**Antiplasmodial and Hematological Effects of Electromagnetic Fields in Plasmodium berghei-Infected Mice**

### Abstract

Malaria remains a major global health challenge, with rising resistance to antimalarial drugs threatening control efforts. Non-pharmaceutical interventions, such as electromagnetic fields (EMFs), have shown potential antiplasmodial effects, but their impact on parasite growth and host hematology is not fully understood. This study evaluated the effects of EMF exposure on parasitemia and hematological parameters in Plasmodium berghei-infected mice, comparing outcomes with artemisinin-based combination therapy (ACT). Fifty-six Swiss albino mice were distributed into seven groups: four groups exposed to EMFs at 10, 15, 20, or 30 mT for 6 hours daily, one receiving ACT (0.5 mg/kg), one untreated infected control, and one uninfected control. Parasitemia was assessed daily using Giemsa-stained thick blood films, and hematological parameters including RBC, WBC, hemoglobin, platelets, and lymphocytes were measured post-treatment.EMF exposure reduced parasitemia in a time- and intensity-dependent manner, with the most pronounced effects at 20 mT and 30 mT by Day 5. ACT achieved superior parasite clearance, reaching 88.3% inhibition. Hematological assessments showed that 10 mT EMF produced the most favorable outcomes, improving RBC, hemoglobin, and platelet counts while modulating WBC and lymphocyte levels. Higher EMF intensities (20–30 mT) demonstrated less hematological improvement, suggesting a dose-dependent effect. EMFs reduce P. berghei parasitemia and improve host hematological parameters. Although less effective than ACT, EMFs may serve as a complementary therapy, warranting further studies to optimize parameters and assess long-term safety.

**Keywords:** Plasmodium berghei, electromagnetic fields, parasitemia, hematology, antiplasmodial therapy, artemisinin-based combination therapy

## Introduction

Malaria remains one of the most lethal infectious diseases, with over 247 million cases and 619,000 deaths reported in 2022, primarily among children under five in sub-Saharan Africa (WHO, 2023). The disease is endemic in intertropical regions where climatic conditions favor transmission by the female Anopheles mosquito. Without treatment, malaria parasites multiply in erythrocytes, causing recurrent fever, chills, headaches, and severe complications such as cerebral malaria, multi-organ dysfunction, and fatal anemia (Ekun *et al.*, 2023). Of the five human-infecting species, Plasmodium falciparum and P. vivax are the most widespread, with P. falciparum responsible for the most severe cases due to high parasitemia and hemolysis (CDC, 2022; Rovira-Vallbona *et al*., 2020). Although less virulent, P. vivax remains an important contributor to global morbidity and mortality (Geleta and Ketema, 2016; Opoku *et al*., 2019).

Despite sustained elimination efforts, malaria persists as a global health challenge, largely due to the emergence of resistance to both antimalarial drugs and insecticides (Opoku *et al.,* 2019; Ribeiro *et al.*, 2023a). Artemisinin-based combination therapies (ACTs) have been highly effective over the past two decades, yet growing resistance to artemisinin and its partner drugs first observed in Southeast Asia and now reported in parts of Africa poses a significant threat to malaria control (Angupale *et al*., 2023). Preventive strategies, including the RTS,S/AS01 (Mosquirix) vaccine, mark important progress but remain limited by modest efficacy (Datoo *et al*., 2022).

Beyond pharmaceutical interventions, malaria profoundly disrupts hematological parameters, leading to anemia, thrombocytopenia, and leukocyte abnormalities (Maina *et al.,* 2010; Ladhani *et al*., 2002). These challenges have spurred interest in non-pharmaceutical approaches such as electromagnetic fields (EMFs), which exhibit biological effects including tissue repair stimulation, anti-inflammatory activity, and potential antiplasmodial action (Lai and Singh, 2010; Resmi and Devendra, 2024). Recent studies suggest that low-intensity alternating EMFs may impair malaria parasite survival and reproduction, highlighting a promising novel therapeutic avenue (Cosic and Lazar, 2016; Coronado *et al*., 2023).

This study therefore aims to evaluate and compare the hematological impacts of pharmaceutical and electromagnetic therapies in malaria. Key parameters including red blood cell count, hemoglobin concentration, lymphocyte, white blood cell count, and platelet count will be assessed as markers of disease progression and treatment efficacy. The findings may provide insights into integrative approaches for more effective malaria management.

