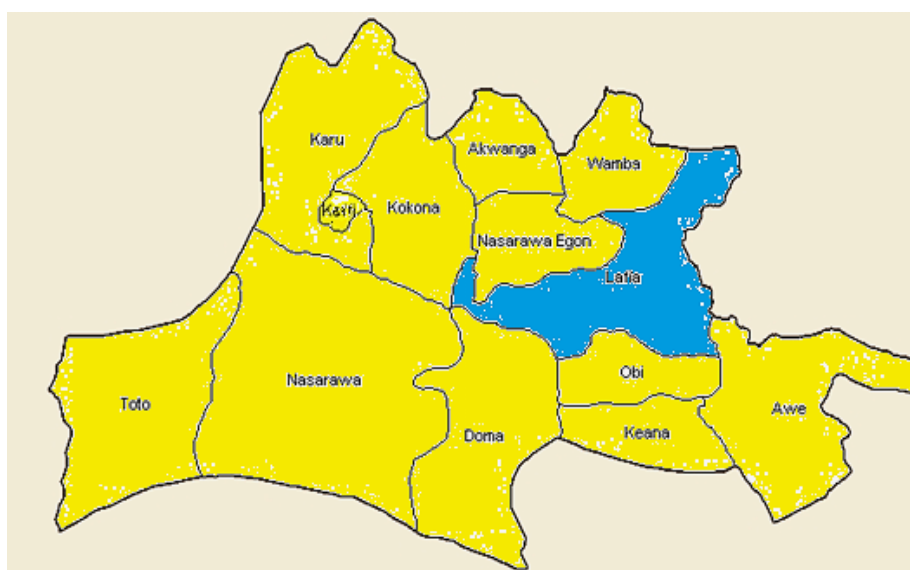


Figure 1: Map of Nasarawa State showing study area (source: Google screenshot)

Ethical approval and consent

Ethical approval was obtained from the Nasarawa State Health Research Ethics Committee (NHREC Protocol No: 18/06/2017) while oral consent was obtained from the subjects who offered to participate in the study upon meeting the criteria for the selection.

Confidentiality

The personal information and medical records of individuals who participated in this study were kept confidential and anonymous. Data were coded and stored in a secure database to protect each individual identity.

Sample size

The sample size was calculated with a 95% Confidence Interval (CI) and precision level of 5% using the standard sample size calculation formula described by Naing *et al.*, (2006).

$$n = Z^2 P(1 - P)/d^2$$

Where:

n = Sample size if the target population is > 10,000

Z = Z statistic for a level of confidence (For 95% confidence level, Z = 1.96)

P = Expected prevalence or proportion (in proportion of one; if 50%, P = 0.5) and

d = Precision (in proportion of one; if 5%, d = 0.05).

Given that Z = 1.96, P = 0.5, d = 0.05 and substituting the values, sample size was calculated thus:

$$n = 1.96 \times 1.96 \times 0.5 (1 - 0.5) \div 0.05 \times 0.05$$

$$n = 3.8416 \times 0.5 \times 0.5 \div 0.0025$$

$$n = 0.9604 \div 0.0025$$

$$n = 384.16$$

A total of 384 malaria patients confirmed with *Plasmodium falciparum* after diagnoses in hospitals who volunteered to participate were included in this study.

Sample collection and analysis

Blood sample was collected by Medical Laboratory Scientist using venipuncture technique. The arm of the patient was tied with a tourniquet and the position of the veins was disinfected using a swab soaked in methylated spirit. Blood was collected into ethylene diamine tetraacetic acid (EDTA) tube and was transported to the hematology unit of the laboratory for analysis.

Malaria parasite detection and count

Thick and thin blood film smear were made to determine the parasite density as described by WHO criteria for malaria parasite density (WHO, 2000; Cheesebrough, 2005). Thin film was made to identify the species of the malaria parasite (Cheesebrough, 2005).

