Predicting the effective lifetime of nets against malaria by micro-simulation

Olivier Briët[1,2,✉], Diggory Hardy[1,2], Thomas Smith[1,2]
1 Swiss Tropical and Public Health Institute,
2 University of Basel,
✉ Olivier.Briet@unibas.ch


Olivier Briët

Swiss TPH
Swiss Tropical and Public Health Institute
Schweizerisches Tropen- und Public Health-Institut
Institut Tropical et de Santé Publique Suisse

Associated Institute of the University of Basel

Background

Long lasting insecticidal nets (LLINs) reduce malaria transmission by protecting individuals from infectious bites, and by reducing mosquito survival. In recent years, millions of LLINs have been distributed across sub-Saharan Africa (SSA). Over time, LLINs decay physically and chemically and are destroyed (attrition). Estimates of the effective lifetime (i.e. the length of the protective epidemiological effect) of a mass distribution facilitate the planning of the timing of subsequent campaigns. Subsequent campaigns are required, as otherwise incidence rises to above pre-intervention levels due to the loss of immunity.

Material & methods

For estimation, we used an ensemble of 14 stochastic individual-based model variants for malaria in humans, combined with a deterministic model for malaria in mosquitoes. This ensemble reflects a plausible model range to address uncertainty on the accuracy of results from any particular malaria model. Through sensitivity analysis around a central scenario, we identified those factors important in determining the effective LLIN lifetime.

Results

Figure 1 shows a single simulation with the central scenario and base model in detail, and Figure 2 shows ensemble results for scenarios at three pre-intervention transmission levels and two LLIN attrition half lives. Figure 3 shows the sensitivity of the effective lifetime (for definition see legend Figure 3) to variations in model parameters. Important parameters were pre-intervention transmission level, attrition rate, and insecticide decay rate. The lifetime was surprisingly insensitive to the hole formation rate. Immunity loss contributed little to shortening a single mass distribution's effective lifetime (not shown). The results indicate that the required LLIN distribution frequency varies widely across SSA, as it is extremely sensitive to the local entomological situation.

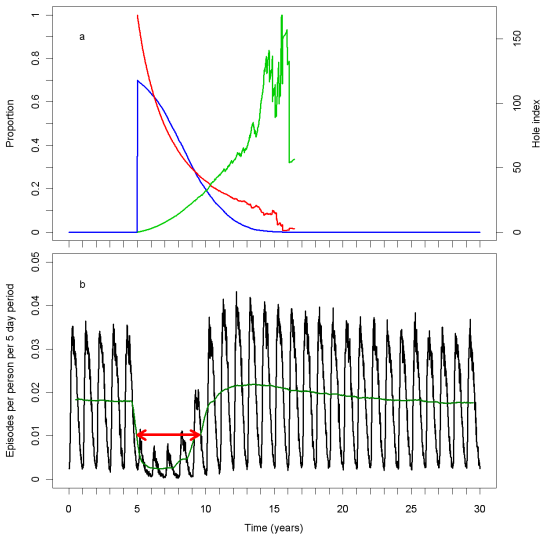

Figure 1 - Central scenario simulation
a) Proportion of the population covered (blue), mean insecticide in the remaining LLINs as a proportion of its initial value (red), and mean hole index in the remaining LLINs (light green on right axis).
b) Number of episodes per person per five-day period (black), one year moving average (green). The red arrow indicates the approximate length of the effective lifetime of the LLIN distribution.

