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MALARIA: CYCLES OF MOSQUITO CONTROL, RESIDUAL SPRAY AND ? ? ?

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ABSTRACT. Prior to the beginning of the global malaria eradication campaign in 1956, the disease had been controlled by antimosquito measures and antimalarial drugs. The effectiveness of mosquito control had been demonstrated throughout the world. It was and still is dependent upon reducing man's exposure to infected mosquitoes through reduction of vector populations. The measures were highly effective and practical for control of urban malaria but had limited applicability in rural areas because of high per-capita costs.

Residual insecticides when sprayed on interior walls of houses provided an economical method for control of rural malaria. Their effectiveness is dependent on killing mosquitoes that enter human habitations independent of vector density considerations. Because of confidence that residual sprays would eradicate malaria in a time limited period, inclusion of comprehensive mosquito control in training curricula for eradication personnel was deemed unnecessary. As a result, the measures have been infrequently used for the control of malaria since the beginning of the eradication campaign.

Both mosquito control and residual sprays, with their differing mode of action, are highly effective for prevention of malaria. Establishment of comprehensive mosquito control demonstration projects would permit retraining of personnel in alternative procedures for controlling malaria and application of the appropriate method in response to local problems.

INTRODUCTION

During the past decade numerous articles have summarized progress and failures of the global program to eradicate malaria. In general, eradication was achieved during the early 1950's where malaria was endemic in temperate countries and in several tropical or subtropical islands. Inability to sustain early progress has resulted in widespread resurgence of rural, urban and man-made malaria.

The title of the paper implies that use of mosquito control measures and residual sprays for prevention of malaria are mutually exclusive. Obviously, there is little logic for the inference since their mode of action differs. The effectiveness of one depends on obtaining significant reduction in mosquito densities while the other relies only on killing those vectors that enter sprayed houses. Nevertheless, the rarity of instances in which comprehensive mosquito control has been applied since the start of the eradication campaign in 1956 lends credence to the existence of distinct cycles.

The premise of the paper is that the "mosquito control" cycle extended from about 1900 to the beginning of the "residual spray" cycle of the malaria eradication campaign sponsored by the World Health Organization (WHO). The purpose of the paper is to affirm the role of each and to suggest needs for embarking on a third cycle: A cycle that recognizes the contributions that can be made by each and which permits selection and application of appropriate measures in response to local problems and needs.

CYCLE OF MOSQUITO CONTROL

The role of *Anopheles* mosquitoes in the transmission of malaria was demonstrated by Ross and others at the turn of the century. In 1901, Watson began his remarkable career in malaria-mosquito control in Malaya and Ross initiated mosquito control in Freetown, Sierra Leone. The Suez Canal town of Ismalia began malaria control operations in 1902. It has been suggested, however, that the dramatic reduction of yellow fever and malaria in Havana, Cuba and in Panama by Gorgas and LePrince provided the stimulus for establishment of malaria-mosquito programs in Europe, Africa, Asia and the Americas (Magoon 1945).

In the United States, New Jersey established pestiferous mosquito control operations in 1904. Penryn, California (1910) is credited with being the first locality to conduct malaria control operations (Herms and Gray 1940). Shortly thereafter, field studies by the U.S. Public Health Service in cooperation with southeastern states where malaria was endemic led to rapid expansion of state and local programs. By the mid 1920's, the causal relation between impounded water and malaria had been established and states had passed legislation for control of mosquitoes on impoundments (U.S. Public Health Service 1947).

Because of the widespread impact of malaria, investigations in various regions of the world contributed more precise information on the (1) epidemiology of the disease and factors influencing its transmission; (2) habits, vectorial capacity and natural history of mosquitoes and (3) improved methods of mosquito control based on emerging epidemiological and entomological data. The investigations indicated that eradication of mosquitoes was not necessary to control malaria, the probability that threshold vector densities were required to sustain transmission and, importantly, the interdependency of multi-professional personnel for development of improved mosquito control methods. The complex technology of mosquito control is synonymous with comprehensive or integrated control.

Comprehensive mosquito control involves the judicious selection and application of engineering, naturalistic, biological and chemical measures for reduction of insect population densities to levels where they no longer sustain disease transmission or contribute to man's discomfort. In it, precedence is given to the permanent elimination or reduction of mosquito populations over attainment of temporary reductions by procedures requiring repetitive action. That is, elimination and reduction of mosquito breeding habitats by engineering or naturalistic modifications (source reduction) is preferable to procedures for control of the aquatic or adult stage of the vector by pesticides. Pesticides are to be used as a supplement to source reduction and not as a substitute.