Changes in parasitized red blood cells help to identify *plasmodium* species and to detect mixed infection of malaria parasite. The number of asexual *P. falciparum* and other species per 100 leukocytes were counted and if ten or more parasites were identified, then the number was recorded, a blood sample was regarded as negative if the examination of thick films failed to show the presence of asexual parasites. The parasite count in relation to the leukocyte count was converted to parasite per micro liter of blood (assuming 6000 leukocytes per micro liter of blood) using the formula below:

$$\text{Parasites}/\mu\text{lof blood} = \frac{\text{No. of parasites counted} \times 6000}{\text{No. of leukocyte counted}}$$

Analysis of ABO/Rhesus blood group types

The blood group was determined using the tile method as described by Pimenta *et al.*, (2012). Blood group determination ABO blood groups was typed by agglutination using Monoclonal® (Anti serum-A, Anti serum-B and Anti serum-D). Three drops of whole blood were placed in three different places of a grease-free clean tile on which a drop of antisera A, B and Rh were added. The blood cells and the antigen were mixed with applicator stick. The tile was then rotated to detect for agglutination and the result was recorded accordingly.

Statistical Analysis

All data were inputted into Microsoft Excel then exported to SPSS version 21.0 (SPSS, Chicago, IL, USA) for descriptive analysis. Pearson's chi-square test was used to determine the association between, blood group type, demographic factors and the malaria parasite. Graphs were represented using descriptive bar charts to display association where necessary. P values < 0.05 were considered statistically significant at a confidence interval of 95%.

Results

Distribution of Malaria in relation to gender and age

The results of this study are represented in a table and in figures as shown below. The gender distribution of the participants reveals that there were more females (59.9%) than males (40.1%). Regarding age, majority (38.5%) of the individuals were between the age of 21-30 years, followed by those aged 31-40 (27.3%); as shown in table 1.

Table 1: Distribution of Malaria Infection by Gender and Age

Characteristics	Frequency(number)	Percentage(%)
Gender		
Female	230	59.9
Male	154	40.1
Age (years)		
10-20	39	10.2
21-30	148	38.5
31-40	105	27.3
41-50	44	11.5
51-60	37	9.6
61-70	11	2.9

The distribution of malaria infection by gender and age is shown in Table 1 above. Females were more infected than males, and the age group 21-30 years had the highest infection rate in the study (see Figure 2.1 and Figure 2.2 for details).

