Malaria: Entomological Aspect

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INTRODUCTION

Preamble

"Of all the ills that afflict mankind few have taken a higher toll than malaria"[1].

Known vectors

Of the three generae in the mosquito tribe Anophilini, only the genus ***Anopheles*** contains species of medical importance. Of the 400 species or so of ***Anopheles*** known, few members are established as sole transmitters of malaria: they are thus the most important vectors of human disease in the world. Gordon & Lavoipierre[2] lists some 25 species of Anopheles as capable of feeding on man. No more than 10 species of *Anopheles* act as transmitters in any one continent, with one or two species only serving as the main transmitters of malaria.

The West African species, ***A. gambiae*** (described as highly anthropophilic) and ***A. funestus*** (described as markedly anthropophilic) have wide distribution in the zone as well as in Africa and indeed are the major transmitters. ***A. melas*** is the West African salt water form. ***A. nili, A. moucheti, A. hargreavesi, A. melas*** and ***A. hancocki*** are vectors of malaria only in limited areas of West Africa.

As of today, only 4 species of ***Plasmodium*** namely, ***P. falciparum, P. vivax, P. ovale*** and ***P. malariae*** are recognized as causing malaria in man. ***P. ovale*** is the rarest type and seems confined to West Coast of Africa, where it produces mild infection. ***P. falciparum*** and its relative ***P. reichenowi*** of Chimpanzees and gorillas constitute simian malaria.

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BRIEF HISTORIES

Anophiline life-histories follow a common pattern. The egg about 1mm long is white at laying but darkens in course of development (fig 1). It is canoe-shaped and bears two lateral floats. Because of the floats, the egg resists submersion even during heavy rains. To develop and hatch, the Anophiline egg must float in suitable water. Some 50-150 such eggs may be laid (singly) by a female on water surface either at a sitting or spread over 2 to 3 nights. Under equable conditions of the tropics, eggs hatch in 2-3 days with the resulting larvae ("wrigglers) feeding at the water surface on bacteria, minute algae, protozoon and rotifers[3].

The 4th instar larva about to pupate measures about 1cm. Again, the resulting pupa (or "tumbler") is suspended on the water surface by palmate hairs and does not feed. In the tropics, the pupa emerges as imago in about 3 days, rests on the water surface or its empty pupal case in order to expand and harden its wings for about one hour prior to flying off subsequently. Before hardening of the wings, the least wind or wave action can cause the young fragile adult to drown. Copulation follows emergence.

Copulation: Emerging males and females meet on the wings in a "swarm" (largely established by males)[4] above the water surface ("dance of the gnats"). Seizure of the female by the male leads to insemination: the now joined pair falls out of the swarm only to disengage some minutes later. Following fertilization, the

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separated couples begin to seek food (nectar for male; blood-meal for female).- The blood meal is a must for maturation of eggs.

Most ***Anopheles*** sp. require one blood-meal to mature each batch of eggs: others may require 2 or more blood meals prior to oviposition, feeding occurring in the dark or during half-lighted periods of dusk or dawn. The female takes 3 to 5 minutes to engorge and is capable of feeding every 2 or 3 days.

Once fed the female resorts to a quiet corner to rest and ripen her eggs. Development of ovaries lasts about 7 days. Thereafter, she leaves the resting place to search for suitable body of water on which to lay. Adult longevity is 9 to 11 days in ***Anopheles gambiae***.

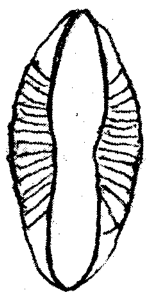

Figure 1 Anopheles egg, dorsal view

BREEDING AND ECOLOGY

According to Gordon and Lavoipierre[2], no type of water is potentially free from breeding of ***Anopheles*** sp. except

(i) Water in domestic utensils (likely to be highly polluted).
(ii) Water puddles (temporary and subject to frequent agitations).
(iii) Water subject to wave action.
(iv) Fast-running currents of streams
(v) Highly polluted water.
(vi) Water saltier than seawater.

It is difficult to give an exhaustive list of the locations in which anophiline larvae will be found. Generalizations are dangerous unless regarded as mere suggestions. Usual locations include:-

Bush, Forest, Jungle, etc: This includes pools and streams, Tree holes, bamboos holes etc; and leaf axils.
Permanent stationary water: Included are large areas with much vegetation (swamps, etc.); smaller areas with less vegetation (Ponds, ditches, etc).
Transitory collections of water: These are flood-water pools, seepage-water pools, puddles, hoof marks etc; ditches and drains; Rice fields, sugar plantation, etc.
Artificial collections of water: These consist of reservoirs and wells, tanks, cisterns, etc; Utensils (barrels, tins, pots, etc.).
Rivers and stream: Backwaters, edges; pools; slow stream; mountain stream.
Brackish waters: Maritime; inland.
Small rock pools: Rainwater in rock; at side of streams; and any available fresh water.

