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Review Article

Nanoparticle-Based Therapeutic Strategies for the Treatment of Malaria: A Comprehensive Review

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ABSTRACT

Nanoparticles are emerging as promising tools in malaria treatment, offering enhanced drug delivery, targeted action, and reduced side effects. Their unique physicochemical properties enable them to overcome challenges such as drug resistance and poor bioavailability. They show key applications as targeted drug delivery, this can be functionalized to specifically target *P. falciparum*, the causative agent of malaria, improving the efficacy of antimalarial drugs. For instance, glucose-based ultra-small gold nanoparticles (Glc-NCs) have been shown to bind to cysteine-rich domains on the parasite's surface, enhancing the delivery of conjugated drugs like ciprofloxacin. Metallic Nanoparticles, Various metal oxide nanoparticles, such as zinc oxide (ZnO), titanium dioxide (TiO₂), and iron oxide (Fe₃O₄), exhibit antimalarial properties. ZnO nanoparticles, for example, have demonstrated activity against chloroquine-sensitive *P. falciparum* strains, with an IC₅₀ value comparable to that of chloroquine. Plant-Based Nanoparticles, this offers a sustainable and biocompatible approach to malaria treatment. These green nanoparticles have shown effectiveness against mosquito vectors and the malaria parasite, providing a dual strategy for disease management. Nanocarriers for Drug Release, liposomes, micelles, and nanosponges can encapsulate antimalarial drugs, improving their stability and controlled release. Challenges and Future Directions for this is the clinical application of nanoparticles in malaria treatment faces challenges including high production costs, scalability issues, and potential toxicity. Future research should focus on optimizing synthesis methods, assessing long-term safety, and developing cost-effective strategies to facilitate widespread use in endemic regions. In conclusion, nanoparticles hold significant promise in revolutionizing malaria treatment through targeted drug delivery, enhanced efficacy, and reduced side effects.

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INTRODUCTION

A serious danger to world health, malaria is a parasite infection spread by the Anopheles mosquito that can cause acute, life-threatening illness [1]. An estimated 1.5 to 2.7 million people die from malaria each year, and two billion people including those in 90 endemic countries and 125 million tourists—run the risk of getting the disease. Malaria pigment, an insoluble haemoglobin metabolite, is accumulated as a result [2]. *P. malariae*, *P. falciparum*, *P. vivax*, *P. ovale*, and *P. knowlesi* are these. The illness generally referred to as malaria is caused by all of the Plasmodium species listed. The sexual and asexual stages of Plasmodium's life cycle occur in both the vertebrate hosts and the vector mosquitoes. The sexual stage of the parasite's life cycle takes place in the vectors, mosquitoes [3]. Humans are malaria's intermediate host and go through the asexual phase of the life cycle. Only female Anopheles mosquitoes are capable of transmitting malaria to humans. *P. falciparum* is the most prevalent species in Africa, but *P. vivax* and *P. malariae* are the most prevalent in the Americas and Europe [4]. Most patients find that their symptoms go away quickly with prompt treatment, although serious side effects such cerebral malaria, severe malarial anaemia, coma, or even death can happen [5]. Species, geographic location, susceptibility, and patient demographics all influence the recommended antimalarial treatment and chemoprophylactic regimens. Microvascular blockage brought on by red blood cell-stage parasites in capillaries is the source of severe malaria complications [6]. Our knowledge of malaria pathogenesis in relation to parasite and vector biology, advancements in diagnostics and novel therapies (drugs and vaccines), chemoprotection, and chemoprevention are the main topics of this primer [7].

Etiology

There are four prevalent Plasmodium species that humans should be concerned about. Plasmodium knowlesi is the fifth species found in Southeast Asia, and while it usually causes simian malaria, it can also infrequently infect people and cause serious illness [8]. *P. falciparum* is responsible for the vast bulk of malarial morbidity worldwide, with *P. vivax* contributing to a smaller extent. Each species has a different incubation period, which affects how long it takes for symptoms to appear. For example, *P. falciparum* takes 8 to 11 days, *P. vivax* takes 8 to 17 days, *P. ovale* takes 10 to 17 days, *P. malariae* takes 18 to 40 days (though maybe up to several years), and *P. knowlesi* takes 9 to 12 days. Although it is less common now because of quick detection and treatment, the classic "malarial paroxysm" of rigours is caused by the periodicity of the Plasmodium lifecycle. This is followed by several hours of fever, diaphoresis, and a drop to normal body temperature (a 48-hour cycle is established by a *P. vivax* infection) [9].

