Research Article

Modulation of Lipoprotein Cholesterol Levels in Plasmodium berghei Malarial Infection by Crude Aqueous Extract of Ganoderma lucidum

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In this study, attempt is made to establish changes in serum and liver lipoprotein cholesterols accompanying Plasmodium berghei malarial infection in mice treated with aqueous extract of Ganoderma lucidum at 100, 250, and 500 mg/kg body weight in comparison with 15 mg/kg chloroquine (CQ). Significant increases in all the lipoprotein fractions were observed in infected untreated mice compared with normal control mice. Treatment with 100 and 250 mg/kg G. lucidum extract produced significant reduction in serum total cholesterol (TC) and low-density cholesterol (LDL-C) contents compared with 500 mg/kg G. lucidum and CQ. Treatment with CQ, however, produced significant reduction in hepatic TC and LDL-C compared with the extract. A dose-dependent significant increase in serum high-density lipoprotein cholesterol (HDL-C) was observed in the G. lucidum treated mice compared with normal control but significantly lower compared with CQ-treated mice. Liver HDL-C level was significantly higher in CQ-treated mice compared with normal control and significantly lower compared with G. lucidum-treated and infected untreated mice. A dose-dependent effect of the extract was observed in both serum and liver very-low density lipoprotein cholesterol (VLDL-C). The implication of these results is discussed with respect to the parasite survival and proliferation in the serum and liver.

1. Introduction

The malarial parasite has been observed to have a tremendous requirement for lipids during the replicative stages that take place in the mammalian host. Biochemical studies on blood-stage Plasmodium malarial parasites have demonstrated the parasite’s proficiency at scavenging and modifying lipids obtained from the host [1]. Studies have also shown that the parasites could obtain free fatty acids (FFAs) directly from the serum or from sources such as high-density lipoprotein (HDL) [2–4]. Within the parasite, scavenged phospholipids can be incorporated without modification [3, 5]. In addition, Plasmodium parasites have the capacity to modify fatty acids as needed by elongation or desaturation and incorporate them into phospholipids, diacylglycerols (DAGs), and triacylglycerols (TAGs) [6, 7].

Indeed, such biochemical revelations have not been possible for liver-stage parasites because of the difficulty in isolating the parasite from the host hepatocytes and the low rate of infection during this stage. However, early studies of malaria in genetically obese Zucker rats (fa/fa) gave indication that host cell lipids are important for Plasmodium liver-stage development [8]. These studies demonstrated that obese Zucker rats, which have hepatocytes with increased fatty acid synthesis, triglyceridemia and triglyceride content, supported growth of four times the number of liver-stage schizonts than their lean counterparts. Additionally, 45 hours
after infection, schizonts in the obese rats were observed to be
twice the size of those in control rats.

While most scavenged and synthesized lipids are likely
incorporated into the membranes of the rapidly growing
parasite, additional roles for fatty acids remain to be eluci-
dated. For example, studies have yet to identify the source of
fatty acids that are incorporated into GPI, which anchors
numerous proteins, including MSP-1, to the merozoite
plasma membrane. The low expression of MSP-1 in fab
knockout parasites suggests that the FAS-II pathway may
act together with elongases and desaturases to generate the
lipid anchor for some surface proteins, including merozoite
surface protein-1 (MSP-1) [9]. Alternatively, the fatty acid
synthesis type II (FAS-II) pathway activity may provide a
signal for progression to the merozoite formation phase of
intrahepatic development. The specific upregulation of the
FAS-II pathway during the liver stage may allow the parasite
to synthesize its own lipids to supplement those provided by
the host hepatocytes during a particularly explosive period of
growth in the Plasmodium life cycle.

Elucidating stage-specific requirements for import, syn-
thesis, and utilization of fatty acids and lipids in malar-
ial parasite infection is both of considerable promise for
developing novel antimalarial intervention strategies and of
fundamental interest in understanding how these parasites
are so successful in establishing infection in the human host.
Thus, monitoring of serum and liver lipid concentrations
during malarial infection could be of immense contribution
in establishing the parasite source of lipids for its propaga-
tion.

