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The Study of Blood Conductivity and Viscosity in Malaria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Malaria is the most widespread disease in Africa and developing countries which has a negative effect on everyday life and causes thousands death each year. To find new, more precise, and less expensive diagnostic methods, an increasing number of studies are needed. In order to replace the conventional method for detecting the presence of malaria parasites in human blood, the electrical conductivity and viscosity of the blood of falciparum malaria were measured. To investigate the effect of malaria on physical properties; a total of hundred blood samples were collected from Khartoum state teaching hospital, samples were subdivided into two groups, fifty from the malaria patient and other fifty from healthy people setting as control group. An Ostwald viscometer, a hematocrit centrifuge and conductivity equipment were used to measure the viscosity, hematocrit and electrical conductivity of blood respectively. In this study it was found that the mean value of hematocrit for healthy individuals was 45.7%. While in malaria patients was 27.7 %, in addition, the mean value of blood viscosity for healthy individuals was 4.4 cp, while 2.8 cp, for patients. The mean value for conductivity of whole blood in healthy individuals was 4.4 m. s, whereas it was 3.9 m.s in patients, but the mean value of serum conductivity was 4.3 in patients a m.s and 8.3 in healthy individuals.

Conclusion: The results obtained in this indicated significantly changed in viscosity, hematocrit and electrical conductivity of blood due malaria parasites. These physical changes caused by Plasmodium falciparum malaria can be used as new malaria diagnostic techniques.

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1. INTRODUCTION

Malaria is undeniably one of the most serious health problems in the world and is a social and economic burden to many developing countries where the disease is endemic and caused by various species of the protozoa genus Plasmodium. It remains a major public health problem in developing countries worldwide, resulting in approximately 200 million new infections per year and more than 500,000 subsequent deaths [1,2,3]. Immigration and human population density-related environmental and ecological factors that support the survival and expansion of the mosquito population are taken into consideration as factor contributing to the spread of malaria. In both cases, it is proved that the spread of malaria increases as the parameters governing environmental and ecological factors increase. It is also found that due to immigration, this infectious disease becomes more endemic [4]. The asexual reproduction cycles of Plasmodium falciparum, the parasite responsible for severe malaria, occurs within red blood cells. A merozoite invades a red cell in the circulation, develops and multiplies, and after about 48 hours ruptures the host cell, releasing 15–32 merozoites ready to invade new red blood cells [5]. Fever or a recent history of fever is the clinical sign of malaria that occurs most frequently. But even in endemic areas, many diseases also exhibit fever as their initial clinical sign, making accurate laboratory testing essential. False positives will result in incorrect antimalarial therapy use, and underdiagnosed cases undoubtedly contribute to an increase in morbidity, mortality, and antimalarial resistance. Microscopy is still the most popular and effective method for detecting malaria infection early on, and it also serves as the gold standard for laboratory confirmation of malaria. In spite of this, its application still has numerous flaws malaria control measures to lower morbidity and mortality due to the difficulty in making an appropriate and accurate diagnosis for the detection of malaria parasites [6]. While there is currently no method that can be relied upon to be 100% accurate, modern technologies can reliably identify Plasmodium infections in areas where they are endemic [7]. The diagnosis is a key factor in how different strategies are used to achieve the goal [8].

Ancient Greek researchers were the first to understand the vital essence of blood and its role in the development of disease. The physical characteristics of blood have been studied for millennia. Scientists have studied how red blood cells (RBC) settle and how they can bend to fit through capillaries that are smaller than they are. A non-Newtonian fluid is one whose viscosity is affected by shear rate, and blood is the prototypical example of one. The viscosity of blood specifically decreases as the shear rate rises due to shear-thinning [9]. Whole blood viscosity exhibits shear thinning behavior, which is characterized by a non-linear decrease with increasing shear rate. Blood's non-Newtonian behavior depends on the circulatory system's dynamic flow and the corresponding variation in shear rates in subsequent vascular compartments with variable radii. According to the following equation, apparent shear rate is proportional to blood flow velocity, which is highest at the centerline and gradually decreases toward the vessel wall [9,10].

$$\gamma = \Delta v\, h \tag{1}$$

Where: γ is the shear rate in s^{-1}, Δv is the radial gradient of flow velocity within a vessel and h is the radial distance between the two measured points.

