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LOW INSECTICIDE DEPOSIT RATES DETECTED DURING ROUTINE INDOOR RESIDUAL SPRAYING FOR MALARIA VECTOR CONTROL IN TWO DISTRICTS OF GOKWE, ZIMBABWE

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ABSTRACT. Questions have been raised about the quality of indoor residual spraying for malaria vector control after the decentralization of the national malaria control program in Zimbabwe. Given the critical role this control method plays, we conducted an exercise to determine the amount of insecticide (mg active ingredient/m^2 of lambda-cyhalothrin) applied during routine house spraying. Severe insecticide underdosing was detected. Spraying efficiency ranged between 63.4 and 76.1% on walls, and 52.7 and 63.2% on roofs. Differences between 2 districts suggested the problem originates from deficient training and lack of pump calibration. Underdosing can undermine effective residual insecticide activity and the expected reduction in disease transmission.

KEY WORDS Indoor residual spraying, malaria vector control, insecticide deposit

INTRODUCTION

Indoor residual spraying of insecticides plays a central role in malaria control programs in Zimbabwe and several other countries in southern Africa. A reduction in malaria transmission is expected after effective residual spraying operations (Schliessmann 1983). Several insecticides are available for indoor spraying, but some of these have become ineffective because of the emergence of resistance, whereas others, although effective, are not acceptable because of their high mammalian toxicity or hazardous persistence in the environment. Insecticide effect is dependent on proper application, which in turn is affected by various factors such as the equipment used and the individual skills of the spray persons. For each insecticide, standard deposits are recommended for sprayed surfaces or treated fabrics following extensive collaborative evaluations involving research institutions, industry, and the World Health Organization (WHO 1971, Wright 1971). The target deposit rate is normally expressed in grams or milligrams of active ingredient (AI) per surface area. Of concern is the observation during postspray evaluation with contact bioassay tests that the residual effect of insecticides is not always certain on surfaces, especially on mud-plastered walls (Masendu et al. 1998). Although variation in deposit rate is inevitable, the magnitude of this variation during routine indoor house spraying under operational conditions has not been fully quantified. We conducted a study to collect empirical data on the insecticide deposit rates with the goal of recommending measures to improve chemical application during routine indoor residual house spraying in Zimbabwe.

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MATERIALS AND METHODS

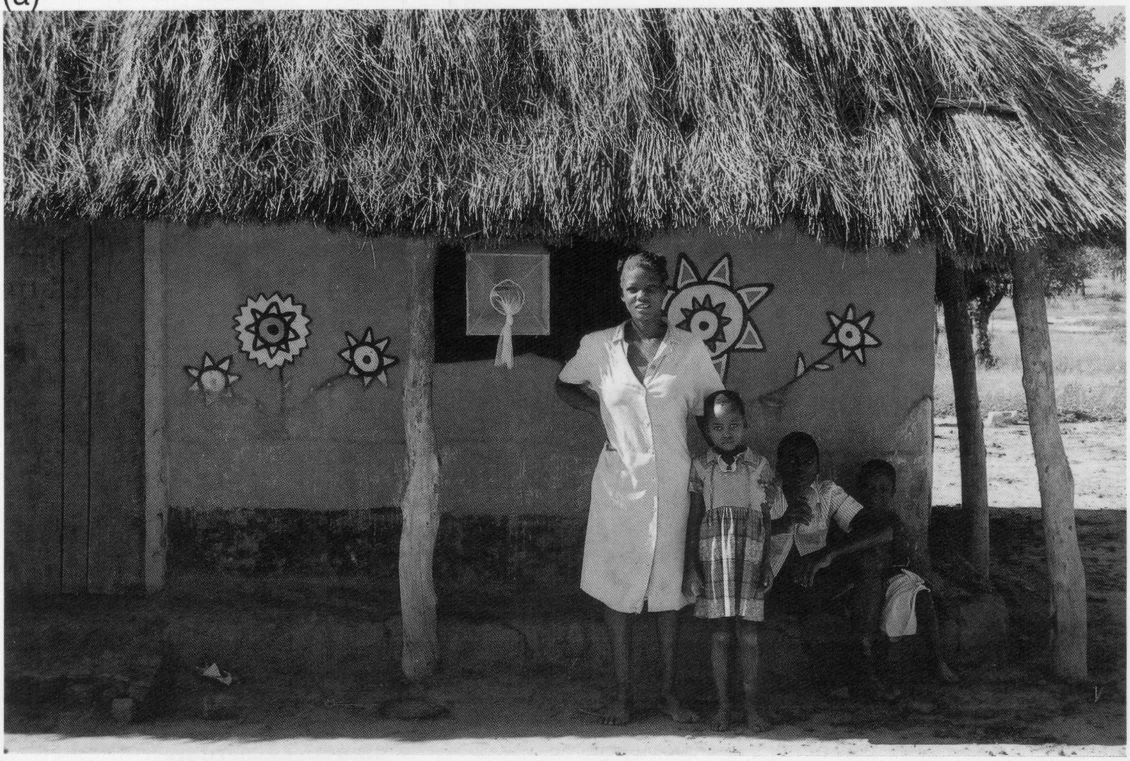
A qualitative analysis of residual house spraying for malaria vector control was conducted in Gokwe North and South districts in December 1999. The objective was to determine the insecticide deposits on hut surfaces during routine indoor spraying. Filter papers were pinned on wall and inner roof surfaces before spraying as previously described by Gratz and Dawson (1963). Major sprayable surfaces in a typical hut consist of mud-plastered walls and a grass-thatched roof (Fig. 1). The sprayers were asked to spray as normally regardless of the presence of filter papers. Filter papers were removed 30 min after spraying after allowing them to dry. The filter papers were packed and labeled according to the hut and sprayed surface. Each sprayer was provided with a form to record details about the pump, chemical, and spraying process. Filter papers were forwarded to Blair Research Laboratory for documentation of the accompanying data, and finally to the Special Analysis Laboratory of the Chemistry and Soil Research Institute of the Ministry of Agriculture for insecticide residue analysis.