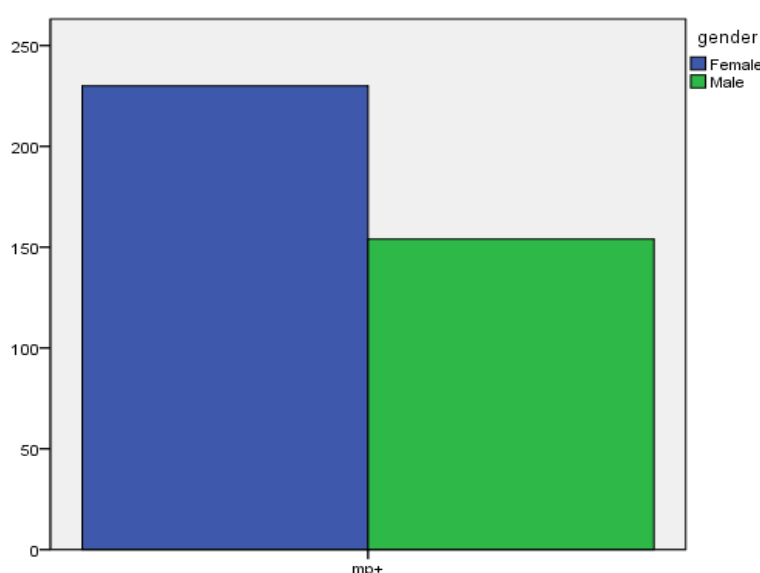


Figure 2.1: Gender Distribution in the sampled Malaria Population

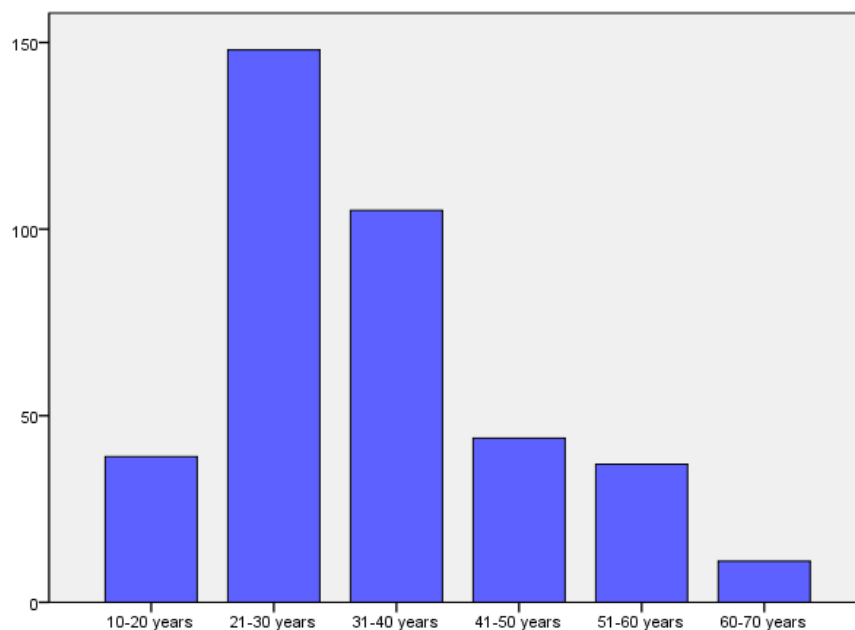


Figure 2.1: Age distribution in the malaria population

Distribution of blood group types in the sampled population

The distribution of blood group types in the sampled malarious population showed 16.1% A+, 3.1% A-, 25.3% B+, 0.5% B-, 2.9% AB+, 0.3% AB-, 46.9% O+ and 4.9% O- respectively, as shown in figure 2.3. The outcome revealed that the dominant blood group type in the study population was the O+.

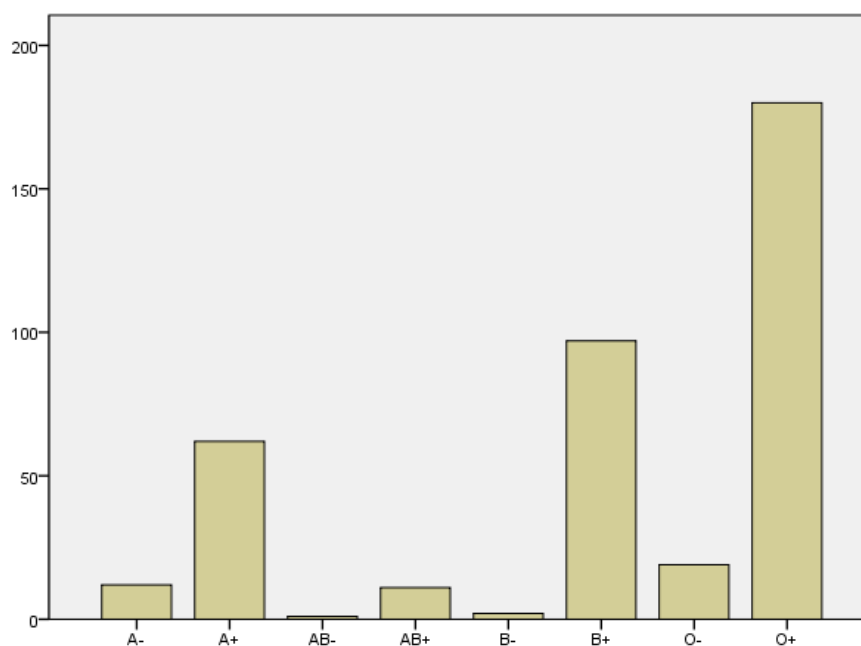


Figure 2.3: Distribution of blood group types in the malaria population

Distribution of blood group type in relation to gender status of the malaria individuals