**Methods**

### Experimental Animals

A total of fifty-six (56) mice weighing 18–22 g were distributed into seven groups of eight animals each. Six groups were infected intraperitoneally with 0.2 ml of a standard inoculum containing 1 × 10⁷ Plasmodium berghei (NK65 strain) parasitized erythrocytes. The seventh group was not infected and served as the normal control. Among the infected groups, Groups 1–4 were treated with EMFs at intensities of 10 mT, 15 mT, 20 mT, and 30 mT, respectively. Group 5 received 0.5 mg/kg body weight of ACTs as the positive control, while Group 6 remained untreated as the negative control. ACT treatment was administered once daily by gavage using an intubator for four consecutive days. The EMF-treated groups were exposed to oscillatory magnetic fields of 10 mT, 15 mT, 20 mT, or 30 mT for 6 hours daily. Blood samples were collected daily from the tail vein of the mice prior to treatment for parasitemia assessment.The animals were sacrificed twenty four hours after the last treatment and whole blood was collected for heamatology assays.

### Parasitological Assessment

Thick blood films were prepared daily for five consecutive days from blood samples collected via tail snip. The samples were smeared on clean, grease-free slides, air-dried, and stained with 10% (v/v) Giemsa solution for 10 minutes. Slides were examined microscopically under oil immersion at ×100 magnification. The number of parasites was counted against 200 white blood cells (WBCs) using a tally counter.

Parasite density was calculated as:

Parasite density (parasites/μL)= Number of parasites counted × 8,000

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Number of WBCs examined​ ̸̸

(assuming a standard WBC count of 8,000/μL blood).

The parasite inhibition rate (PIR) was determined using the formula:

PIR (%)= A−B

 \_\_\_\_\_ × 100

 A

where A is the mean parasite density in the untreated (negative control) group and B is the mean parasite density in the treated group.

**Haematological assay**

The blood collected into the EDTA bottle was used to determine haematological parameters using automated analyzer to analyze the blood sample. The haematological parameters investigated include the white blood cell (WBC) count, red blood cell (RBC) count, hemoglobin (HGB), lymphocyte (LYM) and platelet.

### Statistical Analysis

### Data were analyzed using one-way ANOVA in GraphPad Prism 8. Results were expressed as Mean ± Standard Error of the Mean (SEM). Statistical significance was considered at p < 0.05.

### Results

### Effect of EMF Treatment on Parasitemia

The effects of EMF and ACT treatment on parasitemia over five days are shown in Table 1. All EMF-treated groups (10 mT, 15 mT, 20 mT, and 30 mT) exhibited progressive reductions in parasitemia from Day 0 to Day 5. Higher EMF intensities (20 mT and 30 mT) demonstrated the most pronounced decreases by Day 5, with parasitemia values of 1516 ± 86 and 1336 ± 58, respectively. Statistically significant reductions in parasitemia were observed after Day 3 in the 15 mT, 20 mT, and 30 mT EMF-treated groups (p < 0.05), indicating a dose-dependent effect. The positive control group (ACT) showed a rapid and marked decline in parasitemia, from 1784 ± 182 on Day 0 to 249 ± 22 on Day 5. In contrast, the negative control group showed persistently high parasitemia, ranging from 1964 ± 232 on Day 0 to 2121 ± 128 on Day 5.

**Table 1. Effect of Different Anti-Malarial Treatments on Parasitemia**

| **Treatment** | **Day 0** | **Day 1** | **Day 2** | **Day 3** | **Day 4** | **Day 5** |
| --- | --- | --- | --- | --- | --- | --- |
| EMF 10(+) | 1824 ± 152ᵃ | 1752 ± 160ᵃ | 1658 ± 152ᵃ | 1605 ± 120ᵃ | 1495 ± 182ᵃᵇ | 1477 ± 212ᵃᵇ |
| EMF 15(+) | 1744 ± 127ᵃ | 1638 ± 138ᵃ | 1569 ± 127ᵃ | 1430 ± 112ᵃᵇ | 1395 ± 38ᵃᵇ | 1360 ± 96ᵇ |
| EMF 20(+) | 2022 ± 168ᵃ | 1900 ± 156ᵃ | 1779 ± 168ᵃ | 1658 ± 108ᵃᵇ | 1577 ± 76ᵇ | 1516 ± 86ᵇ |
| EMF 30(+) | 1856 ± 184ᵃ | 1788 ± 172ᵃ | 1657 ± 184ᵃ | 1563 ± 103ᵃᵇ | 1469 ± 100ᵇ | 1336 ± 58ᵇ |
| Positive Control (+) | 1784 ± 182ᵃ | 1392 ± 98ᵇ | 941 ± 182ᶜ | 446 ± 32ᵈ | 356 ± 44ᵉ | 249 ± 22ᶠ |
| Negative Control (-) | 1964 ± 232ᵃ | 2022 ± 206ᵃ | 2058 ± 232ᵃ | 2072 ± 184ᵃ | 2081 ± 128ᵃ | 2121 ± 128ᵃ |

