ARTICLES

SOME RECENT DEVELOPMENTS AND TRENDS IN VECTOR CONTROL ASPECTS OF MALARIA ERADICATION [1, 2]

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The worldwide malaria eradication program, now in its 13th year, has conferred immeasurable health and economic benefits on the peoples of developing countries and is justly proclaimed as one of the great public health endeavors of this century. Forty-four nations in all regions of the world where malaria constitutes a serious problem are coordinating their efforts to eradicate the disease. Supporting and assisting these nations in malaria eradication are the World Health Organization (WHO), the United Nations Children's Fund (UNICEF), and the United States. United States assistance to malaria eradication, including contributions to the WHO Special Malaria Fund, totaled approximately $235 million in the period 1957–1967 and was an essential factor in developing this gigantic and complex undertaking.

In 1966, the Public Health Service (PHS) agreed to accept responsibility from the Agency for International Development (AID) for administering the U.S. program of assistance to worldwide malaria eradication. Accordingly, the PHS must assure that funds, equipment, and materials provided to the countries under agreements with the United States are used to maximum advantage; that malaria eradication methods are sound and effectively implemented; and that programs are keeping pace with scheduled projections for accomplishing malaria eradication.

To meet these responsibilities, the National Communicable Disease Center's (NCDC) Malaria Eradication Program has reviewed each U.S.-assisted program and has found that technical and administrative difficulties have hampered the effectiveness of eradication operations, have delayed the projected completion of eradication programs, and have increased the cost beyond original estimates. In view of these difficulties, special consideration is being given to new developments and to modifications of present methods which might conceivably facilitate operations and speed up progress of eradication campaigns.

Malaria eradication is basically accomplished by mosquito control operations. Since the worldwide malaria eradication program was launched in 1956, principal reliance has been placed on DDT residual spraying in malarious areas. Soper *et al.* (1961) noted that residual spraying for malaria eradication is ". . . based on the habits of the important anopheline vectors, which in most areas of the world, characteristically invade human habitations in search of blood meals. After feeding, the engorged mosquitoes rest upon walls and ceilings of dwellings where they absorb lethal doses of the insecticide." Thus, residual spraying interrupts the cycle of transmission by killing the mosquito before completion of the extrinsic cycle of the malaria parasite. Although elimination of the malaria parasite is the ultimate objective of residual spraying, this is achieved through an attack directed against the adult mosquito; and the success of the operations depends on

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good organization, supervision, and techniques which are essential components of any mosquito control program.

The scope of the residual spray operations in the U.S.-assisted programs is shown in Table 1.

A significant factor related to, but not indicated in, the data in Table 1, is that 13 of the 16 U.S.-assisted programs in 1967 applied DDT at a dosage rate of 2 grams per square meter (2 g/m^2), while only two (India and Pakistan) used 1 g/m^2 applications. One country (Nepal) used 1 and 2 gram dosages interchangeably. The India and Pakistan programs, the largest and second largest in the world, together sprayed 30 million houses in 1967 and directly protected 134.6 million people from malaria.

Because treatment at 1 g/m^2 has given good results in the India and Pakistan programs, the rationale of the 2 g/m^2 dose used in other malaria programs has been questioned. The higher dosage used by most of the countries arises from an erroneous impression that it is the "standard" application recommended by the WHO Expert Committee (Soper *et al.*, 1961). Consequently, most of the countries have held to the application regardless of local transmission factors. Quarterman (1962) pointed out that laboratory and field evidence indicate no significant difference in residual effectiveness of 1 and 2 grams 6 months after application.

Since laboratory and field evidence indicate 1 g/m^2 is satisfactory, the NCDC Malaria Eradication Program has proposed that country programs using 2 g/m^2 consider conversion to the lower dose. It is estimated that this conversion would result in a savings in DDT exceeding $3 million annually in the 13 programs using 2 g/m^2.