• Stages of Infection

Infection: -As the female Anopheles inserts her proboscis into human skin and injects up to 100 sporozoites (sporo-meaning "spores," -zoite meaning "animal") per bite with her saliva, infection takes place during the mosquito's blood meal. Each sporozoite glides at a speed of up to 2 micrometres per second. Successful sporozoites wait one to three hours in the dermis before entering the bloodstream and quickly travelling to the liver, where they must penetrate the sinusoidal barrier in order to reach and infiltrate their target hepatocytes [10]. "Liver Stage" of exoerythrocytic schizogony: - Erythrocytic schizogony is another asexual reproduction cycle that is started when merozoites join the erythrocytes. Each liver schizont ruptures



into 2,000 to 40,000 uninucleate merozoites after 5–21 days, depending on the species [11].

1. Erythrocytic Schizogony - “Blood Stage”:-

Erythrocytic schizogony is another asexual reproduction cycle that is started when merozoites join the erythrocytes. Within the erythrocytes, the parasites start feeding on haemoglobin. Initially resembling rings, they eventually develop into trophozoites (tropho-meaning "nourishment," -zoite meaning "animal"). The parasite eventually produces many merozoites after going through the trophozoite and schizont stages in succession. The waste product produced by biocrystals is hemozoin, a brown pigment. This allows the parasite's haemoglobin meal to safely eliminate the heme molecule that produces free radicals, which would otherwise be harmful to Plasmodium. Trophozoites continue the erythrocytic or "blood" stage by maturing once more into schizonts, which then burst into merozoites. Instead of becoming schizonts, some trophozoites develop into sexual stage gametocytes. Another Anopheles mosquito that is eating may then consume these male and female gametocytes [12].

2. Sporogony- “Mosquito Stage”:-

When male and female gametocytes are consumed by a mosquito, they reproduce sexually in the mosquito's stomach, creating motile ookinetes (oo- meaning "egg," -kinete meaning "relating to motion") that infiltrate the mosquito's midgut wall and develop into oocysts. After that, the oocysts burst, producing sporozoites that infiltrate the mosquito's salivary glands in search of a fresh human host [13].

Pathogenesis

Plasmodium falciparum is the primary cause of severe malaria due to its capacity to cause end-organ dysfunction by causing infected red blood cells (RBCs) to cytoadhere to the vascular endothelium. Patients with cerebral malaria gradually become unconscious and in a coma [14]. The direct causes are thought to be clusters of pRBCs, RBC-pRBC rosettes, and other fibrillar debris obstructing the microvasculature. The production of TNF- α and IFN- γ is stimulated by parasite factors including glycosylphosphatidylinositol (GPI)-anchored elements. This, in turn, increases the expression and relocalization of endothelial receptors such ICAM-1 and PECAM-1/CD31. As a result, mature stage parasites that express adhesins on the surface of pRBCs, like PfEMP1, can attach to the endothelium and interact with the increased receptors [15]. Malaria in the brain Cerebral malaria frequently manifests as multiple convulsions, unconsciousness, and a progressing coma. At first, the pathophysiology of cerebral malaria was thought to be caused by sequestered cells inside the microvasculature's obstructing blood flow [16]. Anaemia is present to some extent in all children and pregnant women with clinical malaria. The non-specificity of parasitological diagnosis in high transmission settings, the prevalence of self-treatment of feverish illness, the inability to characterise previous infections and thus recurrences in point prevalence surveys, and the frequent co-occurrence of hemoglobinopathies, nutritional deficiencies (especially iron deficiency), and intestinal helminth infections—all of which contribute differently to anaemia—confound meta-analyses of the relationship between malaria and anaemia [17].

Placental malaria

Primigravidae women are the main victims of placental malaria in regions where the disease is endemic. Both the mother and the foetus are impacted by the illness. Although some women experience severe malaria at the same time, abortion and low birth weight are rather common. The ability of *P. falciparum* parasites to sequester in significant quantities within the placenta offers a tenable explanation for the low birth weight and impaired foetal feeding of infants born to infected mothers. Nonetheless, the placenta is a favourable location for the parasite to conceal itself from host immune responses due to its low cell-mediated immune response [18].

