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Short Communication

The Potential Use of Methotrexate in the Treatment of Falciparum Malaria: In Vitro Assays against Sensitive and Multidrug-Resistant Falciparum Strains

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SUMMARY: The anti-malarial activity of the anti-cancer drug methotrexate against chloroquine-sensitive T9-96 and the multidrug-resistant K1 strains of *Plasmodium falciparum* was assessed in vitro. Mean IC_{50} values of 0.32 ± 0.05 nM and 48.02 ± 4.40 nM were obtained for T9-96 and K1, respectively, indicating methotrexate's high potency against both sensitive and resistant *P. falciparum* strains in vitro. Our results suggest that methotrexate is potentially effective against falciparum malaria in short-term, low-dose regimens, minimizing the risk of toxicity. This, along with the practical advantages of methotrexate, warrants the clinical investigation of methotrexate in human cases of falciparum malaria.

Malaria kills between 1 and 2 million people worldwide every year. The majority of malarial morbidity and mortality is caused by *Plasmodium falciparum*, with an estimated annual productivity loss of US$12 billion in Africa alone (1). Ineffective drugs continue to be used in many of the poorest regions despite very high levels of resistance and treatment failure.

The development of new, efficacious, cost-effective drugs remains crucial. Extensive searches for novel compounds have met with only limited success. Work by the Walter Reed Army Institute of Research showed that only 10 out of 350,000 compounds screened had anti-malarial potential (2).

Since *P. falciparum* undergoes rapid DNA replication in erythrocytes, we postulated that eukaryotic DNA synthesis and replication inhibitors, particularly anti-cancer drugs, could selectively target parasitized erythrocytes. Methotrexate is a powerful dihydrofolate reductase (DHFR) and thymidylate synthase (TS) inhibitor that has been used in several types of cancers for over 50 years. More recently, owing to its safety at low doses, methotrexate has been successfully used in the treatment of severe psoriasis, rheumatoid arthritis, and even as an abortifacient in combination with misoprostol (3).

Here we present data demonstrating the high in vitro efficacy of methotrexate against both chloroquine-sensitive (CQS) and multidrug-resistant (MDR) strains of *P. falciparum*.

The ability of methotrexate and chloroquine to inhibit the proliferation of CQS (T9-96) and MDR (K1) strains of *P. falciparum* was assessed in vitro using the standardized [^{3}H]hypoxanthine incorporation procedure as described by Warhurst et al. (4). Assays were conducted in triplicate and mean IC_{50} values are presented in Table 1.

Parasite susceptibility to chloroquine and methotrexate was examined in parallel. The IC_{50} values found for chloroquine are consistent with published values for these strains (4) and confirm that K1 is chloroquine-resistant and T9-96 chloroquine-sensitive. Our results demonstrate that methotrexate is 28 times more active against T9-96 and 5 times more active against K1 than chloroquine in vitro. Although the cut-off value in vitro for *P. falciparum*'s resistance to methotrexate is not yet established, both the strains examined are remarkably sensitive to methotrexate. It is interesting that the K1 strain, despite being resistant to other antifolates such as sulfadoxine-pyrimethamine, remains sensitive to methotrexate at concentrations much lower than those used clinically in many methotrexate regimens.

Table 1. IC_{50} of methotrexate against T9-96 and K1 *P. falciparum* strains

Strain	Methotrexate (nM) ± SD	Chloroquine (nM) ± SD
T9-96 (CQS)	0.32 ± 0.05	8.89 ± 1.00
K1 (MDR)	48.02 ± 4.40	240.70 ± 11.50

CQS, chloroquine sensitive; MDR, multidrug-resistant.

While the extrapolation of in vitro values to therapeutic plasma concentrations is complex, the IC_{50} values reported here approximate the unbound in vivo plasma concentrations required to exert similar effects. Conventional doses of 25-100 mg/m^2 (dose/body surface area) of methotrexate produce peak plasma concentrations of $1-10 \times 10^{-6}$ M (5), much higher than the concentrations our results suggest would be required to treat even resistant cases of falciparum malaria.

In other experimental studies, methotrexate has been used to induce in vitro resistance in strains of *P. falciparum* but has not been considered anti-malarial itself. Fidock and Wellems (6) thus showed 100% inhibition of parasite growth at methotrexate concentrations of 100 nM, and a 50-83% inhibition at methotrexate concentrations of 50 nM in 5 falciparum strains tested (3D7, HB3, FCB, Dd2, and V1/S). These results are similar to values presented in the present study for the MDR K1 strain. Our findings are also consistent with an earlier report examining the clinical efficacy of methotrexate against *Plasmodium vivax* infection, which showed that a 2.5-mg oral dose of methotrexate given daily for 3 days completely cleared parasitemia within 48 h, without causing any side effects (7). As is expected with *P. vivax* infections, a recrudescence (3 weeks after termination of methotrexate therapy) occurred unless primaquine was also administered for 14 days. This, together with our results, suggests that methotrexate may also be extremely effective in vivo against *P. falciparum*.