The largest cellular component of blood is called an erythrocyte. Blood viscosity is primarily determined by hematocrit, which is the ratio of RBC volume to total blood volume (normal range: (35% to 45%) [9,11,12].

1.1 Interrelationships of Pressure, Flow, and Resistance

Blood flow through a blood vessel is determined by two factors: the pressure difference between the inlet and the outlet of the vessel and the resistance of the vessel to blood flow. The pressure difference is the driving force for blood flow, and the resistance is an impediment to flow. The relationship between flow, pressure, and resistance is equivalent to the relationship of the current (I), voltage (ΔV), and resistance (R) in electrical circuits, as expressed by Ohm's law ($\Delta V = I \times R$). Blood flow is analogous to current flow and the pressure difference or driving force is analogous to the voltage difference, and hydrodynamic resistance is analogous to electrical resistance. The equation for blood flow is expressed as follows:

$$Q = \frac{\Delta P}{R} \quad (2)$$

Where: Q is blood flow (ml/min), ΔP is the pressure difference (P1- P2) between the two ends of the vessel(mmHg) and R is the resistance (mmHg/mL per min)

This equation states that the blood flow is directly proportional to the pressure difference and inversely proportional to the resistance, see [13-15]. The factors that determine the resistance of a blood vessel to blood flow are expressed by the Poiseuille equation in [14] which state:

$$R = \frac{8\eta L}{\pi r^4} \quad (3)$$

Referring to ref [13] we can write Poiseuille equation in terms of

$$Q = \frac{\pi \Delta P r^4}{8\eta L} \quad (4)$$

Conductance is a measure of the blood flow through a vessel for a given pressure difference, which it is the reciprocal of resistance in blood vessel. This measurement is generally expressed in terms of milliliters per second per millimeter of mercury pressure, it can also be expressed in terms of liters per second per millimeter of mercury or in any other units of blood flow and pressure. It is evident that conductance is the exact reciprocal of resistance is in agreement with the equation in ref [13], so it can be written as:

$$Conductance = \frac{1}{Resistance} \quad (5)$$

The viscosity of blood increases drastically as the hematocrit increases, as obtained in ref [13-16]. Other factors that affect blood viscosity are the plasma protein concentration and types of proteins in the plasma, but these effects are so much less than the effect of hematocrit that they are not significant considerations in most hemodynamic studies. The viscosity of blood plasma is about 1.5 times that of water. Referring to equation (5) the relationship between conductivity and resistivity can be written in terns of Poiseuille equation as follows:

$$\sigma = \frac{\pi r^4}{8\eta L} \quad (6)$$

Where $\sigma$is the Conductivity of blood

2. MATERIALS AND METHODS

All samples used in this study were conducted during January 2005 and October 2009 in Khartoum state teaching hospital Laboratory, Sudan**.** In order to identify the physical changes brought on by malaria parasites in human blood a comparison between 50 patients and 50 control has been investigated. Patients were those who had either received treatment or not and met the criteria for the clinical diagnosis of malaria. people without an infection served as the control. This investigation used measurements of blood viscosity, hematocrit, blood conductivity, and serum conductivity. By contrasting the physical characteristics of the patient's blood with those of the control group, it was possible to detect the physical changes in the blood. In this study the physical characteristics of blood conductivity, plasma conductivity, blood viscosity, and hematocrit were examined as follows:

Hematocrit was measured as the ratio of red blood cell volume to total blood volume. The ratio can be measured and expressed as a decimal or percentage fraction after the blood sample is drawn into a capillary and centrifuged. In order to measure the blood conductivity and serum conductivity, the conductivity meter with accuracy 0.001μs has been used (model 10175 MD- USA)

The standard solution's temperature was set to 25°C room temperature. Two clean beakers (100-ml) were filled with the standard solution to a depth of 2 cm each, and then the beakers covered. The cover of the conductivity meter has been removed and turned on. The electrode used in the measurement was sterilized and dried before immersing it in the solution to conduct the measurements. The counter probe was placed in the first standard beaker. The solution was stirred gently for two seconds, then the meter probe removed from the first beaker and inserted into the second beaker with gentle stirring till the reading confirmed on the device screen and the result has been taken.

