In Vitro Activities of the Biguanide PS-15 and Its Metabolite, WR99210, against Cycloguanil-Resistant Plasmodium falciparum Isolates from Thailand

M. D. EDSTEIN,*1 S. BAHR,1 B. KOTELKA,1 G. D. SHANKS,1,2 AND K. H. RIECKMANN1

1Australian Army Malaria Institute, Brisbane, Australia, and U.S. Army Medical Research Unit—Kenya, Nairobi, Kenya

Received 13 December 1996/Returned for modification 28 March 1997/Accepted 17 July 1997

The in vitro activities of the new biguanide PS-15 and its putative active metabolite, WR99210, were determined against seven different isolates or clones of Plasmodium falciparum. The mean 50% inhibitory concentrations of PS-15 and WR99210 were 1.015 and 0.06 ng/ml, respectively. WR99210 was up to 363 times more potent than cycloguanil, the active metabolite of proguanil, against cycloguanil-resistant parasites. The pronounced activity of WR99210 against multidrug-resistant P. falciparum indicates that further studies are required to determine the value of the prodrug, PS-15, as an antimalarial agent.

Plasmodium falciparum resistance to chloroquine and the antifolate drugs pyrimethamine-sulfadoxine (Fansidar) and proguanil is widespread in Southeast Asia (4, 9). In Thailand, resistance to mefloquine has developed rapidly over the last decade. New antimalarial drugs are urgently needed both for treatment and for prophylaxis. Recently, a biguanide related to proguanil, designated PS-15 [also known as WR250417; N-3-(2,4,5-trichlorophenoxypyroxy)-N′-(1-methyl-ethyl)-imidodercarbonimidic diamide], was developed as a potentially new antimalarial drug (2). PS-15 is metabolized to its putative active metabolite, WR99210 [also known as BRL6231; 4,6-dia-mino-1,2-dihydro-2,2-dimethyl-1-(2,4,5-trichlorophenoxypyroxy)-1,3,5-triazine], a structural analog of cycloguanil, the active metabolite of proguanil.

In 1973, Rieckmann (12) demonstrated the potent in vitro antimalarial activity of WR99210 against the highly chloroquine- and pyrimethamine-resistant strain Viet-Nam (Marks). The potency of WR99210, its lack of in vivo cross-resistance with chloroquine, pyrimethamine, and cycloguanil (6), and the relative difficulty of inducing resistance to the triazine in Plasmodium berghei-infected mice (7) led to clinical trials with WR99210. Oral administration of this compound was associated with gastrointestinal intolerance, possibly due to poor drug absorption (1). Nevertheless, because of the significant antimalarial activity of WR99210, it provided the impetus for the synthesis of the prodrug PS-15, which was designed to circumvent the toxic effects and limited bioavailability of WR99210 (2).

Studies with PS-15 with eight Saimiri monkeys indicated that the prodrug is readily metabolized to WR99210 (13). None of the monkeys developed diarrhea or other observable side effects. The similar concentrations of WR99210 in serum obtained by bioassay and high-performance liquid chromatographic analysis, coupled with the far greater susceptibility of parasites to WR99210 than to PS-15 in vitro, indicated that the metabolite was responsible for most of the antimalarial activity observed in vivo after administration of PS-15. These investigations also demonstrated that the antimalarial activity in serum was 20 to 86 times higher in monkeys receiving PS-15 than in those receiving WR99210, indicating that the prodrug was absorbed much better from the gastrointestinal tract than WR99210.

Although WR99210 has been shown to have potent in vitro activity against different strains of P. falciparum, previous studies were carried out with a limited number of isolates or clones (2, 12) or in culture medium not suitable for the assessment of antifolates (3). The aim of this study was to assess the intrinsic in vitro activities of PS-15 and WR99210 in folate and paraaminobenzoic acid (PABA)-free medium and to compare their activities with those of proguanil and cycloguanil against a larger number of Thai isolates or clones of P. falciparum with diverse levels of resistance to cycloguanil, pyrimethamine, and dapsone.

Six culture-adapted isolates or clones of P. falciparum from Thailand were used in the study, and their activities were compared to that of the drug-sensitive D6 clone (11). The chloroquine- and pyrimethamine-resistant K1 isolate (15) and the chloroquine- and mefloquine-resistant CH12 isolate (16) had been in culture for at least 10 years. The other four isolates or clones had been adapted to culture more recently. The GA3 clone was obtained from a malaria-infected Thai patient who had failed sulfadoxine, pyrimethamine, and mefloquine (Fansimef) treatment (7a). Isolates PD-234, PD-701, and PD-728 were obtained from malaria-infected Thai soldiers who were not protected by daily proguanil-dapsone prophylaxis (14).