It is beyond the scope of this paper to describe the measures of comprehensive mosquito control that were highly successful in controlling malaria in urban and densely populated areas throughout the world in the first half of the century. In 1949 Watson reported that "if I may substitute 'malaria' for 'yellow fever' in Soper's epigram, since 1920 malaria in towns has not been a public health problem but an administrative crime." Pampana (1969) placed limitations on use of anti-mosquito measures in eradication programs but concluded "there should be no doubt that antilarval measures alone should be able to interrupt transmission. . . ." Since continuing progress has been made in the technology of mosquito abatement, there can be little doubt that proven, improved and practical methods are available to prevent malaria in urban or densely populated areas. As in the past, however, the procedures may not be routinely practical or applicable to rural areas.

CYCLE OF RESIDUAL SPRAY

The development after World War II of DDT and other low cost insecticides with residual action revolutionized malaria control. For the first time, a practical and affordable method became available for control of rural malaria—a method that provided hope to the majority of the populations of developing countries that the "scourge of the tropics" could be controlled.

Between 1945 and 1955 the effectiveness of DDT application as a residual spray to interior walls of houses was demonstrated in such areas of the world as Italy by Missiroli, Panama by Trapido, Venezuela by Gabaldon, Sardinia by Logan and India by Singh. In those areas of Venezuela inhabited by *An. darlingi* Root, an anthropophilic and endophilic vector, malaria and the mosquito were reported to have been eradicated. Malaria reductions were achieved in Panama and India with no apparent decrease in vector densities of *An. albimanus* Wied. or *An. culicifacies* Giles, respectively, both of which are anthropophilic and zoophilic. In contrast, application of DDT every 3 months in the Philippines failed to reduce either morbidity or the density of *An. flavirostris* (Ludlow) (Otto 1951, Soper and Kerr 1970, Gabaldon 1983). Pilot projects in Africa south of the Sahara reduced malaria morbidity but failed to interrupt transmission (Farid 1980). From these and other observations it was concluded that residual sprays provide an excellent means for controlling malaria but not necessarily a method for controlling mosquitoes. Their effectiveness is dependent on killing potentially or actually infected mosquitoes that enter habitations that have been sprayed.

The enthusiasm which stemmed from eradication of malaria from Sardinia and parts of Venezuela led to endorsement of the concept of eradication. Though lacking a consensus among malariologists, the campaign for the global eradication of malaria was undertaken in 1955 under the aegis of the World Health Organization. The operational strategy was outlined in the June 1956 meeting of WHO's Sixth Expert Committee on Malaria (World Health Organization 1957). It consisted of the periodic application of residual insecticides, usually for a minimum period of 3 years, with detection and treatment of cases. The committee noted that antilarval procedures and antimalarial drugs might be introduced as supplementary attack measures as the case detection program developed. By the end of 1958, programs were being conducted in 63 countries (16 in the Americas) covering 700,000,000 people or 65% of the world's population living in malarious areas.

Staffing requirements for international and national programs, including those of the U.S. Agency for International Development (AID), far exceeded the available number of experienced technical personnel. Smith (1982) noted that AID provided monetary assistance to 37 countries and at one time had some 70 malaria advisors assigned overseas. By the early 1960's, the 24,000 personnel employed by national governments in the Americas included 278 malariologists, 119 engineers and 37 entomologists. The technical staff of the Pan American Health Organization (PAHO) included 33 malariologists, 19 engineers, 13 entomologists and 50 sanitary inspectors. Farid (1980) reported that India during the same period had 426 malariologists, 115 entomologists, 13,000 malaria inspectors, 40,000 surveillance workers and apparently no engineers.