MALARIA TRANSMISSION AND SPECIES SPECIFICITY

For human malaria, the vector specificity for various species of *Plasmodia* vary[5].
P. vivax is transmitted by many species of Anopheles such as ***A. maculipennis*** and ***A. darling***; ***P. malariae*** in nature is found in ***A. gambiae, A. funestus*** and ***A. darlingi***; ***P. ovale*** is transmitted, in Tropical Africa, by ***A. gambiae*** and ***A. funestus***; while ***P. falciparum*** is transmitted by a wide range of Anopheles but especially by ***A. Funestus, A. gambiae, A. bancrofti*** and ***A. stephensi.***

Effectiveness and efficiency as vectors

Efficacy of Anopheles as vectors may be attributed to the adaptability of the mosquito trophy, food habits and the relatively long lifespan of adults.

Thus, although the male lacks ability to puncture human skin due to lack of mandibles, the female mosquito has greatly modified mouthparts. The components are all elongated: in particular, mandibles and maxillae (both paired) are stylets used in piercing human skin and protective thick shirts and linen materials on the stretch or the average socks. As the stylets enter the skin capillary, they are guided by the labium. To draw blood, the mosquito pumps salivary juice into the wound mainly to inhibit coagulation and blockage of food canal (by blood corpuscles). The cibarial pump and the pharyngeal pump have capacity to draw fluids into the food canal and finally into the insect gut.

Additionally, *Anopheles* species have relatively lengthy lifespan (9-34 days at the extreme) as to be able to first feed (preoviposition), accommodate infectivity period of plasmodium (10-16 days) by surviving for long and then to feed again in order to transmit malaria parasites, now processed into the salivary glands and trophi. The peculiar cyclical changes that produce infective plasmodia in Anopheles cannot occur in other forms of mosquitoes even if they drank human blood that is infected[3].

Malaria risk attributable to vector species

Although some 25 species of Anopheles are reportedly capable of feeding on man, certain species such as ***A. stephensi*** (in India) that show equal liking for human and animal blood but less opportunity to draw human blood become less important to malaria transmission just as the "wild" anopheles that depend less on human blood. "Wild" anopheles such as ***A. algeriensis*** has restricted opportunities to bite man. On the other hand, species such as ***A. gambiae*** in Africa and ***A. darlingi*** in America that readily enter human dwellings and prefer human blood to that of animals are literally exclusively responsible for malaria transmission over considerably large territories. In consideration of exophilic and endophilic species of Anopheles, there are also risks related to occupation and types of human homes occupied. Nomads and those involved in military operations may dwell in tents and open "houses" most of the time: such persons risk bites from "outdoor biters" than "indoor biters".

VECTOR CONTROL

Background: Even from the Roman times, the draining of swamps envisaged as source of poison gases erroneously responsible for the disease condition (fever) was advocated as control strategy. Later and more correctly so, the swamps were drained as suitable habitats for developing Anopheles eggs, larvae and pupae. This practice was further supplemented with destruction of immature stages on water surface using modern synthetic insecticides. Though still useful, these old-time procedures have not only proved expensive, if not impossible, especially when contemplating control on large scale such as during eradication campaigns. This is because many of the breeding habitats of Anopheles are difficult to locate, drain or treat, as they may be inaccessible (e.g. domestic receptacles; gutters/drains; tree holes; wells; leaf axils etc).

Available general methods for control of mosquitoes (ecological in nature) coincide with those for control of Anopheles. They include attacking oviposition or breeding sites; attacking immature stages; and attacking the adult stages.

Available modern methods of control of Anopheles involve: –

Attacking Oviposition or Breeding sites

Ridding human homes and their immediate surroundings of bushy overgrowths, empty containers capable of sustaining stagnant pools of water and even of broad-leafed crops, which encourage breeding of mosquitoes prevents breeding of mosquitoes.

Attacking Immature Stages

This is achieved through the spraying of receptacles with appropriate insecticides, namely, the biodegradable organophosphates and carbamates as larvicides. The residues of these chemicals rapidly break down. Examples of Organophosphates are: Malathion, dichlorvos (DDVP), temephos (Abate). They are noted for low mammalian toxicity.