Of the 59.1% females and 40.1% males in the sampled population, the distributions of blood groups in females accounted for 18.3% A+, 3.0% A-, 23.9% B+, 2.6% AB+, 0.4% AB-, 46.1% O+ and 5.7% O-. The results of blood groups in males were 3.2% A-, 13.0% A+, 1.3% B-, 27.3% B+, 3.2% AB+, 3.9% O- and 48.1% O+, as shown in Figure 2.4. The distributions of blood groups both in females and males showed that O+ was the most prevalence in the study population. A Pearson chi-square value of 6.452 and non-significant p-value of 0.488 were obtained.

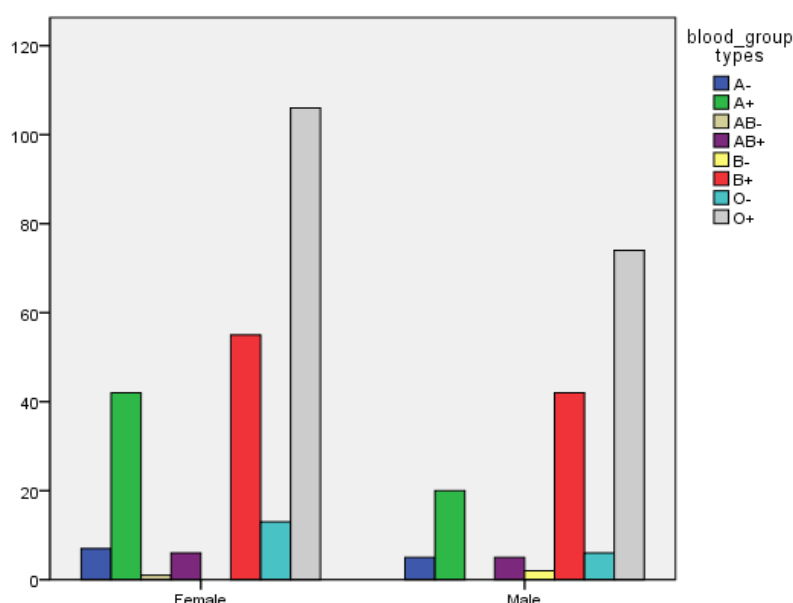


Figure 2.4: Gender distribution of blood group types in the malaria population. p-value = 0.488

Distribution of age groups in blood group types of malaria individuals

The relationship between the blood group types and the age groups of individuals in the sampled malaria individuals is represented in figure 2.5. The outcome revealed that individuals within the age group of 21-30 years were the majority. A Pearson chi-square value of 44.176 and non-significant p-value of 0.137 were obtained.