Mushrooms have been known to have medicinal proper-
ties since 1200AD in Chinese folk medicine [10]. In recent
years there has been renewed interest in cholesterol lowering
properties of mushrooms, including Ganoderma lucidum
(Reishi mushroom) [11, 12], Pleurotus ostreatus (Oyster
mushroom) [13], and Agaricus bisporus (champignon) [14].
In this study, our focus is G. lucidum, an important medicinal
fungus belonging to the Ganodermataceae family that has
been studied for its many interesting health promoting prop-
erties, including antitumour, anti-inflammatory, antiplatelet
aggregation, antidiabetic, and hypocholesterolemic proper-
ties [15–19]. The cholesterol lowering property of G. lucidum
is explored in this study for its possible effects in preventing
the proliferation of malarial parasites in mice.

2. Materials and Methods

2.1. Fungal Materials. Fruiting bodies of G. lucidum were
obtained locally from open forest at Ipele in Ose Local Gov-
ernment Area of Ondo State, Nigeria. The fungal material
was identified by Dr. S. Fakoya of the Department of Biolog-
ical Sciences, Joseph Ayo Babalola University, Ikeji-Arakeji,
Osun State, Nigeria, where voucher specimen number 1103
has been deposited.

2.2. Extract Preparation. Fruiting bodies of G. lucidum were
sorted, washed to remove debris and dust particles, and then
dried under shade for two weeks. The dried materials were
cut into pieces and ground into powder using mechanical
grinder. The powdered sample was kept in an airtight container
and stored at 4°C until required for further analysis. One
hundred gram (100 g) of the powdered fungal material was
soaked in 1000 mL distilled water and placed in an orbital
shaker at room temperature for 48 hr. The aqueous extract
was filtered with a muslin cloth. The resulting filtrate was
evaporated to dryness at 37°C by the help of a Speed Vac
(Model 7811001, Labconco, USA). The recovered extract
was weighed and formulated in distilled water to give the
required dose.

2.3. Animals and Treatment. A total of forty-eight (48)
males Swiss albino mice (15–22 g body weight) obtained
from the animal laboratory of the Department of Medical
Biochemistry, University of Ibadan, Nigeria were used for
the study. The animals were housed in stainless steel cages
with raised wired floor at 30°C under standard conditions of
humidity and 12 h light/dark cycle. They were fed standard
feed (Guinea Feeds Ltd) and water ad libitum. The animals
were kept for an initial period of two feed to acclimatize
with their new environment. Before the commencement of
the experiment animals were fasted overnight (but allowed
access to water ad libitum) and weighed. All experimental
protocols complied with NIH guidelines [20].

2.4. Malarial Parasite. Chloroquine sensitive Plasmodium
berghei berghei (NK-65) obtained from the Institute for
Advanced Medical Research and Training (IMRAT), Uni-
versity College Hospital, University of Ibadan, Nigeria, and
kept at the Department of Biochemistry, Joseph Ayo Babalola
University, Ikeji-Arakeji, was used for the study. The parasite
was subsequently maintained in our laboratory by serial
blood passage from mouse to mouse [21] every four days.

2.5. Inoculums. One milliliter parasitized erythrocytes were
obtained from a donor-infected mouse by cardiac puncture
in heparin and made up to 5 mL with normal saline. Mice
were inoculated intraperitoneally with 0.2 mL blood
suspension containing 10⁶–10⁷ parasitized erythrocytes on
day zero. Infected mice with parasitemia of 10–12% were
allocated to five groups. The fungal extract and the standard
drug (CQ) administration were carried out for four days
postinfection.

2.6. Treatment Regimen. Forty-eight mice (consisting of 40
infected divided into five groups of eight animals each; a
sixth group of eight normal mice, as positive control) were
used for this study. The four day postinfection treatment
commenced at the establishment of parasitemia in the mice.
The treatment administered to each group is as follows:

(i) negative control—infected mice treated with 0.2 mL
normal saline;

(ii) extract test group I (AQ100)—infected mice treated
with 100 mg/kg G. lucidum aqueous extract;

(iii) extract test group II (AQ250)—infected mice treated
with 250 mg/kg G. lucidum aqueous extract;

(iv) extract test group III (AQ500)—infected mice treated
with 500 mg/kg G. lucidum aqueous extract;
(v) reference test group (CQ)—Infected mice treated with 15 mg/kg chloroquine phosphate;

(vi) positive control—normal mice treated with 0.2 mL distilled water.