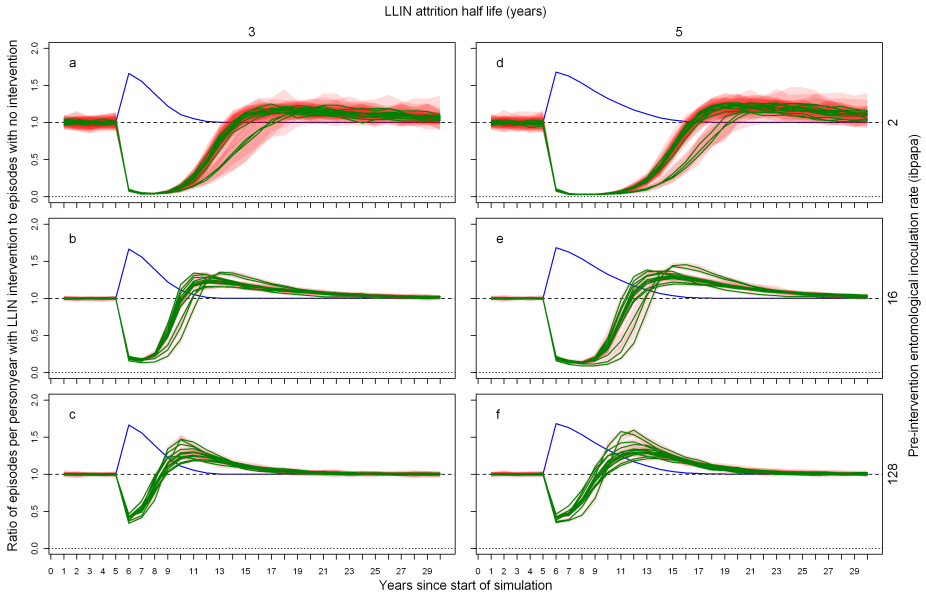

Figure 2 - Ratio of episodes per year with an LLIN mass distribution to episodes with no intervention, depending on pre-intervention entomological inoculation rate (EIR), attrition half-life and model variant
Each green line represents the median number of episodes of 10 simulation runs (each with unique random seed) with LLINs distributed to 70% of the people (population size = 10,000) at the beginning of year 6, each divided by the number of episodes in a simulation run without LLINs (also with unique random seed). The red semi transparent polygons represent the range of the 10 runs. Per panel, there are 14 green lines and red polygons, each representing a malaria model variant. Blue lines represent the proportion of people using a LLIN, plus 1.

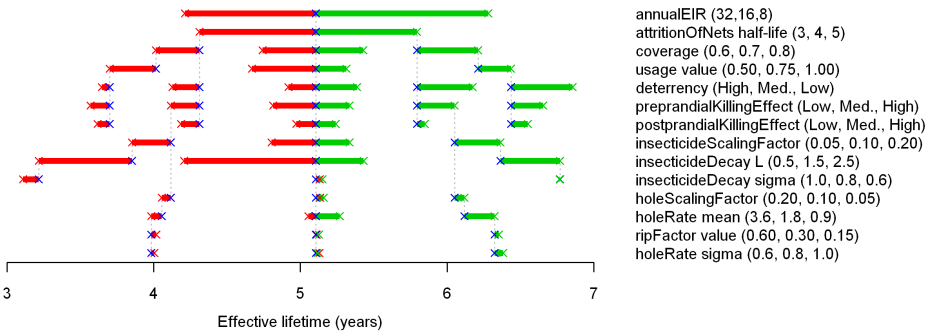

Figure 3 - 'Skeleton' diagram of model parameters
For each parameter (group), the effective lifetime of a mass LLIN distribution, depending on the parameter value, is plotted on the horizontal axis. The effective lifetime was defined as the length of the period since mass distribution that the number of prevented episodes was above half the value for the year with maximum impact (*i.e.* the year with the minimum number of episodes), as compared to a scenario without any intervention. For each parameter, three values were chosen (in parenthesis), which represent roughly the lower, central, and upper values of the plausible parameter range. The central value is not necessarily the mean of the extreme values. These values are listed in order of effect on the outcome; the first has the lowest associated outcome, the last parameter has the highest. Crosses represent models; identical models are connected with dotted black vertical lines. Blue crosses indicate models with the central parameter value, green crosses indicate models with the extreme parameter value with an associated high outcome, and red crosses indicate models with the extreme parameter value with an associated low outcome. Red lines connect red and blue crosses, green lines connect blue and green crosses. Apart from results with models varying only the parameter value in question (the other parameters taking the central value), also outcomes are plotted for selected parameter combinations, often contingent on each other, where the selected parameters all have the values with the lower (red crosses), or higher (green crosses) associated outcomes.

Discussion

This work highlights the need for monitoring malaria transmission before and during intervention programmes, particularly since there are likely to be strong variations between years and over short distances. The majority of SSA's population falls into exposure categories where the effective lifetime is relatively long, but because exposure estimates are highly uncertain, it is necessary to consider subsequent interventions sooner than at the end of the expected effective lifetime based on an imprecise transmission measure.

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Swiss TPH, Socinstrasse 57, P.O. Box 4200, Basel, Switzerland
T+41612848111, F+41612848101, www.swisstph.ch