Reduction of Malaria Prevalence by Indoor Residual Spraying: A Meta-Regression Analysis

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INTRODUCTION

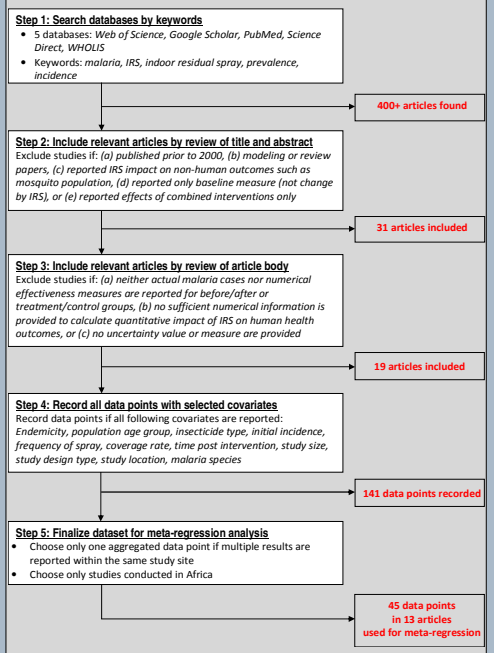
A number of field studies have reported the effectiveness of IRS in reducing malaria prevalence, but it is hard to generalize from any single study how effective IRS is at reducing malaria prevalence, as various studies have shown conflicting results. Few researchers have attempted to quantify the effects of IRS even on a small scale, and fewer have addressed what factors might be major versus minor contributors to the relative success or failure of IRS programs around the world. Additionally, although there are many reviews arguing that DDT is safe, toxicity data from animal studies and recent epidemiological studies suggest that there may be previously unrecognized long-term negative health consequences for those exposed to insecticides, particularly DDT, even at the low levels seen with IRS.

The goal of this study is to determine the overall effectiveness of IRS in reducing malaria prevalence, and to gain information on the different factors that may contribute to the relative strength or weakness of the effect of IRS in different scenarios. A systematic literature review is performed to synthesize information from a collection of published studies and identify a range of potential outcomes and key factors that are different among these studies. We expand upon the findings of the Cochrane Collaboration literature review by widening the criteria for inclusion and used meta-regression analysis techniques to synthesize and statistically analyze the results while controlling differences across the included studiess. We limited our literature search to only papers published in 2000 or later in order to minimize a confounding effect by the papers that might represent IRS effectiveness before insecticide resistance was a concern.

METHODS

Figure 1 illustrates the process used to search for literature and compile the dataset before conducting the meta-regression analysis. In the first step, the following five electronic databases were searched, with finds restricted to articles in peer-review journals within the last 10: Web of Science, Google Scholar, PubMed, Science Direct, and WHOLIS. More than 400 articles were found by this initial search.

Figure 1. Literature Search and Meta-Regression Analysis Process



In the second step, titles and abstracts were scanned for articles that fit three broad inclusion criteria: (1) observational or experimental study designs, (2) reported change in measurable human health outcome due to IRS interventions, and (3) a study design that allowed for measurement of effect of IRS alone. In the third step, these studies were retrieved in full and reviewed in order to confirm they actually met the criteria stated above. We collected and recorded detailed information on the study location, study population, the intervention, and finally the health measurements and effects. In the fourth step, we recorded actual data points from the selected studies associated with the numerical information for the selected covariates. As a result, the final sample for the meta-regression model includes 45 data points from the 13 studies. Finally, several covariates were reclassified and calculated such as relative risk (RR). Data were organized using Excel (Microsoft 2007) and statistical analysis was performed using STATA 10 software (StataCorp, Texas, USA).

RESULTS

Table 1 provides a summary of the final 13 publications included in the meta-regression analysis.