Treatments were given once daily by gavage using intubator for four consecutive days according to the method of Builders et al. [22]. On the fifth day (postinfection) thick smears of blood films were obtained from the peripheral blood on the tail from each mouse and used in the determination of the suppressive effect of the extract on the parasitemia level. Thereafter, extract and drug treatment were stopped while mice in each group were placed under surveillance until signs of death were noticed in the infected untreated group (negative control) after which mice in each group were sacrificed.

2.7. Blood Collection and Serum Preparation. As soon as signs of death were noticed in the infected untreated mice group (negative control) mice in each group were weighed anesthetized (in chloroform saturated chamber) and sacrificed by jugular puncture. Blood was obtained through their jugular vein into plain sterile bottles and allowed to clot for 2 h and then centrifuged at 3,000 × g for ten minutes at room temperature to obtain the sera. The sera samples were collected by aspiration using a pasture pipette into sterile bijou bottles and stored frozen until required for analysis, which was done within 72 h.

2.8. Tissue Preparation. Upon sacrifice, liver and kidneys of each mouse were quickly excised, rinsed in normal saline, blotted dry on tissue paper, and weighed. Each tissue was placed in separate plastic vial containing ice-cold normal saline and stored at −8°C until required for further analysis.

2.9. Preparation of Tissue Homogenate. A weighed portion of liver and kidneys of each mouse was cut out, chopped into small pieces and homogenized using precooled pestle and mortar in a bowl of ice cubes. A 5% homogenate of each tissue was obtained in buffer solution (50 mM Tris-HCl) using normal saline solution, and stored at −8°C until further analysis was carried out.

2.10. Assays. Total cholesterol (TC), low-density lipoprotein (LDL) cholesterol, and high-density lipoprotein (HDL) cholesterol were determined using commercial kits (Randox Laboratory Ltd., UK) following the manufacturer’s instruction while very low-density lipoprotein (VLDL) cholesterol concentration was determined by difference.

2.11. Statistical Analysis. Results presented are means ± SEM of eight independent determinations. Results obtained from this study were statistically analyzed using one way analysis of variance (ANOVA) and Duncan’s Multiple Range Test (DMRT) using SPSS 17.0. Significant differences between the treatment means were determined at 95% confidence level.

3. Results

The effects of the extracts treatment compared with CQ and SP as reference drugs on percentage suppression and mean survival time are presented in Table 1. There was no significant difference in % suppression observed in mice treated with 100 mg/kg and those treated with 250 mg/kg aqueous extract and aqueous 200 and aqueous 500 groups, though a significant decrease was noticed in % suppression on comparing aqueous 100 and aqueous 500 treated groups.

From Table 2, serum cholesterol fractions (TC, LDL, HDL, and VLDL) were observed to be significantly elevated (P < 0.01) above normal control level in the infected control mice and infected mice treated with CQ (Table 1). However, significant decreases (P < 0.05) were observed in serum TC, LDL, HDL, and VLDL levels in infected mice treated with aqueous extract of *Ganoderma lucidum* (at 100, 250 and 500 mg/kg body weight) compared to infected untreated mice though these values were significantly higher compared to normal control level. Serum TC and LDL-C concentrations were not significantly (P > 0.05) changed in mice treated with 100 mg/kg and 250 mg/kg body weight of the extract. The extract at 100 mg/kg and 250 mg/kg body weight produced significantly lower reductions in serum TC and LDL-C compared to 500 mg/kg extract concentration.

As shown in Table 3, liver TC, LDL-C, HDL-C, and VLDL-C concentrations were significantly (P < 0.01) higher in infected control mice compared with normal control. The liver concentration of these cholesterol fractions were significantly (P < 0.05) reduced in *P. berghei* infection as a result of treatment with aqueous extract of *G. lucidum*. Liver TC, LDL, HDL and VLDL cholesterol were significantly (P < 0.05) higher in infected mice treated with 100, 250, and 500 mg/kg body weight *G. lucidum* aqueous extract compared to those administered CQ.