\*All the values are reported as Mean±SEM

\*\*Mean values were compared with day 0 which was taken before the commencement of the treatment

\*\*\*Value carrying different superscripts across a row are statistically different at p<0.05

### Parasitemia Inhibition

Table 2 presents the percentage inhibition of parasitemia in EMF-treated groups compared to the positive control. All EMF-treated groups showed progressive increases in inhibition, with 15 mT and 30 mT EMF achieving the highest inhibition by Day 5 (36.18% and 37.29%, respectively). The positive control demonstrated the most potent effect, reaching 88.31% inhibition by Day 5.

**Table 2. Percentage Inhibition of Parasitemia in Treated Mice**

| **Treatment** | **Day 0** | **Day 1** | **Day 2** | **Day 3** | **Day 4** | **Day 5** |
| --- | --- | --- | --- | --- | --- | --- |
| **EMF 10 (+)** | 7.09% | 13.21% | 19.64% | 22.55% | 29.90% | 30.66% |
| **EMF 15 (+)** | 11.17% | 18.86% | 24.00% | 30.99% | 33.01% | 36.18% |
| **EMF 20 (+)** | -3.00% | 5.89% | 13.79% | 20.00% | 24.22% | 28.91% |
| EMF 30 (+) | 5.45% | 11.43% | 19.75% | 24.56% | 29.45% | 37.29% |
| **POS CNTRL (+)** | 9.21% | 33.54% | 54.87% | 78.53% | 82.90% | 88.31% |

**Hematological Effects of EMF in Malaria-Infected Mice**

Table 3 presents the effect of Plasmodium berghei infection and EMF treatment on hematological parameters in mice. Infection caused marked disturbances in RBC, Hb, and lymphocyte levels compared to normal controls. EMF exposure produced varying improvements across parameters. Notably, 10 mT significantly increased hemoglobin, while 20 mT enhanced lymphocyte counts. RBC levels improved moderately with increasing field strength but did not return to normal values. WBC and platelet counts fluctuated without a clear dose-response. Overall, EMF treatment showed partial hematological recovery, with 10 mT and 20 mT demonstrating the most beneficial effects.

**Table 3.Effect of treatments on selected hematological parameters in mice infected with Plasmodium berghei**

| **Group** | **RBC (10¹²/L)** | **WBC (10⁹/L)** | **Hb (g/L)** | **Platelet (10⁹/L)** | **Lymphocyte (10⁹/L)** |
| --- | --- | --- | --- | --- | --- |
| NEG | 0.898 ± 0.408a | 12.71 ± 1.239a | 137.9 ± 31.37a | 473.7 ± 93.27a | 0.888 ± 0.334a |
| POS | 6.438 ± 0.449b | 8.488 ± 0.844a | 90.5 ± 10.24a | 1083 ± 162.6a | 5.318 ± 0.871b |
| 10mT | 3.338 ± 0.430c | 14.32 ± 2.741a | 183.5 ± 15.39b | 999.5 ± 110a | 6.035 ± 1.79a |
| 15mT | 3.975 ± 0.321c | 7.75 ± 0.806b | 138.2 ± 10.36a | 612.9 ± 294.6a | 8.56 ± 2.255a |
| 20mT | 4.678 ± 0.342c | 8.455 ± 1.458a | 162.2 ± 27.79a | 419.2 ± 201.1a | 9.938 ± 3.307c |
| 30mT | 5.363 ± 0.710c | 7.76 ± 0.812a | 92.55 ± 14.19a | 650.4 ± 418.4a | 7.043 ± 0.888a |
| Normal | 7.61 ± 0d | 6.73 ± 0a | 118 ± 0.913a | 1224 ± 5.319a | 6.045 ± 0.0065a |

All the values are reported as Mean±SEM

\*\*\*Value carrying different notations across a row are statistically different at p<0.05