Assessment of spray teams, equipment, and chemicals: Information on the organization of the spray teams, pumps, chemicals used, and spraying operations was collected during the time of spraying.

Method of sampling: The team leader randomly identified huts for inclusion in the trials. Filter papers were randomly pinned onto walls and roofs of each hut before spraying. In each hut, 4 filter papers were placed on the walls and 4 were placed on the inside of the roof. We used Whatman No. 1 filter paper (Whatman International, Maidstone, England) of 12.5 cm diameter.

Residue analysis: Lambda-cyhalothrin deposits were analyzed by using the gas liquid chromatography (GLC) technique described in the manual of the Natural Resources Institute (1995). The amount of insecticide on each filter paper was determined from the whole filter paper, with a surface area of

(a)



(b)

Fig. 1. Typical appearance of a rural house in Zimbabwe, showing the grass-thatched roof and the mud-plastered wall. The inner wall and roof surfaces are treated with residual insecticide during routine spraying to kill mosquitoes that enter sprayed houses.

0.0122769 m^2. The 1st step involved extraction of the pesticide by using the surface rinse procedure. Each filter paper was soaked in 100 ml of hexane overnight. The extract was decanted, evaporated down, and then made up to 25 ml with hexane before GLC analysis. The efficiency of recovery of this method exceeds 95%. In the 2nd step, the diluted sample was analyzed on a Varian 3400 GLC instrument fitted with an electron capture detector (ECD). The ECD is extremely sensitive to compounds containing chlorine and will detect nanogram quantities. The column (200 cm × 2-mm internal diameter; Varian Inc., Walnut Creek, CA) was packed with 1.5% OV-17 (Varian) + 1.95% OV-210 (Varian) on CWHP 80/100 (Varian). The operating temperatures were 235°C for the column, 245°C for the injector, and 300°C for the detector. Nitrogen was the carrier gas with a flow rate of 30 ml/min. The detection limit of the GLC was 0.01 ng. The GLC peaks of the test material were compared to those of reference lambda-cyhalothrin (>98.7% purity). A stock solution of 100 ng/μl was prepared by dissolving 0.0101 g in 100 ml of hexane, and a working solution of 0.1 ng/μl was used. A solvent blank (hexane) was run for each lot of samples and in between injections on the GLC.

Statistical analysis: An average of 4 wall and 4 roof filter papers per hut collected from 22 huts were analyzed. The *t*-test was applied to determine the similarities between observed and expected deposits on the wall and roof surfaces.

RESULTS

Spraying teams and equipment

Two types of spray pumps, the Hudson (H. D. Hudson Manufacturing, Chicago, IL) and the Gloria 172R (Hochleistungs-Spruhgerat, Gloria-Werke, Wadersloh, Germany), were in use in the 2 districts. An inventory of pumps available conducted in the Gokwe North camp showed that the Gloria to Hudson ratio was 6:1. In response to a questionnaire administered among the sprayers, 11 Gloria and 4 Hudson pumps were in use, indicating the predominance of the Gloria pump. Seven sprayers did not indicate the type of pump they were using. Generally, the pumps seemed to be in good condition; the Hudson pumps in Gokwe North had code marks indicating year of manufacture ranging from 1992 to 1995. The year of manufacture could not be determined for the Gloria pumps. Pumps did not have lance extensions or constant pressure-regulating facilities. Nozzle material was indicated as either steel ($n = 8$) or brass ($n = 9$), whereas the remainder was not specified ($n = 5$). Various flat fan nozzles (Spraying Systems Company, Wheaton, IL) were in use, including from Teejet 8002-E ($n = 5$), 8004 ($n = 3$), 9002 ($n = 3$), and 9003 ($n = 1$). Nozzle type could not be determined on some pumps. Some of the common problems associated with the pumps included damaged rubber hose and plungers, blockages, and even loss of nozzles and faulty pressure gauges.