4. Discussion

Lipids have been observed to play important roles in pathological changes observed in disease conditions and are implicated in the production of immunity against diseases [23]. Serum lipids primarily bound to lipoproteins can be elevated by an increase in biosynthesis and/or by a decrease in their removal. Both of these processes appear to contribute to the hyperlipidemia that is often produced by some pathological changes. Although the source of increase in erythrocyte lipid component in malaria infection is not from lipid of the parasite there is no indication that the increase in the serum lipid is due to the lipid content of the parasite [24].

The results obtained from the suppressive, curative, and prophylactic tests indicate that the aqueous, chloroform and ethanol extracts of *G. lucidum* possessed significant antiplasmodial activity as evident from the chemosuppression obtained during the four day early infection test. However, on established infection the plant extracts also exhibited significant activity as evident from the curative effect of the extracts. Agents with suppressive activity against *Plasmodium berghei* were known for antimalarial activity...
It is noteworthy that the antiplasmodial activity of the extract at all doses during early and established infections was comparable to that of the standard drug, CQ. There was a dose-dependent chemosuppression of parasitemia seen with the extract. In infected untreated mice, the parasite count increased daily until the death of the animals which was also observed in other studies [25, 26]. It is evident based on the findings from this study that aqueous extract of the fruiting bodies of *G. lucidum* represent potential antiplasmodial agent. The activity (antiplasmodial) may be attributed to terpenes, sterols, and flavonoids present in the extract as confirmed in this study. Antiplasmodial screening of plant substances has implicated terpenes, flavonoids and alkaloids [27–29]. These compounds could be acting singly or in synergy with one another to exert the antiplasmodial activity observed in this study.

Results obtained in the present study show significant increases in serum and liver total, LDL, VLDL, and HDL cholesterol in mice infected with *Plasmodium berghei*. This observation is consistent with reports from earlier studies by Onyeneke et al. [30] and Onongbu and Onyeneke [31] which showed increased serum lipoprotein fractions in malarial patients compared with apparently healthy control subjects. The observed increases in hepatic lipoproteins content are consistent with the degree of parasitemia in mice infected with *Plasmodium berghei*. This is evident based on the findings from this study that aqueous extract of the fruiting bodies of *G. lucidum* represent potential antiplasmodial agent. The activity (antiplasmodial) may be attributed to terpenes, sterols, and flavonoids present in the extract as confirmed in this study. Antiplasmodial screening of plant substances has implicated terpenes, flavonoids and alkaloids [27–29]. These compounds could be acting singly or in synergy with one another to exert the antiplasmodial activity observed in this study.

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**Table 1:**Suppressive effect of aqueous extract of *Ganoderma lucidum* on parasitemia in mice infected with *Plasmodium berghei*.

| Treatment groups | Parasite count | % suppression |
|------------------|----------------|--------------|
| Controls         |                |              |
| Normal (P-CTR)   | —              | —            |
| Infected (N-CTR) | 31.10 ± 1.20   | —            |
| Aqueous extract  |                |              |
| AQ100            | 14.20 ± 0.60   | 54.20 ± 3.70a |
| AQ250            | 17.40 ± 1.20   | 43.82 ± 6.03b,c |
| AQ500            | 19.40 ± 0.90   | 37.42 ± 5.31bc |
| Reference drug   | CQ             |              |
|                  | 2.25 ± 0.85    | 93.65 ± 0.47c |

Results are means ± SEM of eight independent determinations. Values in the same row carrying different superscripts are significant (P < 0.05) from each other.

**Note.** AQ100: infected mice treated with 100 mg/kg aqueous extract; AQ250: infected mice treated with 250 mg/kg aqueous extract; AQ500: infected mice treated with 500 mg/kg aqueous extract; CQ: infected mice treated with chloroquine.