The Life Cycle of Malaria Parasite

Anopheles mosquitoes and vertebrates are both involved in the intricate life cycle of the malaria parasite. The sporozoites in mosquito saliva enter the human host's epidermis and bloodstream during the initial stage of infection, after which they infiltrate hepatocytes to replicate asexually [19]. Thousands of merozoites are released during this phase, also known as the hepatic or pre-erythrocytic phase, when infected hepatocytes burst. An infected mosquito injects sporozoites into the skin as it feeds on the blood of a vertebrate. By entering the bloodstream, the motile sporozoite makes its way to the liver. After arriving in the liver sinusoids, sporozoites penetrate the sinusoidal barrier and enter the hepatocytes, where they differentiate in a first cycle of asexual reproduction and form a parasitophorous vacuole [20]. Depending on the species, a multinucleated exo-erythrocytic schizont (or meront) with millions of daughters merozoites forms over the period of two to three days. Relapses may result from these hypnozoites, which allow the parasite to survive for a long time [21]. Merozoites are grouped in membrane-bound vesicles known as merozoites upon leaving the hepatocyte, and they

are subsequently sent back into the bloodstream through the liver sinusoids. After merozoites infiltrate red blood cells (RBCs), a second asexual schizogony occurs. Over the course of 24–72 hours, this asexual replication cycle can produce up to 32 merozoites (these parameters vary between species). When some trophozoites develop into male and female sexual progeny, or gametocytes, the sexual reproduction cycle of malaria begins. These gametocytes mediate the malaria parasite's transfer from the mammalian host to the mosquito [22]. The matured gametocytes will be transported to the mosquito's midgut during an anopheles bite. Gametocytes are transformed into viable gametes inside the midgut, and zygotes are then transformed into invasive, motile ookinetes [23].

Effect Of Malaria on Various Systems.

- **CVS:** In areas where malaria is endemic, the disease remains a major health concern. Given the low reporting incidence, cardiac involvement appears to be uncommon; yet, research has indicated that late identification may be common and potentially fatal. To enhance prognosis, CV impairment must be detected early [24].
- **CNS:** Malaria is still regarded as a very deadly illness that causes survivors to experience aftereffects. Heme and hemozoin, which are byproducts of the parasite's metabolism, are known to activate endothelial cells in the pathophysiology of malaria, resulting in BBB failure [25].
- **Kidney:** One of the more common side effects of severe malaria is acute kidney injury (AKI). There have been conflicting reports regarding the prevalence of malaria-induced AKI in children; some estimates put it as high as 46%. Haemodynamic abnormalities, immune-mediated glomerular damage, and metabolic disruptions are

believed to be part of the pathophysiology of malarial AKI [26].

- **Skeletal system:** Depending on the severity of the disease, the skeletal muscle's microvascular function and oxygen consumption are greatly compromised, and in patients with severe malaria, oxygen consumption decreases similarly to that of patients with sepsis [27].

Symptoms

The symptoms of malaria usually include fever, chills, and headaches. As it worsens, it may result in serious or fatal complications. People's reactions to it can differ greatly. While some people only have minor symptoms or none at all, others may develop serious illnesses. Malaria symptoms are classified as either severe or uncomplicated.

Uncomplicated malaria

When a person has symptoms of malaria but no indication of a serious infection or organ malfunction, it is referred to as uncomplicated malaria. However, it can develop into severe malaria if treatment is not received or if the patient has a weakened immune system. Usually lasting 6 to 10 hours, the symptoms can mimic those of the flu and return every other day. On the other hand, some parasite strains may induce mixed symptoms or have a longer cycle [28]. The general symptoms include chills and fever, perspiration, headaches, nausea, vomiting, body aches, weakness, an enlarged liver, and moderate jaundice, which can give the eyes a yellow appearance.

Severe malaria

Malaria can occasionally worsen and impact important body organs. More than 5% of the red blood cells are now afflicted with malaria

parasites. Among the symptoms are severe anaemia. Blood in the urine, altered blood coagulation, altered consciousness, altered behaviour, elevated blood and bodily fluid acidity, seizures, and coma. Severe malaria is a medical emergency that can be fatal [29].

Diagnosis

Health care professionals might not be familiar with malaria in areas where it is no longer endemic, like the United States. When treating a patient with malaria, clinicians may overlook the disease as one of the possible diagnoses and fail to request the necessary diagnostic tests. When looking at blood smears under a microscope, laboratory personnel who are unfamiliar with malaria may miss parasites. Malaria transmission can be so severe in some malaria-endemic areas that a significant percentage of the population is infected but not unwell due to the parasites. These carriers are immune to malarial sickness but not to malarial infection since they have developed a slight immunity. In that case, the presence of malaria parasites in a sick individual does not always indicate that the parasites are the cause of the sickness [30].