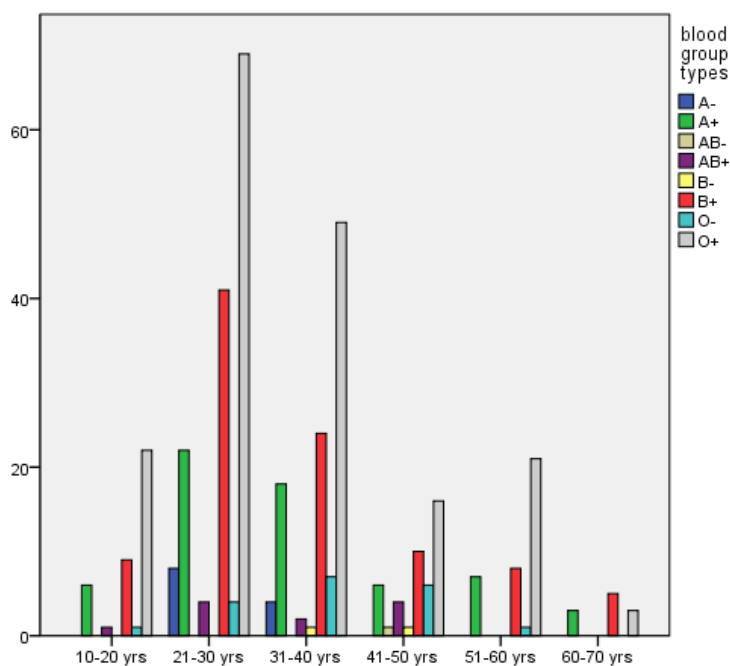


Figure 2.5: Age distribution in blood group types of malaria population. p-value = 0.137

Discussion

Malaria is a complicated illness that is influenced by numerous unclear host genetic variables (Amodu *et al.*, 2019; Band *et al.*, 2022; Driss *et al.*, 2011; Egan, 2018). The differences in blood groups play an important role in the pathogenesis of malaria. Numerous studies have linked malaria susceptibility to non-O blood group (Degarege *et al.*, 2019; Yeda *et al.*, 2022). Among the non-O group, malaria incidence is higher among individuals with blood group B (Degarege *et al.*, 2019; Panda *et al.*, 2011). A higher probability of malaria incidence in blood group AB (Deepa *et al.*, 2011; Zerihun *et al.*, 2011) has also been reported. Olajewo *et al.*, (2013) reported more incidence of malaria infection in blood group O(38.4%), closely followed by A(34.6%), moderate in B(23.1%) and least in AB(3.9%) whereas Gayatri *et al.*, (2013) reported B(40.9%), O(34.16%), A(16.09%) and AB(8.78%). Despite these associations, the impact of ABO and Rhesus (Rh) blood types on malaria has not been fully explored, especially in the Nasarawan population. Here we assess the relationship between the ABO blood groups and the laboratory outcomes of patients with malaria in Nasarawa State, Nigeria.

In our study, the frequency distribution of blood group types in malaria patients showed O+(46.9%), B+(25.3%), A+(16.1%), O-(4.9%), A-(3.1%), AB+(2.9%), B-(0.5%), AB-(0.3%). This showed that individuals with blood group O+ had the highest frequency of malaria infection, followed by B+ and A+. It is possible that the general distribution of blood group types in the study area could have contributed to the high rate of blood group O being infected with malaria. According to a recent study conducted by Abriba *et al.*, (2025) in Nasarawa State, the prevalence of blood groups A, B, AB and O were 28.7%, 22.7%, 3.3%

and 45.3% respectively. These values are consistent with the overall prevalence in Nigeria, which showed 52.93% for blood group O, 22.77% for blood group A, 20.64% for blood group B, and 3.66% for blood group AB (Anifowoshe *et al.*, 2017). Similarly, our results align with the publication of Nkansah *et al.*, (2023) who had earlier reported O+(44.39%), B+(27.56%), A+(21.95%) among their study participants. Aninagyei *et al.* (2024) had also reported higher frequencies in O+(54.9%), B+(43.3%), A+(37.2%), which is also consistent with Onaiwu *et al.*, (2019) that earlier reported higher frequency distribution in O+(58.3%), B+(17.9%), and A+(16.5%). This observation agrees with previous publications on this subject matter (Deepa *et al.*, 2011; Panda *et al.*, 2011). Our findings is however in contrast to a report by Abebe *et al.*, (2024), that reported higher prevalence of malaria infection among individuals with blood group A, followed by those of blood groups B and AB, and the least affected being blood group O+. The observed disparities in prevalence rates may be attributed to differences in vector abundance, malaria seasonality, control measures, study population, and sample size. Different locations may have varying malaria transmission intensities, affecting the observed associations. Also, individuals with previous malaria episodes may have developed immunity for the disease or the use of prophylaxis may have reduced the risk of malaria infection, thereby, influencing the observed relationship between blood group type and malaria susceptibility. For instance, the study by Abebe *et al.*, (2024) was conducted in Northeast Ethiopia, which may have distinct environmental and genetic factors influencing malaria susceptibility. Also, variations in study design and methodology may contribute to the observed differences.