The same procedure in ref [17] has been used to determine the viscosity. In the following relationship, fluid viscosity values were calculated from the (Ostwald viscometer, VAPRO, Model 5520, USA) observations as in equation (7).

$$\eta_{blood} = \frac{t_{blood}}{t_{water}} . \frac{\rho_{blood}}{\rho_{water}} \quad (7)$$

Where: t_{blood} , t_{water} is time of blood and water flow respectively and $\rho_{blood}, \rho_{water}$ is density of blood and water respectively.

3. RESULTS

In order to measure the blood's hematocrit, viscosity, and conductivity, the samples of fifty patients and fifty control were examined. The data listed in Table 1.is analyzed using Statistical Package for social science (SPSS) program version 11.

As shown in Fig. 1, there is a noticeable difference between malaria patients and controls in terms of hematocrit and viscosity, with the exponential relationship between hematocrit and viscosity.

Fig. 2 showed the exponential relationship between hematocrit and conductivity which illustrate inversion exponential relationship where the hematocrit increases the conductivity decreases.

Fig. 3, showed a noticeable difference between malaria patients and controls in terms of viscosity. The Figure is satisfied the relation obtained in equation 6 where there is inverse relation between viscosity and conductivity. Also it clears from Fig. 3 the people who affected by Plasmodium falciparum their blood viscosity and conductivity were decrease clearly. By referring to equations 1 and 8 the conductivity not only depend on viscosity but also depend on the patient's temperature, shear rate and velocity of blood flow. With help of the Origin6 program we could analyze the graph and comparing the equation generated program with equations 1, 6, 8 as written below. More interpretation will provide the coming discussion section.

$$Y = Y_\circ + \mathrm{A}_1 \mathrm{e}^{\frac{-\mathrm{x}}{\mathrm{t}_1}} , \quad \sigma = 3.7 + (838 \mp 361)\mathrm{e}^{\frac{-\eta}{0.57}}$$

$$\sigma = \sigma_\circ + Ae^{\frac{-\dot{\gamma} v}{KT}\boldsymbol{\eta}} \quad (8)$$

Where

Y= σ = Conductivity of whole blood
$Y_O = \sigma_O$ =Serum Conductivity
A_1= A=Constant

$\frac{X}{t_1}$=$\frac{-\dot{\gamma} v}{KT}\eta$

In Fig. 4, there was a noticeable difference between malaria patients and controls in terms of Serum Conductivity with the Linear relationship of inverse proportion between Serum Conductivity and Conductivity.

Through the study of Fig. 5 presented the case of infection with the falciparum malaria parasite, the inverse relationship between the hematocrit and ratio of the electrical conductivity of whole blood and the conductivity of serum increased, which indicated that during the period of infection with the falciparum malaria parasite, the electrical conductivity in our body was more dependent on serum conductivity.

Table 1. obtain the mean values and their stander deviation of hematocrit, blood viscosity, blood conductivity and the serum conductivity of 50 samples for patients and control

Properties	Case	No	Maximum	Minimum	Mean	Std. deviation
Hematocrit (HCT)%	patients	50	36.00	16.00	27.700	4.39503
	control	50	52.00	38.00	45.700	5.49304
Blood Viscosity (cp)	patients	50	3.55	2.28	2.762	0.43515
	control	50	5.43	3.83	4.377	0.41961
blood Conductivity (m.s)	patients	50	4.19	3.45	3.820	0.25696
	control	50	4.89	4.01	4.436	0.25223
Serum Conductivity (m.s)	patients	50	7.71	2.14	4.271	1.42672
	control	50	12.00	4.51	8.344	2.21605