Sprayers were provided with basic protective clothing, namely overalls and masks, except they were not provided with goggles. Sprayers did not have stretcher beds or mattresses to sleep on in camp while on tour of duty. Soap was provided for laundry and bathing. Experienced staff trained the teams with support from the private sector a week before deployment. The Gokwe North group consisted of 38 sprayers, including 2 camp guards, 1 supervisor, 1 driver, and 5 team leaders, making up 2 teams each with a team leader and a deputy. Ideally, the team should have a warner (who alerts communities about the spraying exercise in advance) and a pump minder in addition to 15 sprayers. Ten insecticide charges were issued per person per day and each sprayer was expected to spray 3–5 huts per charge depending on structure size. Teams were deployed early in the morning to take advantage of the cooler temperatures given the harsh weather conditions in the area. Remuneration was US$18 (ZD$950) per person for 23–25 working days per month. While in camp, visitors were discouraged to reduce interruption of day-to-day activities, and for general security reasons.

Spraying procedure

Insecticide charges were prepared by mixing 62.5 g of lambda-cyhalothrin (Icon®; Zeneca, Fernhurst, Surrey, England) 10 WP with 10 liters of water for Hudson or Gloria pumps. Because Icon is supplied in water-soluble sachets, the mixing is done directly in the pump rather than in a bucket. The resulting mixture is an aqueous suspension containing 0.0625% of the active ingredient. The volume per surface area that sprayers were trained to apply could not be determined. The recommended target deposit of lambda-cyhalothrin is 30 mg AI/m^2 with the acceptable range of 25–30 mg AI/m^2. Spraying at 40 ml/m^2 is calculated to result in a deposit of 25 mg/m^2, whereas spraying at 48 ml/m^2 would result in a deposit of 30 mg/m^2 without runoff.

Insecticide deposits

Average lambda-cyhalothrin deposit rates on walls and roofs surfaces were both less than the acceptable minimum of 25 mg/m^2 (Table 1). Considerable variation occurred in insecticide deposits, which ranged from 0.35 to 89.37 mg/m^2. The average insecticide deposit on the roofs was lower than on the walls, but this difference was not significant ($t = 109$; df = 164; $P = 0.28$).

After analysis of variance ($F = 58.8$, $P = 0.001$, df = 1), the data from the 2 districts were analyzed separately. Gokwe North had more acceptable insecticide deposits, whereas Gokwe South figures in-

Table 1. Insecticide deposit rates (on filter papers) grouped to indicate categories of acceptable, underdosing, and overdosing with respect to a target of 30 mg active ingredient (AI)/m².

Locality	Hut surface	$\bar{x}$ Deposit (mg AI/m²) (n)[1]	Percent (%) of filter papers in different insecticide deposit rate categories (sample size in parentheses)[2] <18.75 mg/m²	18.75–25 mg/m²	25–30 mg/m²	30–36.2 mg/m²	>36.25 mg/m²
Gokwe South	Wall	9.9 (40)	85 (34)	12.5 (5)	2.5 (1)	0	0
	Roof	5.3 (39)	94.8 (37)	2.6 (1)	2.5 (1)	0	0
Gokwe North	Wall	27.1 (45)	37.7 (17)	35.5 (16)	13.3 (6)	2.2 (1)	11.1 (5)
	Roof	25.6 (42)	47.6 (20)	14.3 (6)	11.9 (5)	9.5 (4)	16.6 (7)
Overall	Wall	19 (85)	60 (51)	24.7 (21)	8.2 (7)	1.2 (1)	5.9 (5)
	Roof	15.8 (81)	70.4 (57)	8.6 (7)	7.4 (6)	4.9 (4)	8.6 (7)

[1] $\bar{x}$ = mean; n = sample size (number of filter papers analyzed).
[2] Insecticide deposit rates of 18.75 and 36.25 mg/m² represent arbitrary cutoff values equivalent to 25% below the acceptable minimum of 25 mg/m² and 20% above the acceptable maximum of 30 mg/m².