PS-15 hydrochloride, WR99210 hydrochloride, dapsone, and pyrimethamine were kindly supplied by Jacobus Pharmaceutical Company (Princeton, N.J.). Proguanil hydrochloride and cycloguanil were supplied by ICI Pharmaceuticals (Macclesfield, United Kingdom). The susceptibility of each isolate or clone to the antifolates was determined by the radioisotopic method of Milhous et al. (10), with minor modifications. Parasites were synchronized repeatedly with 5% sorbitol to produce experimental cultures consisting predominantly of parasites 6 to 12 h into the cycle (8). The parasite suspension (225 m lwell) consisted of infected erythrocytes (1.5% hematocrit, 0.3 to 0.5% parasitemia) in folate and PABA-free RPMI 1640 medium (GIBCO, Grand Island, N.Y.) supplemented with 10% human serum, 25 mmol of HEPES (N-2-hydroxyethylpiperazine-N′-2-ethanesulfonic acid) buffer per liter, 25 mmol of NaHCO3 per liter, and gentamicin (25 mg per liter). The microculture plates were initially incubated for 48 h at...
37.5°C in a gas mixture of 5% O₂–5% CO₂–90% N₂ to allow for merozoite reinvasion of the erythrocytes. [³H]hypoxanthine (25 μl containing 0.5 μCi) was then added to each well. After a further 18 h of incubation, the cells were harvested to measure the level of incorporation of [³H]hypoxanthine as an index of parasite growth inhibition. The 50% inhibitory concentration (IC₅₀) was defined as the drug concentration that inhibits 50% of parasite growth inhibition by the parasites relative to the level of incorporation by parasites in drug-free control wells. The concentration-response data were analyzed by linear regression analysis. Each test was repeated at least three times.

The in vitro activities of PS-15, proguanil, cycloguanil, WR99210, pyrimethamine, and dapsone against isolates or clones of *P. falciparum* are given in Table 1. PS-15 showed poor antimalarial activity against the D6 and GA3 clones and the K1 and CH12 isolates and was not appreciably more active than proguanil. WR99210 was more than 1,000 times more active than PS-15 and was also 46 to 363 times more active than cycloguanil and pyrimethamine suggests that the mechanism of action of WR99210 differs from those of other antifolates. The lack of cross-resistance with cycloguanil and pyrimethamine suggests that the mechanism of action of WR99210 differs from those of other antifolates.

Table 1. In vitro antimalarial activities of PS-15, proguanil, cycloguanil, WR99210, pyrimethamine, and dapsone against *P. falciparum* isolates or clones cultured in folate and PABA-free RPMI 1640 medium

<table>
<thead>
<tr>
<th>Isolate or clone</th>
<th>IC₅₀ (nm) of the following antifolates*:</th>
<th>Ratio of IC₅₀ of CYC to IC₅₀ of WR99210</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PS-15</td>
<td>PROG</td>
</tr>
<tr>
<td>D6</td>
<td>70 ± 22</td>
<td>219 ± 39</td>
</tr>
<tr>
<td>K1</td>
<td>3,133 ± 1,465</td>
<td>3,786 ± 1,869</td>
</tr>
<tr>
<td>CH12</td>
<td>326 ± 82</td>
<td>608 ± 143</td>
</tr>
<tr>
<td>GA3</td>
<td>532 ± 122</td>
<td>844 ± 252</td>
</tr>
<tr>
<td>PD-234b</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>PD-701b</td>
<td>ND</td>
<td>ND</td>
</tr>
<tr>
<td>PD-728b</td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>

* PROG, proguanil; CYC, cycloguanil; PYR, pyrimethamine; DDS, dapsone; ND, not determined. Mean ± standard deviation IC₅₀ vs are based on the results of three or more experiments.

† Isolates of *P. falciparum* obtained from Thai soldiers while on proguanil-dapseone prophylaxis.

Our findings indicate that WR99210 is remarkably active against older and newer parasite isolates from Thailand, where current antimalarial agents are often no longer effective against falciparum malaria. The lack of cross-resistance with cycloguanil and pyrimethamine suggests that the mechanism of action of WR99210 differs from those of other antifolates. The data support those obtained with old clones or isolates from other countries (2, 12) where parasites generally remain more susceptible to antimalarial drugs than in Thailand.

No definitive toxicity studies have yet been carried out with PS-15. However, drug-induced toxicity was not seen in rodents (5) or *Saïmiri* monkeys given PS-15 (13). If humans are able to tolerate, absorb, and metabolize PS-15, the substantial in vitro activity of WR99210 against multidrug-resistant *P. falciparum* suggests that PS-15 is a prime candidate for further development as an antimalarial drug.

We thank Kyle Webster and Dennis Kyle for providing clones D6 and GA3 and the CH12 isolate. This paper is published with the permission of the Director General of Army Health Services.

REFERENCES