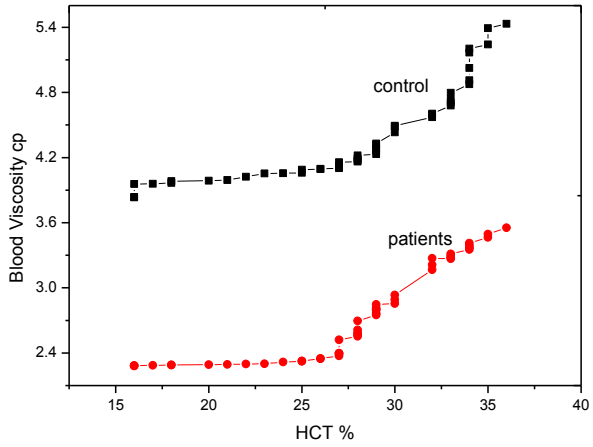

Fig. 1. shows the exponential relationship between hematocrit (control and patients) and the viscosity of whole blood

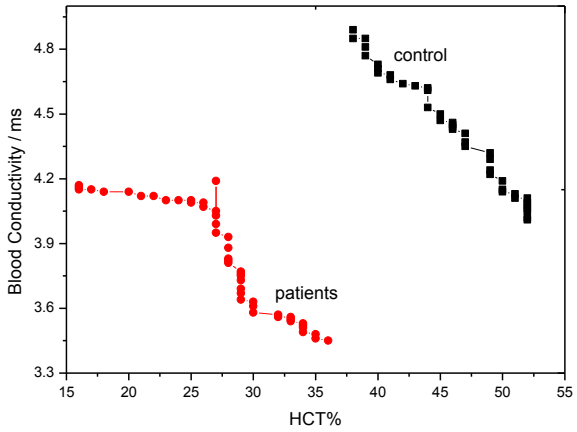

Fig. 2. shows the exponential relationship between hematocrit (control and patients) and the conductivity of whole blood

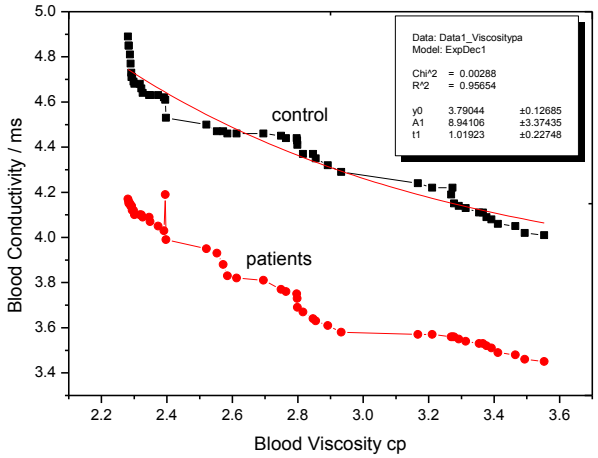

Fig. 3. shows the exponential relationship between viscosity (control and patients) and the conductivity of whole blood. After analyzing

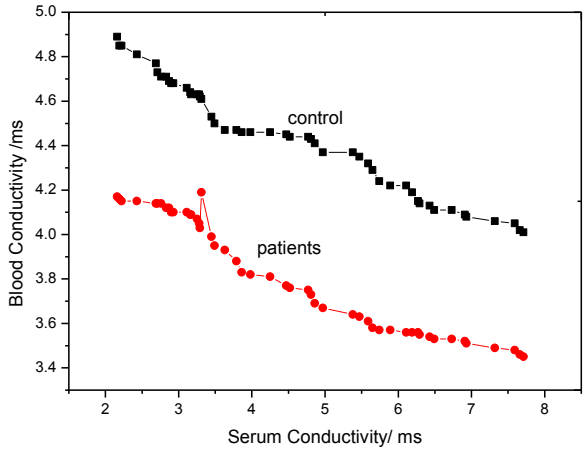

Fig. 4. shows the exponential relationship between serum conductivity (control and patients) and the conductivity of whole blood