To meet the manpower requirements, international training centers were established. The 3 month curriculum was influenced by Professor Missiroli's 1946 pronouncement that drainage and filling were no longer important for control of malaria in Italy pending availability of adequate supplies of DDT (Soper and Kerr 1970) and recommendations of the WHO Expert Committee. In the confident assumption that malaria transmission would be interrupted in 3 or 4 years by residual sprays, in-depth training in epidemiology, entomology and comprehensive mosquito control was deemed unnecessary. As a consequence, training was largely limited to operational strategy with emphasis in epidemiology on classification of cases as autochthonous or imported; entomology on reaction of mosquitoes to insecticides; and in engineering on logistics, training and supervision of efficient and timely spraying of all houses. Despite increasing reports of problems of persisting transmission in the early 1960's the potential contributions of mosquito control continued to be largely ignored. For example, the 1969 Textbook of Malaria Eradication by Pampano, a former director of the WHO Division of Malaria Eradication, includes methods of attacking mosquitoes other than by residual insecticides in just 9 of 593 pages. He states "in eradication programs the use of antilarval methods is fortunately required only in exceptional cases . . . filling and draining may have a place in those rare programs in which the attack phase must rely on larval control."

DISCUSSION

The efficacy of mosquito control to prevent malaria was demonstrated throughout the world in the first half of the century. Knowledge had been acquired whereby the continued presence of urban malaria could be considered as a public health administrative option and man-made malaria was controllable. While procedures were applicable to densely populated areas, they were not economically practical for control of the disease in rural areas in which the majority of the world's population exposed to malaria reside. Despite this limitation, it is suggested that the eradication campaign ended a cycle that had evolved from the cooperative efforts of multi-professional personnel to develop a complex technology of mosquito control for prevention of malaria based on detailed knowledge of the epidemiology of the disease and the natural history of the vector. A cycle which believed and practiced that "with many methods for the control and eradication of malaria . . . the selection of the right method or methods is clearly of importance, if the work is to be done efficiently and economically. None but a sanitarian familiar with the details of every method can be relied on to give good advice. Ignorance of engineering has led to extraordinary mistakes in techniques, and to wrong conclusions which have greatly delayed progress of malaria control throughout the world" (Watson 1949).

The cycle of residual sprays began in the late 1940's and has continued. Eradication of malaria in several areas of the world together with sharp reductions in morbidity and mortality in many tropical and subtropical countries attest to their effectiveness. Despite current problems besetting the campaign and continued classification of vector resistance as a technical failure instead of a failure in methodology, it is emphasized that residual sprays made possible the greatest gains in control of malaria the world has ever seen. Where vectors are susceptible, they are the method of choice in rural or sparsely populated areas.

It cannot be overemphasized that comprehensive mosquito control and residual spraying of houses are separate and distinct methods for prevention of malaria. The effectiveness of mosquito control is dependent upon reduction of vector densities to levels where they can no longer support transmission—a threshold level that may vary with species. In contrast, residual sprays protect man by killing only potentially or actually infected mosquitoes that enter sprayed houses. With exception of strongly anthropophilic and endophilic species, residual insecticides will have little or no effect on reduction of vector densities. Their effectiveness is somewhat analogous to control obtained early in the century through screening of barracks and use of pyrethrum sprays. Thus, residual spraying of houses is a proven and highly effective method of controlling malaria transmitted by predominantly anthropophilic and endophilic vectors. They may neither be a means for controlling malaria nor mosquitoes, however, where the vectors are highly zoophilic and exophilic. As noted by Gabaldon (1983), the effectiveness of pyrethrum and residual sprays relies on their destruction of the mosquito before it becomes infective. Since the procedures are directed against the parasite, they may not be properly considered measures of mosquito control.

Why were comprehensive mosquito control measures used infrequently in the eradication program? First, because of confidence in the universal effectiveness of residual sprays, technical personnel were not trained in the technology of mosquito control. The warning of Russell (1952) that "DDT too often receives blind reverence, while the study of mosquitoes and of how to eliminate their breeding places is ignored" went unheeded. That the campaign strategy appeared to have been set in concrete was confirmed by the 1980 observation of Farid, a former WHO staff member, that "Confidence in DDT spraying blinded everybody to the need . . . to extend the utilization of conventional antilarval, engineering or biological methods. . . ."

Is it not paradoxical that WHO assisted countries in planning, conducting and evaluating residual spray operations but failed to encourage the introduction of alternative measures for attacking vectors in areas of persisting transmission? In response to the widespread resurgence of malaria, however, a number of short-term training seminars on mosquito control were sponsored by WHO with the cooperative assistance of national and international agencies. In general, the brief didactic discussions of pestiferous mosquito control methods and peripatetic observations of mosquito abatement operations in developed countries were inadequate to provide the expertise required to control local vector and transmission problems. During this period, efforts by the WHO Division of Vector Biology and Control in reviving and stimulating interest in larviciding, control of man-made malaria and environmental management for mosquito abatement are to be commended (World Health Organization 1974, 1982). Unfortunately, the number of personnel trained by the Division in mosquito control technology was limited because of administrative and budgetary considerations. (It is hoped that the curricula in the recently established WHO training center in Kuala Lumpur, Malaysia will include the broadest aspects of the epidemiology and control of vector-borne diseases.)