In terms of gender status, more females had malaria infection compared to males which is contrary to recently published report by Abebe *et al.*, (2024), who reported more malaria infection in males than females. The higher prevalence of malaria among females in our study could be attributed to differences in exposure patterns, outdoor activities, or clothing that increase susceptibility to mosquito bites. Also, the hormonal fluctuations in females could potentially explain the gender-based differences in malaria susceptibility. The variation in various studies could be due to genetic factors, prevailing environmental conditions as at the time the research was being carried out and methodology of the study adopted.

It is important to note that despite the non-significant associations between blood group types and malaria susceptibility in our study, blood group studies remain relevant to malaria pathophysiology and population genetics. Also, blood group antigens could influence the immune response to malaria, and understanding these interactions could provide meaningful insights into disease mechanisms and identify potential targets for intervention. Furthermore, blood group distributions vary across populations, and studying these patterns may inform population genetics and evolutionary studies, thereby, shedding more light on the selective pressures exerted by malaria and other infectious diseases.

Conclusion

In conclusion, our study contributes to the growing body of evidence on the relationship between ABO/Rhesus blood group types and malaria susceptibility. This study found that individuals with blood group O+ had the highest frequency of malaria infection, followed by B+ and A+. However, the association between ABO blood group types and malaria susceptibility was not statistically significant. The findings suggest the need for a multi-state study with larger sample sizes, which would enable researchers to capture a more diverse population and account for regional variations in malaria transmission and genetics. Also, other markers of malaria susceptibility should be evaluated as blood group type may not be the only significant predictor.

The findings of this study have practical relevance for malaria risk profiling, enabling targeted interventions and optimized resource allocation. Additionally, understanding the relationships between blood group and malaria infection can inform transfusion practices, particularly in endemic areas, to minimize the risk of transfusion-transmitted malaria.

Limitation of the study

While our study provides key insights into the relationship between ABO/Rhesus blood group types and malaria susceptibility, there are several potential limitations to consider. For instance, our sample size was limited to 384 malaria-positive individuals, which might have impacted our ability to detect significant differences between groups. The lack of a control group hinders our ability to compare blood group distributions between malaria patients and healthy individuals. Also, the cross-sectional design precluded inference of causality between blood groups and malaria infection, the hospital-based sample may have introduced selection bias, as individuals seeking medical care may not be representative of the broader population. Additionally, unmeasured variables such as socioeconomic status, immunity and access to healthcare may have influenced our findings.

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Conflict of interest

The authors declare that they have no financial or other relationships that might lead to any conflict.

References

Abebe Alemu, D. M., Mihret, M., Adugna, M., & Gebeyaw, M. (2012). Ten year trend analysis of malaria prevalence in Kola Diba, North Gondar, Northwest Ethiopia. *Parasites & Vectors*, 5(1), 1–6.