In all but one program, DDT is applied at least twice a year, usually at 6-month intervals, for a period of 4 years. This interval is based on the observation that DDT maintains an effective residual toxicity for at least 6 months. The twice yearly application is regularly maintained regardless of the intensity, geographic distribution, or seasonal duration of malaria transmission. The only exception is the program in East Pakistan, which completes one total coverage spraying cycle immediately before the transmission season begins, then selectively sprays areas where transmission may continue longer than the expected residual effectiveness of the insecticide. By adjusting the timing and coverage of spraying to fit the characteristics of malaria transmission, East Pakistan has utilized its limited resources to maximum advantage.

The appearance of malaria vectors with physiological resistance to DDT has raised serious problems for some malaria eradication programs. The problem is mainly limited to the U.S.-assisted malaria programs in four Central American republics: Guatemala, El Salvador, Honduras, and Nicaragua. Resistance of *Anopheles albimanus*, the main malaria vector, to DDT and dieldrin virtually excludes effective use of these compounds in the intensely malarious areas of these countries. While none of the newer insecticides compare with DDT and dieldrin in duration of residual effectiveness, a few appear adequate as substitutes in special situations. In El Salvador, a methyl carbamate

TABLE 1.—Status of residual spray operations in 16 U.S.-assisted malaria eradication programs, 1967.

Insecticide used	Amount used (Tons)	No. houses sprayed	Population protected
DDT	21,447* 3,107**	44,300,000	199,478,000

* Supplied by U.S. (43 million pounds).
** Supplied by UNICEF (6 million pounds).

(OMS/33; = Bayer 39007 or Baygon®) has been tested and shows promise, a principal drawback being its present high cost (World Health Organization, 1967). Schoof *et al.* (1961) and Gratz (1965) reported that malathion is effective for 3–5 months on wood and other impervious surfaces but loses its residual effectiveness in a few weeks on mud surfaces.

Residual spray field trials with OMS/33 in El Salvador confirmed an airborne toxic effect against *A. albimanus* (Fritz, 1968 personal communication). Significant numbers of caged mosquitoes died in experimental huts 30 weeks after the walls had been treated with OMS/33; the airborne effect was also detected in the immediate vicinity of sprayed huts. In subsequent field trials where entire villages were sprayed in several countries, the same result was again confirmed with anopheline mosquitoes. Although to predict the potential value in malaria eradication is premature, aerial spraying appears promising as a supplementary method for solving problems of extra-domiciliary transmission in some areas.

The significance of outside biting and resting of malaria vectors as a factor in maintaining malaria transmission in areas under residual spray is receiving increasing recognition. The behavior may be a natural characteristic or one induced by the repellent and irritant effects of DDT (de Zulueta, 1962). Also, the vectors may be influenced to bite and rest indoors or outdoors on different occasions depending on weather conditions, seasonal factors, sleeping habits of people, and availability and location of human and animal hosts (Garrett-Jones, 1964). While not documented in many of the countries, extra-domiciliary biting and resting is generally believed to be a contributing factor to the persistence of malaria transmission. Where extra-domiciliary biting and resting occur, residual spraying alone is not likely to be sufficient to stop transmission without supplementing it with other antimosquito measures.

Larviciding has proven to be an effective supplement in a number of U.S.-assisted malaria eradication programs. Until recently, the method had been limited to relatively small-scale activities in a few programs, notably India, Jordan, and Pakistan. Interest in the method, however, has been revived recently because of limitations of residual spraying and antimalaria drugs to interrupt transmission in many areas. Past cursory use of larviciding in malaria eradication is considered more the result of inexperience with technical and operational aspects of the method rather than lack of genuine need and usefulness in the programs. Most programs lack personnel with the capability to identify areas suitable for larviciding and to organize and supervise the operations. Although residual spraying is still the basic method of attack and the most economical, antilarval measures could be beneficially employed in at least two situations: (1) as a supplement to residual spraying where local vectors are resistant to residual insecticides, and (2) where outdoor transmission by exophilic vectors reduces or nullifies the effectiveness of residual spraying. Moreover, dry season larviciding has many practical applications, and urban malaria invariably is best combatted by antilarval measures.

India has used larvicides for a number of years to control urban malaria transmitted by *A. stephensi*. The programs in East and West Pakistan presently employ antilarval measures; and these programs may be expanded, particularly in West Pakistan which experienced an unusual outbreak of urban malaria in Karachi in 1967 (Lobel, 1968).