TABLE 1

Summary of studies included in meta-regression of reduction of malaria prevalence by indoor residual spraying

Variable	All responses (no.)
Study location	Equatorial Guinea (3), Kenya (2), Madagascar (2), Mozambique (2), Democratic Republic of Sao Tome and Principle (1), Eritrea (1), Sudan (1), Uganda (1), Zambia (1)
Study type	Cohort (7), cross-sectional (4), randomized control trials (2)
Malaria species	*Plasmodium falciparum* (10), *P. falciparum/vivax* (3)
Insecticide type, chemical class	Pyrethroid (6), organochlorine: DDT (4), carbamate–bendiocarb (2), organophosphate: malathion (1)

Figure 2 is a forest plot which illustrates the contribution of each study to the random effects meta-regression analysis. Relative weight of each study is shown by the area of a box whose midpoint represents the size of the relative risk estimated from each study. The plot shows not only the summary relative risks for each of the 13 studies, but also the combined relative risk of 0.38, indicating a reduction in malaria prevalence of 62% due to IRS implementation (95% CI = 0.31 – 0.46).

Figure 2. Forest plot of the meta-regression analysis of relative risk

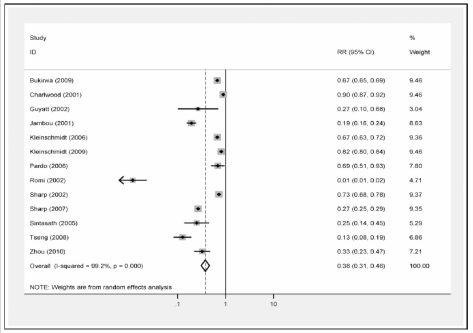


Table 2 shows the best-fit meta-regression model which includes the variables with positive influences on the relative risk (use of organophosphate class insecticide, use of carbamate class insecticide, *P. falciparum*-caused malaria only, cross-sectional study design, and cohort study design) and with negative influences (log-transformed proportion of study population with malaria before intervention, use of multiple rounds of spraying, and use of organochlorine insecticide).

TABLE 2

Meta-regression results (n = 45) of reduction of malaria prevalence by indoor residual spraying*

Covariate (dependent variable = log RR)	Coefficient (95% confidence interval)
Log of initial prevalence (proportion of study population with malaria before intervention)	−0.447 (−0.736 to −0.158)†
Multiple rounds of spraying (1 = yes, 0 = no)	−1.911 (−2.632 to −1.191)†
Total sample size	0.000003 (−0.000037 to 0.000043)
Use of organochlorine class insecticide	−0.918 (−1.843 to 0.006)‡
Use of organophosphate class insecticide	2.610 (0.041 to 5.179)§
Use of carbamate class insecticide	1.426 (0.589 to 2.263)†
Child less than 15 years of age	−0.487 (−1.307 to 0.333)
Plasmodium falciparum only	1.052 (0.412 to 1.691)†
Cross-sectional study design	2.269 (1.275 to 3.264)†
Cohort study design	1.404 (0.260 to 2.547)§
Constant	−3.076 (−4.182 to −1.969)†

*Adjusted $R^2 = 0.786$; $\tau^2 = 0.2255$. RR = relative risk.
†$P < 0.01$.
‡$P < 0.1$.
§$P < 0.05$.

DISCUSSION

The results from the meta-regression analysis provide some interesting information that can help governments and NGOs direct their strategic plans. First, the relationship between IRS effectiveness and starting prevalence shows that programs in communities with higher initial malaria rates might benefit more from IRS. Second, DDT is indeed more effective at reducing malaria prevalence than pyrethroids or other insecticides, which could serve to change the cost-benefit analysis of DDT use on a local or regional scale. Third, IRS is more effective when multiple rounds of spraying are administered in a community where falciparum/vivax malaria is more prevalent, which could inform the malaria control program officials on the efficient allocation of limited resources for maximum impact. Finally, the magnitude of IRS effectiveness appears to be significantly different among study design types, with RCT studies the largest effects and cross-sectional studies the smallest effects. All these information can serve as a guide to health policy makers and malaria control program officials for a better interpretation and utilization of various results of IRS effectiveness.

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