dicated serious underdosing. When compared with the target dose of 30 mg/m², the deposits for Gokwe North were not significantly different for both walls ($P < 2.02$, $t = 0.78$, $n = 45$ at 95% confidence limit) and roofs ($P < 2.02$, $t = 1.61$, $n = 42$ at 95% confidence limit). In contrast, the values for Gokwe South were significantly lower than the target for both walls ($P > 2.04$, $t = 18.4$, $n = 40$ at 95% confidence limit) and roofs ($P < 2.02$, $t = 26.27$, $n = 39$ at 95% confidence limit). The greatest proportion of the samples had insecticide deposits lower than 18.7 mg/m², reflecting serious underdosing. This was more evident in Gokwe South, where 85% or more of the filter paper deposits were below 18.7 mg/m² (Table 1). Small proportions of the sample amounting to 2.5% in Gokwe South and 13.3% in Gokwe North had insecticide deposits falling within the acceptable range of 25–30 mg AI/m². Only limited overdosing was recorded and this was con fined to samples from Gokwe North. In addition to being wasteful, excessive insecticide can have a repellent effect on the targeted endophilic *Anopheles arabiensis* Patton by preventing this vector mosquito from resting on treated surfaces.

Efficiency of the spraying technique

Taking 25 and 30 mg/m² as acceptable minimum and maximum target deposit rates, respectively, the efficiency of spraying on the walls and roofs ranged from 63.4 to 76.1% and 52.7 to 63.2%, respectively. The overall spraying efficiency for the whole hut ranged from 58.1 to 69.68%.

The lower limit of 20 mg AI/m² recommended for lambda-cyhalothrin in the range 20–30 mg AI/m² (Chavasse and Yap 1997) is considered too little for the sorptive soils that constitute the relatively coarse and porous mud plastering used in most rural homes in Zimbabwe. The Vector Control Subcommittee of the National Malaria Control Program recommends a deposit rate of 30 mg AI/m² when Icon 10 WP is used. The rationale is that high deposit rates would counteract rapid insecticide loss due to porous mud surfaces (Bami 1961, Gerolt 1961).

We did not determine insecticide falling on the floor, which results from bounce-off. Insecticide falling on the floor has several implications, ranging from wastage, potential beneficial impact on other household pests, and unintentional insecticide poisoning of house occupants, especially children who play and sleep on the floor. Falling spray deposits may also increase the exposure to insecticide and poisoning of the sprayers during the spraying, especially of those with inadequate protective wear (Durham 1963). Lambda-cyhalothrin was reported to cause itching, especially when sprayers cooked on an open fire. Characteristic of all alpha-cyano pyrethroids, lambda-cyhalothrin is known to cause skin and throat irritations, as reported here. Icon 10 WP was the only insecticide used in the assessed areas, which reflects the central insecticide procurement process at national level. Chemical content in 3 randomly sampled sachets that were analyzed ranged from 9.4 to 10.1% lambda-cyhalothrin, thereby ruling out possible faulty chemical supplies.

DISCUSSION

Underdosing of insecticide clearly occurred on both wall and roof surfaces during routine spraying. Although obtaining a uniform application rate is acknowledged to be impossible, deviation from the mean should remain within acceptable limits. Indications are that the low insecticide deposits are a problem related to the skills of the spray persons. The problem of underdosing apparently was related to application technique, possibly due to spraying at too fast a rhythm. That training was the likely problem is supported by the different performances observed between the 2 districts. Sprayer fatigue resulting from the workload also could be a contributing factor because spraying an estimated 40 huts per day may be asking too much from 1 sprayer. Rushed spraying may ensue to achieve these targets, resulting in the underdosing such as reported here. That deposits on the roof were found to be lower than on the wall probably stems from the lack of face protection; sprayers risk getting insecticide in their eyes if they look toward the roof during spraying (WHO 1986). Provision of pump lance extensions would improve reach and thus aid insecticide application in high conical roofs, which tend to receive less than the desired rates. Frequent agitation of the pump is necessary to prevent insecticide sedimentation after the initial mixing. Pilfering of chemical by sprayers may result in the over-dilution of remaining charges to compensate and thus ostensibly achieve the expected coverage. Chemical pilfering is probably linked to the small remuneration package, which often is paid after the performance of work. The sample size was not large enough to assess the effect of pump and nozzle variation on insecticide application. One direct implication of these disturbing observations on vector control is that effective impact on disease transmission cannot be expected under such a situation. Insecticide rates below target may eventually enhance the development of insecticide resistance, a situation that would have far reaching consequences on disease prevention and control.

Recommendations

Calibration of pumps to suit the particular insecticide in use at all times is urgently needed. Sprayer training should be reviewed and assessed regularly to ensure adherence to specific technical requirements. Supervision of sprayers and spray teams should be reinforced to ensure the proper preparation of charges and application of insecticide. Reduction of the number of structures sprayed by an individual per day may be necessary to increase efficiency. Adequate protective gear should be provided for the sprayers and its correct use should be encouraged.

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