Carbamates, include Carbaryl (Sevin) and Propoxur (Arprocarb) with knock-down effect similar to that of Pyrethrum compounds. Again they are noted for low mammalian toxicity. Both are used for surfacing of stagnant pools with petroleum oils or preferably Oil specially formulated for mosquito larva control (Flit MLO & Malariol H.S) into which spreading agents e.g. Triton X-100 had been incorporated, to suffocate immature stages of Anopheles. Since pupae do not feed, the mineral insecticide – Paris green is ineffective against pupae because it has to be ingested.

In aquaculture practices, the routine is to introduce top minnows (fish) into the water body: minnows are capable of avidly consuming larvae and pupae of Anopheles. On the principle that mosquito larvae and pupae do not thrive in bodies of water containing fish, species such as *Gambusia* have been effectively used in biological control of mosquitoes.

Attacks against adult Anopheles (especially the females) had entailed: -

Avoidance of mosquito bites or contact with mosquitoes through the screening of our homes (especially sleeping places) and offices is a useful strategy. This is because the anthropophilic species habitually visit such places for "food" (human blood). The female may also rest therein to mature her eggs. This method has proved effective since blood meal is vital for egg maturation.

The contact – avoidance technique can also use Repellents. These are synthetic compounds which either when applied to human skin or clothing, prevent attacks by undesirable anthropods. For example, Diethyltoluamide and the mixture known as 6-2-2 can be applied to skin or impregnated into clothing. In the former case, protection can last for up to 2 hours; in the latter treatment, protection can last for a few weeks.

Equally protective and capable of warding off adult mosquito/Anopheles attacks are certain dry formulations combining insecticidal action with combustible fillers which smolder upon ignition. The resultant 'smoke' dissuades the mosquito from biting. Styled pyrotechnics, the formulations could take the form of powders of nicotine such as is used in fumigation of greenhouses whereas pyrethrum formulations are used in mosquito coils. The use of mosquito coils in Nigeria is widespread, both indoors and outdoors. As stressed elsewhere, avoidance of contact with Anopheles adults is reasonably controlling since the action can deprive the mosquito of the blood meal that may be vital for egg maturation, thus disrupting the insects' lifecycle meaningfully.

Residual house spraying by which house interiors – air space, walls, ceilings etc – are routinely sprayed against endophilic insects using cylindrical pressurized sprayers. Otherwise called aerosols, these canisters incorporate commonly pyrethrum compounds which quickly knockdown flying insects including Anopheles that periodically invade homes. This is more or less a temporary measure. Regular application can ensure that contact with night-biting Anopheles is broken.

In the more professional arrangement, homes (especially walls and ceilings) are sprayed with residual insecticides such as lindane in the hope that adult mosquitoes must perch somehow and in the process might pick up lethal doses of the insecticide as to become dead soon after. This is a complicated procedure requiring knowledge, organization and calculations. Earlier, potent materials like DDT etc. were used for this purpose, but in view of their low mammalian toxicity, biodegradability and yet broad-spectrum action, Malathion (Organophosphate) and Carbamate spray formulations have replaced Organochlorine insecticides (including DDT) as relevant contact insecticides.

Most of the insecticides in use – botanicals, organochlorine compounds, organophosphates and carbamates effectively kill by their mere contact with the exterior of the insects concerned. That is to say that the poisons can be picked up through the feet, body wall, trachea etc.

Eradication: The outright destruction of adult Anopheles/Mosquito populations over wide territories/areas as part of the fight against malaria has been practiced successfully in certain parts of the world. For instance, under the umbrella of the WHO (World Health Organization), the glaring cases of success in this exercise had involved substantial parts of USSR, Venezuela and Mexico, India, Mainland

China and Taiwan. The advent of DDT and related. Organochlorine insecticides later revolutionalized eradication campaign procedures on grounds of their effectiveness and longer retention of potency. Eradication efforts, though expensive, differ markedly from the general control methods in the thoroughness with which the former are planned and executed in order to avoid emergence of resistance. In Nigeria, eradication efforts are well documented according to Onyeka[6]. Between 1949 and 1976 one programme in western Nigeria and three programmes in Northern Nigeria achieved different results, table 1.

Table 1 Some major Vector (and Disease) Control Programmes in Nigeria[6]

Location and Duration of Project	Area Covered	Method of Control	Immediate Result
Ilaro, Ogun State 1949 - 1953	Unspecified	3-monthly indoor residual spraying against *Anopheles gambiae* and *Anopheles funestus* using BHC	Tremendous reduction in population density of mosquitoes
Gwandu Emirate, Sokoto 1954 - 1958	1,740Km^2, inhabited by 120,000 people	6-monthly indoor spraying against vectors using DDT and Dieldrin	Reduction in indoor resting vectors and also in spleen rate
Gwandu Emirate, Sokoto 1957 - 1964	11,600Km^2, inhabited by 465,000 people	6-monthly indoor spraying against malaria vectors using DDT and Dieldrin	Reduction in resting vectors and spleen rate
Garki District, Kano 1969 - 1976	Unspecified but inhabited by 50,000 people	Indoor residual spraying against malaria vectors using Propoxur combined with Mass Drug (antimalarial) Administration (MDA)	Reduction of parasite (*P. falciparum*) rate in the protected people from 50% to about 3%

Development of Resistance: Resistance is manifested when applications of insecticides, which controlled a pest no longer do so, the symptom being that after initial repeated treatments, increased dosages are necessary to achieve the same kill.