- Abebe, W., Fasikaw, W., Gebreeyesus, D., Foziaya, F., & Agenagnew, A. (2024). Prevalence and association of malaria with the blood group on febrile patients at Woldia Comprehensive Specialized Hospital, Northeast Ethiopia. *Journal of Parasitology Research*, 2024, Article ID 9942758.
- Abkarian, M., Massiera, G., & Braun-Breton, C. (2011). A novel mechanism for egress of malaria parasites from red blood cells. *Blood*, 117(15), 4118–4124.
- Abossie A, Yohannes T, Nedu A, Tafesse W, Damitie M. (2020). Prevalence of Malaria and Associated Risk Factors among Febrile Children Under Five Years: A Cross-Sectional Study in Arba Minch Zuria District, South Ethiopia. *Infection and Drug Resistance*.13: 363–372.
- Abriba S. P, Nongsat T., Osadolor H. B., Toyrija J. (2025). ABO Rhesus D Blood Group Distribution among Pregnant Women Attending Federal Medical Centre, Keffi, Nigeria. *Sokoto Journal of Medical Laboratory Science*; 10(2): 174-182.
- Aninagyei, E., Agbenowoshie, P. M. A., Asiewe, S. B., Menu, R. Y., Gbadago, F., & Asmah, R. H. (2024). ABO and Rhesus blood group variability and their associations with clinical malaria presentations. *Malaria Journal*, 23, 257.
- Chandley P, Ranjan R, Kumar S, Rohatgi S (2023). Host-parasite interactions during Plasmodium infection: implications for immunotherapies. *Front Immunol*13:. <https://doi.org/10.3389/FIMMU.1091961>
- Cheesbrough, M. (2022). Examination of blood for parasites. In *District Laboratory Practice in Tropical Countries* (2nd ed.). Cambridge University Press.
- Dalvi, A., & Kumar Pulipaka, H. (2018). Determination of blood group using image processing. *International Journal of Scientific and Engineering Research*, 9, 24–27.
- Dawaki, S., Al-Mekhlafi, H. M., Ithoi, I., Ibrahim, J., Atroosh, W. M., Abdulsalam, A. M., Sady, H., Elyana, F. N., Adamu, A. U., Yelwa, S. I., Ahmed, A., Al-Areeqi, M. A., Subramaniam, L. R., Nasr, N. A., & Lau, Y. L. (2016). Is Nigeria winning the battle against malaria? Prevalence, risk factors, and KA assessment among Hausa communities in Kano State. *Malaria Journal*, 15, 351. doi: 10.1186/s12936-016-1394-3
- Deepa, A. V., Rameshkumar, K., & Ross, C. (2011). ABO blood groups and malaria-related clinical outcome. *Journal of Vector Borne Diseases*, 48(1), 7–11.
- Degarege, M. T. G., Ibanez, G., Wahlgren, M., & Madhivanan, P. (2019). Effect of the ABO blood group on susceptibility to severe malaria: A systematic review and meta-analysis. *Blood Reviews*, 33, 53–62
- Fernandes, J., Pimenta, S., Soares, F. O., & Minas, G. (2015). A complete blood typing device for automatic agglutination detection based on absorption spectrophotometry. *IEEE Transactions on Instrumentation and Measurement*, 64(1), 112–119.
- Franchini M, Liumbruno GM (2013). ABO blood group: old dogma, new perspectives. *Clin Chem Lab Med*. 2013; 51:1545–53. doi: 10.1515/cclm-2013-0168. [\[DOI\]](#) [\[PubMed\]](#) [Google Scholar](#)
- Gajida AU, Iliyasu Z, Zoakah AI(2010). Malaria among Antenatal Clients attending Primary Health Care Facilities in Kano State, Nigeria. *Annals of African Medicine*. 9: 188–193.
- Gayathri, B. N., Harendra, K. M. L., Gomathi, N., Jeevan, S., & Reethesh, R. P. (2013). Relationship between ABO blood groups and malaria with clinical outcome in rural area of South India. *Global Journal of Medicine and Public Health*, 2(2), 1–7.
- Lowe J. (1993). The blood group-specific human glycosyltransferases. *Baillieres Clin Haematol*. 6:465–90. doi: 10.1016/s0950-3536(05)80155-6. [\[DOI\]](#) [\[PubMed\]](#) [Google Scholar](#)
- Moll, K., Palmkvist, M., Ch'ng, J., Kiwuwa, M. S., & Wahlgren, M. (2015). Evasion of immunity to Plasmodium falciparum: Rosettes of blood group A impair recognition of PfEMP1. *PLoS ONE*, 10(12), e0145120. doi: 10.1371/journal.pone.0145120
- National Malaria Elimination Programme. (2015). National Malaria Indicator Survey (NMIS).