Clinical diagnosis

The patient's symptoms and physical examination results serve as the basis for the clinical diagnosis. Clinical symptoms such as confusion, coma, neurologic focal signs, severe anaemia, and respiratory difficulties are more noticeable in cases of severe malaria, which is mainly caused by *Plasmodium falciparum*. These symptoms may raise the suspicion level for malaria. A laboratory test for malaria should always be performed to validate clinical findings. [31]

Microscopic diagnosis



A drop of the patient's blood spread out as a "blood smear" on a microscope slide can be examined under a microscope to identify malaria parasites. To give the parasites a unique look, the specimen is stained before examination, usually using the Giemsa stain. This method is still the most reliable way to confirm malaria in a lab. However, the quality of the microscope, the reagents, and the laboratory's experience all play a role [32].

Antigen detection

To identify antigens from malaria parasites, a variety of test kits are available. These immunologic ("immunochromatographic") tests typically employ a dipstick or cassette format and yield results in 2–15 minutes. These "Rapid Diagnostic Tests" (RDTs) are a helpful substitute for microscopy when accurate microscopic diagnosis is not available [33].

Molecular diagnosis

The polymerase chain reaction (PCR) is used to identify parasite nucleic acids. Despite having a marginally higher sensitivity than smear microscopy, this method is not very useful for diagnosing critically ill patients in a typical medical context. PCR data are frequently not accessible fast enough to be useful in making a malaria infection diagnosis. Once the diagnosis has been made using either smear microscopy or RDT, PCR is most helpful in verifying the species of malarial parasite [33].

Imaging studies

If there are respiratory problems, chest radiography could be useful. A computed tomography (CT) scan of the head may be performed if CNS symptoms are present in order to assess for signs of cerebral oedema or haemorrhage [34].

Treatment

Both preventive and therapeutic measures are used in the management of malaria. The first fundamental tenets of malaria therapy are early diagnosis and sensible, efficient treatment, as untreated uncomplicated malaria can develop into severe malaria. WHO advises using combination therapy for all malaria episodes using at least two efficacious antimalarial drugs with distinct mechanisms of action in order to stop or slow the spread of antimalarial drug resistance [35].

• Pharmacological Treatment of Malaria

According to their chemical structures and/or modes of action, antimalarial drugs can be divided into three categories: quinoline derivatives, antifolates, and artemisinin derivatives. Quinolone derivatives' antimalarial mechanism is thought to be the consequence of two steps: first, they are thought to slow the deposition of heme onto the crystal surface by enclosing the developing hemozoin crystals; second, they are thought to complex with free heme in the digestive vacuole lumen. Both procedures ultimately result in the parasite's death by stopping its heme crystallisation once it has been liberated from the haemoglobin [36]. Depending on how they work, antifolate antimalarial drugs can be divided into two classes: class I and class II. By blocking the enzyme dihydropteroate synthase (DHPS), class I antifolate drugs prevent the formation of dihydrofolic acid and, consequently, nucleic acid. Class II antifolate medicines prevent dihydrofolate from being reduced to tetrahydrofolate by blocking the parasite's dihydrofolate reductase (DHFR) enzyme. The synthesis of amino acids and nucleic acids depends on tetrahydrofolate. Class II drugs target the parasite's asexual state and have schizonticide activity. Class I antifolate agents include sulfoxide, whereas Class II antifolate agents include proguanil and pyrimethamine [37].



Natural sources include artemisinin and its derivatives, such as dihydro-artemisinin, artesunate, and arteether. The original proposed mechanism of action for artemisinin and its derivatives was the production of free radicals. Because the malaria parasite causes the haemoglobin in the host cell to be proteolyzed, it is known to be high in heme.

- **Malaria Vaccine**

Resistance of the parasite to antimalarial agents and toxicity associated with chemoprophylaxis arose the need for the development of an effective vaccine against malaria. As of right now, one candidate has made it to a sizable Phase III trial with the recent focus on vaccine design [38]. In general, malaria vaccines can be grouped as pre-erythrocytic, erythrocytic, and transmission-blocking vaccines based on their target on the malaria parasite lifecycle [39].