**Table 2:** Serum TC, LDL-, HDL-, and VLDL-cholesterol levels in mice *Plasmodium berghei* infected mice treated with aqueous extract of *Ganoderma lucidum*.

| Treatment groups | TC      | LDL    | HDL    | VLDL   |
|------------------|---------|--------|--------|--------|
| Controls         | 6.03a,b | 3.71a,b| 1.20a,c| 3.70a,b|
| Infected         | 14.62c  | 9.37b,c| 1.92b,c| 3.38b,c|
| AQ100            | 17.18b  | 9.92b,c| 3.13b,c| 2.22b,c|
| AQ250            | 15.09b  | 9.66b,c| 1.60b,c| 3.74b,c|
| AQ500            | 17.02b  | 11.08b,c| 2.26c | 3.95b,c|

Results are means ± SEM of eight independent determinations. Values in the same row carrying different superscripts are significant (P < 0.05) from each other.

**Note.** P-CTR: positive control mice; N-CTR: negative control mice; AQ100: infected group treated with 100 mg/kg *G. lucidum*; AQ250: infected group treated with 250 mg/kg *G. lucidum*; AQ500: infected mice treated with 500 mg/kg *G. lucidum*; CQ: infected mice treated with chloroquine.

**Table 3:** Liver TC, LDL-, HDL-, and VLDL-cholesterol levels in *Plasmodium berghei*-infected mice treated with aqueous extract of *Ganoderma lucidum*.

| Treatment groups | TC      | LDL    | HDL    | VLDL   |
|------------------|---------|--------|--------|--------|
| Controls         | 11.56d  | 7.10c  | 1.33e  | 2.68e  |
| Infected         | 15.46c  | 9.37b,c| 1.92b,c| 3.38b,c|
| AQ100            | 17.18b  | 9.92b,c| 3.13b,c| 2.22b,c|
| AQ250            | 15.09b  | 9.66b,c| 1.60b,c| 3.74b,c|
| AQ500            | 17.02b  | 11.08b,c| 2.26c | 3.95b,c|

Results are means ± SEM of eight independent determinations. Values in the same row carrying different superscripts are significant (P < 0.05) from each other.

**Note.** P-CTR: positive control mice; N-CTR: negative control mice; AQ100: infected group treated with 100 mg/kg *G. lucidum*; AQ250: infected group treated with 250 mg/kg *G. lucidum*; AQ500: infected mice treated with 500 mg/kg *G. lucidum*; CQ: infected mice treated with chloroquine.
this assertion as the level of parasitemia correlates with hepatic lipoprotein composition.

As observed from this study, administration of aqueous extract of *G. lucidum* downregulates serum and liver lipoprotein content. The observed effect of the extract was to be negatively correlated with parasitemia level. The hypocholesterolemic property of *G. lucidum* has been established in our earlier study [19].

Malaria disturbs liver function though there is no evidence of hepatic insufficiency. In malarial infection, the liver is commonly enlarged and congested with parasitized red cells in sinusoids and centrilobular veins and swollen parenchymatous and kuffer cells [32]. Lipid metabolism is therefore deranged and the resulting lipoprotein particles synthesized by the liver undergo drastic changes in composition. Maurois et al. [33] have demonstrated that increased levels of parasitemia reduces serum-deranged and the resulting lipoprotein particles synthesized by the liver undergo drastic changes in composition. Maurois et al. [33] have demonstrated that increased lipolysis induced by threshold of parasitemia promotes VLDL synthesis and their metabolism into LDL. Thus, with increase in parasitemia there was a progressive increase in LDL fraction and with the resulting incorporation of cholesterol particles, the overall LDL cholesterol was found to be increased. There is also the possibility of a reduction in LDL by the infective liver tissue thereby leading to an increase in these particles. It is also likely that the elevation in LDL cholesterol may be due to decrease uptake by the infected erythrocytes as a result of increased levels of parasitemia.

In conclusion, results obtained from this study show that aqueous extract of *G. lucidum* reduces serum and liver lipoprotein cholesterol with a corresponding decrease in parasitemia levels in both tissues. Therefore, it could thus be inferred that the antimalarial property of the extract could possibly be mediated by mechanisms involving reduction in liver lipids.

**Conflict of Interests**

The authors do not have a direct financial relationship with the commercial identity mentioned in this paper.

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