- National Malaria Indicator Survey (NMIS, 2015): Key indicators. National Malaria Elimination Programme, Abuja Nigeria. ; p96 & 99.
- National Malaria Indicator Survey. (2015). Key Indicators.
- National Population Commission (NPC, 2019). Nigeria Demographic and Health Survey 2018. Abuja, Nigeria, and Rockville, Maryland, USA: NPC and ICF.
- National Population Commission. (2019). Nigeria Demographic and Health Survey 2018. Natl. Acad. Sci. U. S. A 118, (2021).
- Nigeria Federal Ministry of Health. (2009). National Malaria Control Programme Strategic Plan 2009-2013.
- Nmadu PM, Peter E, Alexander P, Koggie AZ, Maikenti JI (2015). The Prevalence of Malaria in Children between the Ages 2-15 Visiting Gwarinpa General Hospital Life-Camp, Abuja, Nigeria. *Journal of Health Sciences*; 5: 47–51.
- Okagu IU, Aguchem RN, Ezema CA et al (2022) Molecular mechanisms of hematological and biochemical alterations in malaria: a review. *Mol Biochem Parasitol* 247:111446. <https://doi.org/10.1016/j.molbiopara.2021.111446>.
- Oladebo O, Oyeyemi AS, Titiloye MA, Adeyemi AO, Burnett SM, Apera I (2019). Malaria testing and treatment knowledge among selected rural patent and proprietary medicine vendors (PPMV) in Nigeria. *Malar J* ;18:103. <https://doi.org/10.1186/s12936-019-2732-z>.
- Olukemi K. Amodu, Obioma C. Uchendu (2014). https://www.researchgate.net/publication/271533876_Differences_in_the_Malariometric_Indices_of_Asymptomatic_Carriers_in_ThreeCommunities_in_Ibadan_Nigeria
- Pimenta, S., Minas, G., & Soares, F. O. (2012). Spectrophotometric approach for automatic human blood typing. *Proceedings of the IEEE 2nd Portuguese Meeting*, 101-104.
- Pimenta, S., Soares, F. O., & Minas, G. (2012). Development of an automatic electronic system to human blood typing. *Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, 2712-2715.
- Robert Herriman (2023). Nigeria approves R21 Malaria Vaccine. Available at <https://www.nafdac.gov.ng/press-briefing-by-profmojisola-christianah-adeyeye-director-general-national-agency-for-food-and-drug-administration-and-control-nafdac-on-the-regulatory-approval-of-r21-malaria-vaccine-by-nafdac/>
- Storry JR, Olsson ML (2009). The ABO blood group system revisited: a review and update. 25:48–59. [\[PubMed\]](#) [\[Google Scholar\]](#)
- Uneke, C. J., Ogbu, O., & Nwojiji, V. (2006). Potential risk of induced malaria by blood transfusion in South-eastern Nigeria. *McGill Journal of Medicine*, 9(1), 8-13.
- US President's Malaria Initiative (2023). FY 2023 Nigeria Malaria Operational Plan.
- WHO (2021) World Malaria Report 2021, 1st edn. World Health Organization, Geneva. <https://www.who.int/teams/global-malaria-programme/reports/world-malariareport>.
- World Health Organization. (2022). Malaria key facts.
- World Health Organization. (2023). World Malaria Report 2023.
- World malaria report (2024). Available at: <https://www.who.int/publications-detail-redirect/9789240064898>.
- Yamamoto F, Clausen H, White T. (1990). Molecular genetic basis of the histo-blood group ABO system. *Nature*; 345:229–33. doi: 10.1038/345229a0. [\[DOI\]](#) [\[PubMed\]](#) [\[Google Scholar\]](#)
- Zerihun, T., Degarege, A., & Erko, B. (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 DOI: 10.1016/S2221-1691(11)60045- 2.