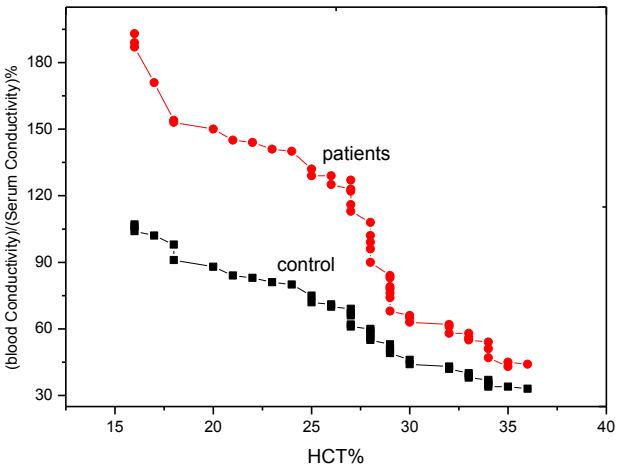

Fig. 5. (Blood Conductivity)/(Serum Conductivity)% as function of HCT for control group blood

4. DISCUSSION

The findings of the current study showed that the hematocrit, whole blood viscosity, whole blood conductivity, and serum conductivity of falciparum malaria patients was significantly decreased when compared with healthy individuals. To discuss these results, the physical equations was used and compared with previous studies.

Firstly, study showed that the hematocrit of falciparum malaria patients significantly decreased when compared with healthy individuals. This outcome was consistent with a study [18-24]. present study also showed that there was a very clear decrease in the values of blood viscosity when infected with the falciparum malaria parasite when compared to healthy individuals, and this result could be validated in two ways. The first method was the relationship of hematocrit with viscosity, a directly proportional curve relationship, as indicated by the results of the current study and agreeing with earlier studies [13-16]. The second method by comparing with the previous studies According to studies done by Well and Dondorp [16,25], the decreased in RBCS functioned as a perfect nonconductor. Which decreases RBC. S decreases viscosity. As a result, anemia reduces blood viscosity as well, as RBC.S. were primarily responsible for blood friction and viscosity.

In addition, the current study revealed that both the conductivity of whole blood and the conductivity of plasma were significantly decreased in patients with falciparum malaria compared with healthy subjects, which means that both the viscosity and conductivity of whole blood have decreased significantly. This is contrary to mathematical equation (6), which states that the relationship between the conductivity of whole blood and its viscosity is an inverse proportional relationship. Since Equation 6 refers to the conductivity of whole blood, the results regarding the conductivity of plasma do not conflict with it. Therefore, the question is how the inverse relationship between blood's conductivity and viscosity, which has been demonstrated by science, works in practice. The relationship improved after the malaria parasite's effects. We'll go over the variables influencing how blood conductivity and viscosity change to clarify this. Equation (8) explains the reasons for the lack of viscosity and conductivity values when infected with falciparum malaria, as one of the symptoms of the disease is a high temperature and a drop in blood pressure, and thus a decrease in the flow velocity through the blood vessels. All of this explains the decrease in conductivity with viscosity, according to the mathematical equation. And all these previous studies [26-29] explain the reasons for the lack of blood conductivity when infected with the falciparum malaria parasite. The reverse balance and ability to overcome it will therefore the increased due to the conductivity of blood, even though the viscosity of blood decreases with an increase in conductivity but the conductivity of plasma was more decreasing. This was clarified in his experimentation study [30], which demonstrated a direct correlation between the ratio of conductivity in our current study, we drew a graphic relationship between whole blood to plasma conductivity and the volume of compressed blood cells (hematocrit), which was proportional to blood viscosity as previously discussed. Comparison of this graphic relationship with the chart made by study 30, and was completely agreed which may supports the primary cause of the low viscosity and conductivity of whole blood of patients with falciparum malaria.

