Evidence Against Rapid Emergence of Praziquantel Resistance in *Schistosoma haematobium*, Kenya

Charles H. King,* Eric M. Muchiri,† and John H. Ouma†

*Case Western Reserve University School of Medicine and University Hospitals of Cleveland, Cleveland, Ohio, USA;

†Ministry of Health, Nairobi, Kenya


Appendix

The following system of differential equations was used to model the level of schistosome infection and prevalence of resistant worms in the treated study population, where

\[ \sigma \text{ is the number of sensitive schistosomes per host,} \]

\[ \rho \text{ is the number of resistant schistosomes per host, and} \]

\[ \sigma + \rho = M, \text{ the mean number of worms per host.} \]

If \( p \) = the proportion of treated infections each year, and

\[ h = \text{the efficacy of one course of treatment, then} \]
c = - \ln (1 - ph) is the relative increase in the per capita death rate of sensitive worms due to treatment. The basic death rate for sensitive and resistant parasites is an aggregate function of parasite and host death rates, represented in the equations as

\[
\gamma_r = \frac{1}{\text{resistant parasite lifespan}} + \frac{1}{\text{host lifespan}}
\]

and

\[
\gamma_s = \frac{1}{\text{sensitive parasite lifespan}} + \frac{1}{\text{host lifespan}}
\]

\(R_0\) represents the basic reproductive rate of the susceptible worm. If \(\varphi = \) the relative loss of reproductive fitness of the resistant phenotype (with value from 0 to 1), then

\[R_{0r} = R_0 (1 - \varphi)\] represents the spontaneous mutation rate of resistant worms. To reflect the impact of obligate sexual mating and unequal distribution of worms among hosts, \(F\) is a fecundity expression where

\[\psi = \text{the mating probability},\]

\[z = \text{the density-dependent effect on worm fecundity},\] and

\[k = \text{the aggregation constant of the negative binomial distribution of worms},\]

\[F (\sigma + \rho) = \Psi \left[ 1 + (\sigma + \rho) \frac{(1-z)}{k} \right]^{(\kappa+1)}\]

such that
Then, along the lines of equation 17.5 of Anderson and May (29) for repeated treatment, and assuming resistant parasites to be completely unaffected by treatment,

For the numerical analysis of these equations, we used the ODE solver of MathCAD (MathSoft, Inc., Cambridge MA) based on the

\[
\frac{d\sigma}{dt} = \gamma_s \cdot \sigma \cdot [R_0 \cdot F(\sigma + p) - 1 - \frac{c}{\gamma_s}]
\]

Runge-Kutta estimation with ≥1,000 steps for a model time span of 20 years.

Initial variable estimates were taken from our field data (treatment coverage among total infected population, \(p = 0.25 \text{ to } 0.75\); treatment efficacy, \(h = 0.65 \text{ to } 0.95\); aggregation constant, \(k = 0.067\); host lifespan = 50 years) or from previously published estimates for \(S. haematobium\) biology (\(R_0 = 2 \text{ to } 4\); parasite lifespan = 3 to 5 years; density effect on fecundity, \(z = 0.96 \text{ to } 0.99\)) (29).

Acknowledgments

We thank the staff of the Division of Vector Borne Diseases, Ministry of Health, Kenya, and the students, residents, and faculty of Case Western Reserve University who worked to make the Msambweni Study a success; the people of the Msambweni area of Kwale District for their enthusiastic participation; and Daren Austin for his description and helpful discussions of macroparasite resistance models.

This work was supported by grants from the Edna McConnell Clark Foundation, the WHO-TDR/UNDP Research Training Program, and the National Institutes of Health (AI 33061, AI45473).

Dr. King is an associate professor of Medicine and International Health at Case Western Reserve University in Cleveland, Ohio. His current research focuses on modeling of transmission of infectious diseases and prevention of disease due to helminthic infection.
References


Address for correspondence: Charles H. King, Division of Geographic Medicine, Room W137, Case Western Reserve University School of Medicine, 10900 Euclid Avenue, Cleveland, Ohio, USA 44106-4983; Fax: 216-368-4825; e-mail: chk@po.cwru.edu