Second, WHO initially delegated responsibility to the Division of Malaria Eradication (ME) to develop the strategy, operational guidelines and a program of technical assistance to National governments. Somewhat later, a Division of Vector Control (VC) was established to study the toxicological, biological and chemical properties of residual insecticides. Following the widespread resurgence of malaria, a Revised Strategy of Malaria Eradication was adopted in 1969 but virtually no change in operational procedures was introduced. In the early 1970's the Divisions of Malaria and Parasitic Diseases (MPD) and Vector Biology and Control (VBC) were established with broader responsibilities than their antecedent organizations.

In addition to malaria, MPD was delegated responsibility for a number of parasitic diseases differing broadly in control methodology such as schistosomiasis but not for the mosquito-borne diseases of yellow fever, dengue fever and viral encephalitis. The reorganization further fragmented responsibility for mosquito-borne diseases, diverted attention from malaria and reduced contact of WHO with National Eradication Programs. For example, ME utilized meetings of the Expert Committee on Malaria as a resource for establishing policies and recommendations. From 1956 through 1970 the Committee met 10 times. Since 1970 and the establishment of MPD, there have been 2 meetings and WHO Headquarters and Regional Offices have significantly curtailed technical assistance to countries. In recognition of the scope of problems of malaria resurgence, MPD actively promoted malaria research with and through the WHO Tropical Disease Research Program (TDR) and bilateral agencies such as the U.S. Agency for International Development. Research interests have focused on parasite biology, immunology, chemotherapy, computer epidemiology, and vector genetics, ecology, taxonomy, reaction to insecticides and biological control.

That such research is warranted and requires continuing support is unquestionable. In view of research progress during the past 25 years toward developing a malaria vaccine and/or methods for biological or genetic control of vectors, however, what control developments may realistically be expected by the end of the century? As a pragmatic public health engineer, the lack of concern by theoreticians and public health administrators to apply and demonstrate available mosquito control technology for control of malaria is appalling. Confidence in residual sprays produced a generation of "new" malariologists, entomologists and engineers. It is suggested that the observation of Dubos (1965), . . . "that DDT went further toward the eradication of malariologists than of mosquitos" referred to the "old" malariologist. It is further suggested that the strategy of the time-limited eradication campaign may not have taken into consideration the adaptability of biological life to survive. The vector and the parasite survived by developing resistance to insecticides and antimalarial drugs, respectively—the "new" malariologist survived by not adapting to problems of persisting transmission.

Reviews of national programs during the past 25 years have used numbers of malaria cases and blood parasite rates for assessing progress. Consideration of factors limiting the rate of progress has been limited largely to problems of vector and parasite resistance and/or budget and operational deficiencies. Because of the desire to relate progress of national programs to the status of the global campaign, investigations of the what, when, where, why and who of epidemics or areas of persisting transmission have been extremely rare. As a consequence, nominal references are available describing outbreaks or problems of urban malaria or those associated with water resource development projects.

Problems of urban malaria in Karachi, Pakistan and in Kenshasa, Republic of Zaire have been described by Carmichael (1972) and Ward (1977), respectively. Ward also reported increased transmission in an area of Afghanistan following introduction of irrigation. In 1980, urban problems in Freetown, Sierra Leone and Dar-es-Salaam and Zanzibar, Tanzania were observed as well as persisting transmission in the Gezira irrigation area of the Sudan.

In programs in the Americas, the control of an epidemic in a suburb of Port-au-Prince, Haiti was described (Schliessmann et al. 1973). In the following examples, residual sprays had and were being applied for protection of populations at risk: Between 1969–71, some 8,000 cases of malaria occurred in the 20,000 residents of Choluteca, Honduras and 7,000 cases were reported in the 1980 outbreak (PAHO 1982). In Brazil, Manaus reported about 8,000 cases and Porto Velho had approximately 3,000 in the population of 31,000 in 1972. Approximately 14% of the people in Guayaramerin, Bolivia had positive blood slides in 1973. During the 1970's persisting transmission was observed in localities in Mexico, Nicaragua, Colombia and Haiti and in irrigation areas of Mexico, Nicaragua, Honduras and El Salvador.