Of the 16 U.S.-assisted programs, the Jordan program exemplifies the successful use of antilarval measures in malaria eradication. This fact was corroborated in the recent history of the program. In 1963, "attack" operations of residual spraying and larviciding were withdrawn in the belief that case finding and treatment of cases would suffice to eliminate the remaining scattered foci of malaria, then totaling 225 cases. In 1967, however, the number of cases had risen to 644, and further deterioration in the program was foreseen. To avert total program reversion, antilarval operations and residual spraying were reinstituted in 1965; by 1967, only 27 cases (none indigenous) were reported. Since experience had shown residual spraying to be only partially effective in Jordan, the antilarval measures obviously contributed greatly to the revitalization and success of the program.

In reviewing larviciding operations in Jordan in 1967, possibilities for substantial economies by substituting one of the newer larvicides for diesel oil were noted by Stivers (1967). He reported that preliminary field trials with Abate emulsion as the insecticide demonstrated potential annual economies totaling $55,000 in antilarval operations. Field trials will be continued in 1968 in cooperation with the Jordan program and WHO.

Because of the field-proven usefulness of antilarval measures, the NCDC Malaria Eradication Program is urging that this method be considered in all programs. With this objective in view, Haiti recently instituted a field trial to determine how larviciding might be effectively employed under the special conditions of malaria transmission in that country.

In 1968, the NCDC Malaria Eradication Program plans to broaden and intensify the inquiry into ways and means of improving methods and systems of malaria eradication. Since most of the U.S.-assisted malaria programs are staffed with NCDC malaria advisors, attempts will be made to incorporate improvements into on-going country programs, wherever indicated, working in cooperation with the Directors of National Malaria Eradication Programs and WHO Malaria Advisors.

An exciting new development in biological control for future consideration in malaria eradication has been reported by Davidson (1967). Through painstaking work involving numerous laboratory crosses of strains of *A. gambiae,* he revealed the existence of five mating types of which three are freshwater forms widely distributed throughout Africa. Two are saltwater forms: *A. melas* in West Africa and *A. merus* in East Africa. When any of the five forms are crossed, hybrid male sterility results; and some of the crosses produce grossly abnormal sex ratios. The males are vigorous, long-lived, and exhibit competitive mating ability. The practical application to malaria eradication in Africa has great operational potential. As Davidson reported, members of the *A. gambiae* complex form the principal vectors of malaria in Africa. South of the Sahara, control of the species has not been completely satisfactory with present methods. Moreover, malaria transmission by *A. gambiae* has continued largely unchecked over most of the mid-continent despite many attempts to establish malaria eradication programs using residual sprays and other conventional measures.

Davidson proposes introduction of the egg stage into the wild population because crosses produce nearly all sterile males in the F_1 generation and obviate any need for separation of the sexes. He indicated the practical application of the method would require an insectary "factory" where matings of the two species needed for crossing would produce eggs for seeding in natural breeding sites during the dry season when breeding is limited to relatively few scattered areas and when the adult population has ebbed to its lowest seasonal level. This approach could offer possibilities of a new breakthrough in solving the problems of malaria in Africa. Although special skills will be required to develop and implement this biological method, it appears to offer considerable promise.

The experience gained in the past decade of malaria eradication has pointed up the value of flexibility in the selection and use of the various antivector methods and materials available to malaria programs. Exclusive reliance on residual spraying alone, on one insecticide, or on a "standard" dosage and cycle of application may prove inadequate or uneconomical to cope with the complexities of malaria transmission in all areas. Therefore, every means should be considered; and simultaneous use of a combination of methods, tactics, and strategy may provide the economical solution if selectively and judiciously applied at the right time and place. Although the search for improved materials and methods should be and is being relentlessly pursued to facilitate the accomplishment of malaria eradication, those presently available are considered sufficient if properly utilized. What seems most imperative in the "war on malaria" is improved knowledge and understanding of the factors contributing to persistent transmission and capability to select and apply the most appropriate means at hand.

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