5. CONCLUSIONS

The physical changes that occur in the blood as a result of infection with a malaria parasite led to a difference in the values of conductivity and resistance between healthy people (control) and people infected with the parasite (patients), with a clear decrease in the values. This change could be considered as one of the factors used in the examination of malaria and considered for demonstrated of whole blood viscosity, hematocrit, blood conductivity, and plasma conductivity the decreased levels in response to falciparum malaria. Also could used to assess the effectiveness of malaria therapy.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Honrado C, Ciuffreda L, Spencer D, Ranford-Cartwright L, Morgan H. Dielectric characterization of *Plasmodium falciparum*-infected red blood cells using microfluidic impedance cytometry. Journal of The Royal Society Interface. 2018; 15(147):20180416. Available:http://doi.org/10.1098/rsif.2018.0416
2. Bouyer G, Cueff A, Egée S, Kmiecik J, Maksimova Y, Glogowska E, Gallagher PG, Thomas SL. Erythrocyte peripheral type benzodiazepine receptor/voltage-dependent anion channels are upregulated by *Plasmodium falciparum*. Blood, The Journal of the American Society of Hematology. 2011;118(8):2305-2312.
3. Marginedas-Freixa I, Hattab C, Bouyer G, Halle F, Chene A, Lefevre SD, Cambot M, Cueff A, Schmitt M, Gamain B, Lacapère JJ. TSPO ligands stimulate ZnPPIX transport and ROS accumulation leading to the inhibition of *P. falciparum* growth in human blood. Scientific Reports. 2016;6(1):1-15.
4. Singh S, Shukla JB, Chandra P. Modelling and analysis of the spread of malaria: Environmental and ecological effects. Journal of Biological Systems. 2005;13 (01):1-11.
5. Mauritz JM, Esposito A, Ginsburg H, Kaminski CF, Tiffert T, Lew VL. The homeostasis of *Plasmodium falciparum*-infected red blood cells. Plos Computational Biology. 2009;5(4): e1000339.
6. Fitri LE, Widaningrum T, Endharti AT, Prabowo MH, Winaris N, Nugraha RYB. Malaria diagnostic update: From conventional to advanced method. J Clin Lab Anal. 2022;36(4):e24314.

DOI: 10.1002/jcla.24314. Epub 2022 Mar 4. PMID: 35247002; PMCID: PMC8993657.