Classification Of Antimalarial Drugs

- **Aryl aminoalcohol compounds:** quinine, quinidine, chloroquine, amodiaquine, mefloquine, halofantrine, lumefantrine, piperazine, tafenoquine.
- **Antifolate compounds (“antifols”):** pyrimethamine, proguanil, chlorproguanil, trimethoprim.
- **Artemisinin compounds:** artemisinin, dihydroartemisinin, artemether, artesunate [40].

Most of the antimalarial drugs target the asexual erythrocytic stages of the parasite (blood schizonticidal drugs). There are two kinds: slow-acting (pyrimethamine, sulphonamides, and sulphone) and fast-acting (chloroquine, quinine, and mefloquine). Tissue schizonticidal drugs target the hypnozoites (dormant stage of the

parasite) in the liver whereas gametocytocidal drugs destroy sexual erythrocytic forms of the parasite in the bloodstream preventing transmission of malaria to the mosquito. Sporontocides prevent or inhibit the formation of malarial oocysts and sporozoites in the infected mosquito [40].

Effect Of Nanoparticles for the Treatment of Malaria Disease

- **Strategic role of nanotechnology to combat malaria disease**

Despite being widely used to treat malaria caused by Plasmodium strains, artemisinin and chloroquine's toxicity is still a concern. Moreover, resistance is associated with genetic changes that protect the parasites against anti-malaria drugs [41]. It is crucial to investigate novel treatments and alter the therapeutic regimens of already available medications, such as combining safe preparation with superior pharmacological selectivity and durable release, due to the evident negative and toxic effects of these medications [42].

In this regard, nanotechnology shows itself to be a potent instrument that may satisfy the aforementioned requirements and help create less harmful and more potent anti-malaria medication treatments. Among metallic nanoparticles, silver (AgNPs) and gold (AuNPs) are currently the most commonly used nanostructures, though other metal nanoparticles like zinc oxide (ZnO), selenium (Se), palladium (Pd), copper (Cu), titanium (Ti), nickel (Ni), and cadmium (Cd) were also utilized for this purpose [43].

- **Silver nanoparticles as a useful tool against Malaria disease and Malaria vectors**

Because of their desired qualities, like selectivity and specificity, nanoscale materials have drawn a

lot of attention from researchers in the fields of biology and pharmacology [44]. Due to their exceptional and well-documented antibacterial properties, silver nanoparticles (AgNPs) stand out among the metal-containing compounds, raising interest in preventing malaria infections [45]. AgNPs have frequently been created using chemical techniques. It is possible to alter the capping and reducing agents to obtain the desired shape, size, and rate of dispersion of AgNPs [46]. Numerous reaction factors, such as pH, temperature, precursor type, concentration, and stabilizing and reducing agents, regulate the nucleation and development of AgNPs [47].

Hydrazine, ascorbate, citrate, dextrose, glucose, hydrazine hydrate, N-dimethylformamide, ethylene glycol, hydrogen, and sodium borohydride can all be used to chemically decrease the metal salts [48]. In aqueous solution, the silver ion (Ag^+) undergoes nucleation and growth after acquiring an electron from a reductant to change from a positive valence to a zero-valent state (Ag^0). Colloidal AgNPs are produced as a result of coarse agglomeration into oligomeric clusters. The size and shape distribution of AgNPs can be better controlled by using a weak reductant, which has a slower rate of reduction [49]. However, compared to the biological technique, which exhibits great solubility, yield, and stability, the chemical synthesis of AgNPs is risky and time-consuming [50]. It is believed that the silver ions produced by AgNPs have a significant interaction with the phosphate and thiol groups present in bacterial DNA, enzymes, and proteins [51]. Govindarajan et al. (2016) used an aqueous leaf extract of *Zornia diphylla* as a capping and reducing agent Ag^+ ions in a single-step production process to create AgNPs. The larvae of the dengue vector *A. albopictus*, the malaria vector *A. subpictus*, and the Japanese encephalitis vector *Culex tritaeniorhynchus* were used to evaluate the

bioactivity of *Z. diphylla* leaf extract and the biofabricated AgNPs. The extract and its generated AgNPs shown dose-dependent larvicidal activity against all identified mosquito species, according to the results. However, compared to the leaf aqueous extract, biofabricated AgNPs showed more harmful effects against *A. albopictus* (LC50 value 13.42 $\mu\text{g}/\text{mL}$), *A. subpictus* (LC50 value 12.53 $\mu\text{g}/\text{mL}$), and *C. tritaeniorhynchus* (LC50 value 14.61 $\mu\text{g}/\text{mL}$). *Anisops bouvieri*, *Chironomus circumdatus*, and *Gambusia affinis* were non-target organisms that were not negatively affected by the manufactured nanoparticles; their corresponding LC50 values ranged from 613.11 to 6903.93 $\mu\text{g}/\text{mL}$ in comparison to the targeted mosquitoes.