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From a broader perspective, methotrexate has many advantages. Its half-life (3 - 10 h) is shorter than those of currently used antifolates such as sulfadoxine-pyrimethamine (100 - 200 h) and chlorproguanil-dapsone (12 - 20 h). Thus, resistance to methotrexate may be slower and less likely to develop. Methotrexate is available in oral, intramuscular, and intravenous preparations, an advantage over many antimalarial drugs. As methotrexate is an off-patent drug, low-cost generic formulations are already available and widely used in malaria-endemic countries. Methotrexate's advantage over 'novel compounds' is its well-documented history of clinical use, reducing the expensive and time-consuming process of drug approval.

Miltefosine, an anti-proliferative drug first developed for treating metastatic carcinomas, has been successfully trialled and adapted for the treatment of human leishmanaisis (8,9). Our results demonstrate that methotrexate has a more potent parasiticidal effect on both susceptible and resistant *P. falciparum* strains in vitro than miltefosine does on *Leishmania donovani* promastigotes (IC_{50} 25 μM) (10).

The main concern in the use of methotrexate as an antimalarial would be its side-effects profile. It is promising that other potentially toxic anti-cancer agents, such as Miltefosine, are being successfully used as parasiticidal drugs. Side effects from long-term methotrexate use are numerous and well described (5). However, in a short-term regimen, even at the relatively high single dose of 50 mg/m^2, as when methotrexate is used as an abortifacient, side effects are rare and mild. In a study on 178 women seeking first-trimester pregnancy termination, the only reported side effects attributable to methotrexate were two cases of self-limiting (within 48 h), mild stomatitis (3). Concurrent administration of folic acid or leucovorin may play a role in reducing side effects in higher risk patients. Our results, along with those of Sheehy and Dempsey (7), suggest that only the lowest currently used clinical doses of methotrexate would be required for a period of 24 - 72 h to eliminate parasitemia. Therefore, the risk of serious side effects is minimal.

Possible indications for methotrexate include treatment of both uncomplicated and complicated resistant falciparum malaria as well as emergency standby treatment in areas of known resistant falciparum malaria. In addition, travelers to malaria-endemic regions already on low-dose, long-term methotrexate therapy (rheumatoid arthritis or psoriasis patients) may not require supplementary malaria prophylaxis, as their methotrexate intake may suffice as anti-malarial chemoprophylaxis.

Further research to expand the work of this brief report should include testing methotrexate against a wider variety of resistant strains such as the 108N, 51I, 164L, and 59R triple and quadruple DHFR mutants in both in vitro and murine models. We also advocate the evaluation of methotrexate in combination regimens to test for possible synergy with other antimalarials, thus improving efficacy and reducing the risk of resistance developing. Ultimately, it would be of considerable clinical interest to examine the efficacy of methotrexate in human cases of falciparum malaria.

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REFERENCES

1. World Health Organization (2002): Communicable Diseases 2002. Global Defense against the Infectious Disease Threat. p. 176. World Health Organization.
2. Schuster, B.G. and Milhous, W.K. (1993): Reduced resources applied to antimalarial drug development. Parasitol. Today, 9, 167-168.
3. Hausknecht, R.U. (1995): Methotrexate and misoprostol to terminate early pregnancy. N. Engl. J. Med., 333, 537-540.
4. Warhurst, D.C., Steele, J.C.P., Adagu, I.S., et al. (2003): Hydroxychloroquine is much less active that chloroquine against chloroquine-resistant *Plasmodium falciparum*, in agreement with its physiochemical properties. J. Antimicrob. Chemother., 52, 188-193.
5. Dollery, C. (1998): Therapeutic Drugs. 2nd ed. Churchill Livingstone.
6. Fidock, D.A. and Wellems, T.E. (1997): Transformation with human dihydrofolate reductase renders malaria parasites insensitive to WR99210 but does not affect the intrinsic activity of proguanil. Proc. Natl. Acad. Sci. USA, 94, 10931-10936.
7. Sheehy, T.W. and Dempsey, H. (1970): Methotrexate therapy for *Plasmodium vivax* malaria. JAMA, 214, 109-114.
8. Sundar, S., Jha, T.K., Thakur, C.P., et al. (2006): Oral miltefosine for the treatment of Indian visceral leishmaniasis. Trans. R. Soc. Trop. Med. Hyg., 100, Suppl. 1, S26-33.
9. Soto, J. and Berman, J. (2006): Treatment of new world cutaneous leishmaniasis with miltefosine. Trans. R. Soc. Trop. Med. Hyg., 100, Suppl. 1, S34-40.
10. Verma, N.K. and Dey, C.S. (2004): Possible mechanism of miltefosine-mediated death of *Leishmania donovani*. Antimicrob. Agents Chemother., 48, 3010-3015.