7. Slater L, Ashraf S, Zahid O, Ali Q, Oneeb M, Akbar MH, Riaz MI, Afshan K, Sargison N, Chaudhry U. Current methods for the detection of *Plasmodium parasite* species infecting humans. Curr Res Parasitol Vector Borne Dis. 2022;2:100086. DOI: 10.1016/j.crpvbd.2022.100086. PMID: 35434694; PMCID: PMC9006665.
8. Oyegoke OO, Maharaj L, Akoniyon OP, et al. Malaria diagnostic methods with the elimination goal in view. Parasitol Res. 2022;121:1867–1885. Available:https://doi.org/10.1007/s00436-022-07512-9
9. Tamas Alexy, Jon Detterich, Philippe Connes, Kalman Toth, Elie Nader, Peter Kenyeres, Jose Arriola-Montenegro, Pinar Ulker, Michae J. Simmonds physical properties of blood and their relationship to clinical conditions; 2022. DOI: 10.3389/fphys.2022.906768
10. Alexy T, et al. Physical properties of blood and their relationship to clinical conditions. Front Physiol. 2022;13:906768. DOI: 10.3389/fphys.2022.906768, PMID: 35874542; PMCID: PMC9298661.
11. Trejo-Soto C, Hernández-Machado A. Normalization of blood viscosity according to the hematocrit and the shear rate. Micromachines (Basel). 2022;13(3): 357. DOI: 10.3390/mi13030357. PMID: 35334649; PMCID: PMC8954080.
12. Tao R, Rongjia, Huang KE. Reducing blood viscosity with magnetic fields. Physical review. E, Statistical, Nonlinear, and Soft Matter Physics. 2011;84: 011905. DOI: 10.1103/PhysRevE.84.011905
13. Khonsary SA. Guyton and hall: Textbook of medical physiology. Surgical Neurology International. 2017;8.
14. Linda S. Costanzo. 1600 John F. Kennedy Blvd. Ste 1800 Philadelphia, PA 19103-2899 Physiology, Sixth Edition. ISBN: 978-0-323-47881.
15. Britt Wilson L, Raj Dasgupta, Conrad Fischer, Frank P. Noto. Kaplan USMLE Step 1 Lecture Notes, Physiology; 2016.
16. Wells RE Jr, Merrill EW. Influence of flow properties of blood upon viscosity-hematocrit relationships. J Clin Invest. 1962;41(8):1591-8. DOI: 10.1172/JCI104617. PMID: 14040228; PMCID: PMC291077
17. Vapro 5520 user manual online. Vapor Pressure Osmometer. 5520 measuri ng instruments pdf manual download.
18. Price RN, Simpson JA, Nosten F, Luxemburger C, Hkirjaroen L, ter Kuile F, Chongsuphajaisiddhi T, White NJ. Factors contributing to anemia after uncomplicated falciparum malaria. Am J Trop Med Hyg. 2001;65(5):614-22. DOI: 10.4269/ajtmh.2001.65.614; PMID: 11716124; PMCID: PMC4337986
19. Gbotosho GO, Sowunmi A, Okuboyejo TM, Happi CT, Folarin OA, Michael OS, Adewoye EO. Therapeutic efficacy and effects of artemether-lumefantrine and artesunate-amodiaquine coformulated or copackaged on malaria-associated anemia in children with uncomplicated *Plasmodium falciparum* malaria in Southwest Nigeria. Am J Trop Med Hyg. 2011;84(5):813-9. DOI: 10.4269/ajtmh.2011.10-0582; PMID: 21540395; PMCID: PMC3083753
20. Chotivanich K, Udomsangpetch R, Dondorp A, Williams T, Angus B, Simpson JA, Pukrittayakamee S, Looareesuwan S, Newbold CI, White NJ. The mechanisms of parasite clearance after antimalarial treatment of *Plasmodium falciparum* Malaria. The Journal of Infectious Diseases. 2000;182(2):629–633. Available:https://doi.org/10.1086/315718
21. Jones TR, Stroncek DF, Gozalo AS, Obaldia N, Andersen EM, Lucas C, Narum DL, Magill AJ, Sim BK, Hoffman SL. Anemia in parasite-and recombinant protein-immunized aotus monkeys infected with *Plasmodium falciparum*. The American Journal of Tropical Medicine and Hygiene. 2002;66(6):672-9.
22. La'lang M, Budhy TI, Prastyawati R. Description of hematocrit in malaria tropica (*Plasmodium falciparum*) patients at Jayapura Regional General Hospital. Malaysian J Med Heal Sci. 2021;17:2636-9346.
23. Egan AF, Fabucci ME, Saul A, Kaslow DC, Miller LH. Aotus New World monkeys: Model for studying malaria-induced anemia. Blood, the Journal of the American Society of Hematology. 2002;99(10):3863-6.
24. Rojanasthien S, Surakamolleart V, Boonpucknavig S, Isarangkura P. Hematological and coagulation studies in malaria. Journal of the Medical Association of Thailand= Chotmaihet Thangphaet. 1992;75:190-4.

25. Dondorp AM, Kager PA, Vreeken J, White NJ. Abnormal blood flow and red blood cell deformability in severe malaria. Parasitology Today. 2000;16(6):228-32.
26. Somnath M, Vincent H, et.al. Identification and analysis of dihydrofolate redyctase alleles from plasmodium falciprum present at low frequency in polycolonal patient sample. Am. J. Trop. Med. Hyg. 1990;61(1):131–14.
27. Brooks RR, Ryan DE, Zhang HF. Atom. Spectro. Sc. 1981;2:161–162.
28. Horan FE, Hirsch FG. Surface effects on blood clotting components as determined by zeta potentials. J. Clin. Investigation. 1976;29:2.02.
29. Jacoline S, et al. Conductivity-based hematocrit measurement during cardiopulmonary bypass. J. Clin. Mon. Com. 2007;21(1).
30. Hirsch FG, et al. The electrical conductivity of blood: I. Relation to clotting and clot retraction. Blood. 1997;5:1017-1035.

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