Nanomaterials for diagnosis and biosensing of Malaria disease (nanosensors)

Using advanced methods to diagnose malaria may require costly and time-consuming procedures. Researchers have recently placed a lot of emphasis on creating clinical diagnosis methods that are sensitive, selective, reliable, accurate, quick, and inexpensive [52]. The majority of traditional diagnostic techniques are expensive and ineffective in identifying and stopping the spread of malaria because of the low resource conditions in areas where outbreaks occur [53]. But because to new transducer elements and recognition materials, biosensors have expanded the potential for low-cost malaria detection. This has enabled the development of low-cost biosensor platforms with improved functionality [54]. Ten years ago, there were issues with the quality of the box design, construction, and labeling of malaria quick diagnostic test kits [55]. Examining the possibility of a low-cost nanobiosensor for reliable, quick, easy-to-use, and accurate alternatives to malaria diagnosis is crucial these days. In order to build novel biological technologies (such as

nanobiosensors and imaging probes), devices at the nanoscale can interact directly with the elements that are essential to biological activities [56]. The development of molecular diagnostic systems for infectious diseases based on nanotechnology is currently the main focus of biomedical research [57]. Lab-on-a-chip technology could be used to diagnose malaria quickly, track the disease's progression and medication effectiveness, and facilitate high-throughput screening [58].

Nanoparticle-based electrochemical sensors are advantageous because of their low cost, quick reaction time, and high sensitivity and selectivity [59]. Increased sensitivity has been demonstrated by nanocarriers in studies to diagnose malaria [60]. To diagnose malaria parasites, an electrochemical sensor that uses metal oxide nanoparticles as electroactive species has been developed, and b-hematin has been developed as the identification medium [61]. Among the sensors developed for the detection of b-hematin in blood serum and urine, Au-CuO (C) exhibited the best sensing capabilities [62]. Diagnosing parasitic infections requires identifying and quantifying target metabolites, sometimes referred to as biomarkers, in blood, urine, and saliva [63]. Hemozoin, a paramagnetic nanoparticle byproduct of the malaria parasite, malaria pigment, or malaria biomarker are examples of malaria biomarkers [64] and whose existence in the blood indicates an infection with malaria. In addition to being a potential biomarker for malaria disease diagnosis, beta-hematin has been investigated for the manufacture of antimalarial medications [65]. It has been investigated how Cu-doped ZnO electrospun nanofibers can be used to detect malaria parasites. The electrode's impedance response was enhanced by the nanostructure, and the Cudoped ZnO nanofiber modified electrode's impedimetric detection response demonstrated

exceptional sensitivity ($28.5 \text{ K}\Omega/(\text{g/mL})/\text{cm}^2$ with a lower detection limit of 6.8 ag/mL [66] It has been shown that nanosensors can detect malaria, but more study is required to increase their usefulness [67]. Comprehending Plasmodium pathophysiology and the idea of nano-delivery systems helps to overcome the pharmacokinetic mismatch associated with therapeutic compounds and aids in accurate and timely illness detection [68].

CONCLUSION

Current research on malaria sickness continues to face numerous obstacles. Scientists were attempting to describe a practical method of eliminating malaria at the beginning of the twentieth century. However, because of drug resistance as well as social and environmental issues, no good and optimistic future has been revealed. Advances in nanotechnology have made it possible to treat malaria in a way that is both safe and environmentally friendly in the previous 20 years. Researchers looking into biological and pharmaceutical applications have been very interested in nanoscale materials because of their desired properties, such as specificity and selectivity. Because of their remarkable physicochemical characteristics, metal nanoparticle-based formulations have been shown to have a broad range of uses in the biomedical field. The environmentally friendly metal nanostructures showed encouraging antiplasmodial properties and were thought to be the best option for treating malaria. However, the field of nanotechnology used to treat malaria is still in its infancy and will need further research before it can be effectively pursued. The potential of biosensors to diagnose malaria has increased recently due to its potential as a cost-effective, sensitive, and dependable alternative to traditional detection methods.



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