The discovery of the man-made Organochlorine insecticides was a landmark in Insect Science. Chlorinated hydrocarbons are placed in two main groups: the DDT group and the Lindane-Chlordane group. Recently, many medically important insects such as Anopheles have developed resistance to organochlorine insecticides. Even at this, insects resistant to the DDT group earlier remained susceptible to the Lindane-Chlordane group and vice versa. However certain insects have independently developed resistance to both of these groups to the extent that none of the organochlorine insecticides can effectively control such populations anymore. Resistance has also been traced to certain botanical insecticides. The only way out had been to select from Organophosphates and/or Carbamate insecticides for effectively bringing down mosquito populations, Anopheles inclusive.

Side effects (of available Control methods)

Whether the control method is aimed at attacking oviposition sites or attacking immature stages or attacking adult Anopheles, involves elaborate application of insecticides. It is the ridding of our homes of empties capable of harbouring stagnant pools or biological destruction of immature stages with carnivorous fishes or screening of homes to avoid attacks by adults that may not strictly involve insecticidal materials. Therefore the inherent problems of Insect resistance to insecticides, Persistence of most insecticides in the environment and their killing of non-target organisms, remain unavoidable side effects from use of insecticides. As Service[7] rightly argued, the benefits of freeing people from disease may be balanced against polluting side effects of insecticidal use. The WHO advice is that we should use less persistent and more biodegradable organophosphates and carbamates. The effort is to integrate use of chemical methods with biological methods for better results.

Oils formulated for mosquito larva control have so far not produced resistance nor has the use of mineral insecticide such as the Paris green.

For avoidance of doubt, the possible side effects of organic chemical insecticides used in mosquito control are as follows: -

1. Direct toxicity to applicator or consumer.
2. Development of strains of pests which are resistant to the insecticide.
3. Outbreak of secondary pests that are no longer controlled by their natural enemies.
4. Destruction of non-target organisms such as parasites, predators, honeybees and other pollinators, fishes, birds and other wildlife.
5. Accumulation of harmful residues in crop plant; man and his domestic animals; wildlife; and the environment.

Contraindications:

Elsewhere in this write-up, the safe uses of most insecticides, with their in-built merits and demerits have been briefly discussed. Suffice it at this stage to add that –

1. The burning of mosquito coils in closed apartments is not recommended as the resulting fumes are capable of provoking respiratory allergies, if not disorders, in humans and animals.
2. The use of aerosols, especially in enclosed environments, should entail strict adherence to the manufacturer's specifications.
3. Similarly, insecticidal solutions beyond the manufacturer's recommended concentrations and applications are not advised because of need to minimize fallouts to the environment and their possible "biological concentration" along food chains[8]. Corrosion/damage of equipment must be avoided.

Constraints/difficulties of implementation

Large-scale Anopheles control programmes, which target mainly adult mosquitoes, are rooted in man's potential to spray habitations with potent insecticides. From the sprayed walls and ceilings of such habitations, mosquitoes dose themselves to death. The programmes as such are prohibitive in terms of costs and only well-funded organizations, with cooperation of regional governments, can sponsor the control programmes massively. They are prohibitive because

1. Insecticides per se are very expensive. Added to this is the cost of running laboratories all over the world in search for safer new insecticides.
2. The campaigns also require use of large numbers of sprayers/spraying machines, which call for numerous ordinary operators.
3. Equally regarded as constraint would be need for numerous specialists, some of them full-time e.g. doctors, scientists etc. to draw and analyze blood samples.
4. Involvement of large numbers and different types of houses some of which may require reconditioning through re-plastering and repainting
5. The impermanence of dwellings as seen in nomadic life style of certain inhabitants contributes reasonably to the difficulties encountered. For example, in parts of Brazil where the programme was pursued, most local houses then reportedly had no walls and the spraying programme collapsed.
6. Education of the campaign teams and the people is yet another constraint in terms of costs[1].

Conclusion: Widespread usage of insecticides, resulting in higher standards of health, among other benefits, has made the human society increasingly dependent on them. To achieve the present levels of pest control, chemical insecticides are, for the time being at least, essential.

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