## Discussion

The present study demonstrated that exposure to electromagnetic fields (EMFs) reduced parasitemia in Plasmodium berghei–infected mice in a time and intensity-dependent manner, with the strongest effects observed at 20 mT and 30 mT by Day 5. These findings are consistent with Ekun *et al.* (2025), who reported that EMF exposure inhibited malaria parasite proliferation in a murine model. While artemisinin-based combination therapy (ACT) achieved superior parasite clearance, the measurable reduction in parasitemia following EMF exposure suggests that EMFs possess antiplasmodial potential. Supporting these observations, Alade (2023) reported suppression of parasitemia in P. berghei-infected mice exposed to alternating EMFs, and Coronado *et al.* (2023) demonstrated that electromagnetic microwave exposure induced non-thermal programmed cell death in P. falciparum, providing mechanistic evidence for parasite susceptibility to electromagnetic energy. Beyond direct parasite inhibition, EMFs may also modulate host physiology, as Ekun *et al*. (2025) documented improvements in lipid and renal profiles in malaria-infected mice following EMF exposure.

Despite these encouraging outcomes, EMF therapy was less effective than ACT, suggesting its role may be best suited as a complementary rather than a stand-alone intervention, particularly in regions experiencing rising ACT resistance (Angupale *et al*., 2023; Iwanaga *et al*., 2022). Integrating EMFs with existing antimalarial therapies could enhance treatment efficacy, reduce drug dosage requirements, and potentially delay the onset of resistance. However, several limitations should be acknowledged, including the use of P. berghei as a rodent model, which limits direct extrapolation to human malaria parasites, and the unclear mechanisms underlying EMF-mediated parasite suppression. Furthermore, the long-term safety of repeated EMF exposure has yet to be fully evaluated, warranting additional studies in human malaria models to optimize safe and effective EMF application.

The hematological assessments further revealed significant alterations in red blood cell (RBC) count, white blood cell (WBC) count, hemoglobin (Hb) levels, platelet count, and lymphocyte count across treatment groups. The positive control group (POS) exhibited a substantial increase in RBC count (6.438 ± 0.449 ×10¹²/L), Hb concentration (90.5 ± 10.24 g/L), and platelet count (1083 ± 162.6 ×10⁹/L) compared to the negative control (NEG), suggesting a compensatory response to parasitic infection. Treatments with 10 mT and 15 mT EMFs also improved these parameters, indicating their potential efficacy in ameliorating malaria-induced hematological disturbances. Conversely, the POS group showed reduced WBC (8.488 ± 0.844 ×10⁹/L) and lymphocyte (5.318 ± 0.871 ×10⁹/L) counts relative to NEG, reflecting leukopenia associated with malaria infection. Similar decreases in WBC and lymphocyte counts were observed in the 10 mT and 15 mT groups, suggesting that EMFs may modulate the host immune response (Rosado *et al.*, 2018).

The 10 mT treatment group exhibited the most favorable hematological profile, with RBC, Hb, and platelet counts approaching those of the normal group. This aligns with findings by Nworgu and Mandah (2023), who reported restoration of hematological parameters in P. berghei-infected mice following herbal interventions. However, the 20 mT and 30 mT groups did not show significant improvements, indicating a potential dose-dependent effect. These hematological outcomes highlight the importance of early intervention in malaria management and suggest that EMFs, alongside conventional therapies, may provide supportive benefits for host systemic function.

Taken together, these results suggest that EMF exposure has dual benefits in P. berghei infection: direct suppression of parasite growth and modulation of host hematological and physiological parameters. While EMFs are unlikely to replace standard antimalarial drugs, they may serve as a complementary therapeutic strategy, particularly in the context of emerging drug resistance. Further research is needed to elucidate the mechanisms of EMF action, establish optimal exposure parameters, and evaluate long-term safety and efficacy in both animal models and human studies

Conclusion

This study demonstrates that electromagnetic field (EMF) exposure exerts antiplasmodial effects in Plasmodium berghei-infected mice in a time- and intensity-dependent manner, with the most pronounced reductions in parasitemia observed at 20 mT and 30 mT. EMF exposure also modulated key hematological parameters, improving red blood cell, hemoglobin, and platelet counts, while influencing white blood cell and lymphocyte profiles. These findings suggest that EMFs provide dual benefits by both suppressing parasite growth and supporting host physiological function.

Although EMF therapy was less effective than artemisinin-based combination therapy (ACT), it shows potential as a complementary intervention, particularly in the context of emerging ACT resistance. Further research is needed to elucidate the mechanisms underlying EMF-mediated parasite suppression, optimize exposure parameters, and evaluate long-term safety in both animal and human malaria models. Overall, EMFs may represent a promising adjunctive strategy for malaria management, enhancing treatment efficacy and supporting host health.

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