Since malaria in the Americas was considered a rural disease, virtually all cases in urban areas were classified as imported. The above examples may therefore be only the tip of the iceberg in programs which have spent some 1.4 billion dollars from 1956 through 1981. National expenditures increased from about $51,000,000 in 1962 to $113,000,000 in 1980 and the number of employees from about 24,000 to 27,000. The number of cases of malaria increased from 177,100 in 1962, to 338,400 in 1971, to 638,000 in 1981. The increase cannot be attributable to improved case detection since the percent positivity of blood slides also increased in the respective years from 2.5 to 3.3 to 7.0 (Pan American Health Organization 1982). To what extent the introduction of comprehensive mosquito control might have limited the increase is, of course, speculative. There can be little doubt, however, that the methods could have significantly reduced transmission in cities and possibly in several areas of persisting transmission which have been receiving residual sprays in excess of 20 years. In addition, it is suggested that benefits derived from well planned and supervised mosquito control programs on the morale and training of personnel would have been incalculable.

It is not intended to imply that no anti-mosquito measures were conducted in programs of the Americas. In the early 1960's larviciding was reported to have successfully curtailed transmission in the semi-rural valley of the Danarote River in Guatemala. During the 1970's, larvicidal operations were observed in areas of Guatemala, Nicaragua, Panama, Brazil and Haiti, which were limited in scope, supervision and effectiveness. In contrast, operations in a peripheral section of Acapulco, Mexico were well planned and supervised. Information that the 2.2 million people in the Americas being protected by larviciding in 1981 represented a 100% increase over 1980 is most gratifying (Pan American Health Organization 1982). Since no description of the operations was presented, their quality is suspect in view of observations of previous operations and the reduction from 19 engineers and 13 entomologists in 1962 to 2 each in 1981. Further, the assumption of many that technical personnel engaged in eradication activities for more than 20 years are knowledgeable, experienced and competent in the technology of malaria or mosquito control is unwarranted. For example, for several years virtually all malaria cases in a small city were occurring in its southern section in proximity to numerous vector breeding habitats. A drainage project was constructed some 4 miles north of the foci for its control.

CONCLUSION

During the first half of the century, malaria was controlled by reduction of vectors to levels, ideally, where transmission could no longer be sustained and by the use of antimalarial drugs.

control was developed by vector control specialists in collaboration with malariologists and entomologists. Knowledge of the epidemiology of malaria and of the natural history of the vector were considered essential for the selection of appropriate control measures. The measures were highly effective and practical in urban situations but were too costly for routine control in rural areas.

The development of the residual insecticides after World War II provided the means for economically controlling rural malaria. Their effectiveness depends on their killing potentially or actually infected mosquitos as they rest on sprayed surfaces. They are not a means for controlling mosquitoes since no discernable reductions in vector densities may result unless the vector is highly anthropophilic and endophilic. Residual sprays are credited with eradication of malaria in many countries and are the method of choice in rural and sparsely populated areas.

Mosquito control and residual sprays are separate, distinct and alternative methods for control of malaria because of differences in their mode of action. Comprehensive mosquito control is the method of choice in urban or densely populated areas because the permanent elimination of vectors through source reduction reduces need for continuing use of temporary measures. The principles and practices of mosquito control should also be incorporated into all water resource development projects to minimize problems of man-made malaria. The measures may also be used for supplementing residual sprays in areas of persisting transmission.

Ending the dichtomy that has prevented the appropriate use of mosquito control in programs of eradication dominated by residual sprays is urgently needed. To bridge the gap that has precluded its use, it is suggested that immediate steps be taken by WHO to establish pilot or demonstration projects in selected urban areas of persisting transmission in Africa, Asia and the Americas. The first objective is to adapt current technologies to local conditions and demonstrate their effectiveness in reducing mosquito populations and controlling malaria. Secondly, to utilize the projects for field training of epidemiologists, entomologists, engineers and vector control specialists in principles of interdependency and necessity of focusing their attention on the mosquito for an understanding of malaria transmission and its control. Thirdly, to develop methods of obtaining cooperation of the local people, com-

The initiation of demonstration projects (applied research) would expedite the beginning of the third cycle of malaria control—the appropriate use of comprehensive mosquito control measures *and* residual sprays for prevention of malaria.

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