Protective clothing

Clothing can offer protection from biting insects when it is of a thickness and texture through which insects cannot easily bite. Lighter colours generally attract fewer insects than darker colours. Boots can protect the ankles from biting insects. Thick socks in combination with long trousers offer protection when the bottoms of the trousers are tucked into the socks. Some protection is also offered by long-sleeved shirts, headnets, collars and hats. However, some insects can bite through socks or other clothes; the treatment of clothing with an insecticide or repellent can deter this.

The small biting midges, sandflies and blackflies are unable to bite through clothes, even if these are made of thin material (40). People active during daytime can best protect themselves by wearing thin clothing over as much of the body as possible and applying repellents to the parts of the body left exposed (26, 41). Repellents are only partially effective against swarms of biting midges. Headnets or hooded wide-mesh jackets impregnated with a repellent offer good protection (22, 42–44).

Anti-mosquito garment

A vest has been developed in the former USSR which is too thick for mosquitoes to feed through and which allows the user sufficient aeration of the body. It consists of an undervest, with long sleeves made from a wide-mesh material of which the fibres are about 0.5cm thick, covered with a long-sleeved conventional shirt (45).

Treated clothing

Clothing can be treated with repellents to prevent insects from landing or feeding, or with quick-acting insecticides of the pyrethroid group, such as permethrin. These latter compounds do not repel the insects but allow them to make contact with the fabric and irritate or kill them before they manage to feed. The application of repellents to clothing and other fabrics is preferable to skin application because it reduces the likelihood of allergic reactions. Limited contact with the human skin and strong adherence to fabric fibres make it possible to use higher doses of repellents and insecticides.

Synthetic pyrethroid insecticides are generally preferred to volatile repellents for treating clothing because:

- they act quickly and repel or kill biting insects;
- they are long-lasting and to some extent withstand weathering, sunlight and washing in cold water;
- they are more pleasant to use (little or no odour, colour or greasiness);
- they are safe and do not irritate human skin if applied at the correct doses (46);
- they do not affect plastic products;
- they are cheaper than repellents, only infrequent applications of small amounts being required.
However, if the clothing is treated with a non-repellent pyrethroid, flying insects may feed on uncovered skin, necessitating the application of a repellent to the bare skin. Because of the vapour effect, clothing freshly treated with a volatile repellent offers more protection to uncovered skin than that treated with a pyrethroid insecticide.

Impregnated socks can give effective protection against blackflies, which often bite around the ankles. Impregnated trousers and stockings provide effective protection from ticks and mites (47). Treated clothing is also effective against mosquitoes, sandflies, biting midges, fleas and body lice (47–52). Repellents may remain effective for up to a week when applied to clothing. An extended efficacy can be obtained by sealing the impregnated fabric in a container or airtight bag when not in use to prevent evaporation of the repellent. A repellent applied to clothing normally retains its effect longer than on skin because there is:

- no loss by abrasion;
- no loss due to skin absorption;
- no removal of the active compound by sweating;
- slower evaporation because of lower temperature, except when clothing is exposed to sunlight;
- better adherence to cotton and synthetic fibres.

Clothing treated with permethrin can remain toxic to insects and ticks for several weeks or months, depending on wear and exposure to washing and rain. Treated clothing may remain effective after up to 10 rinses with cold water and soap. However, more permethrin is lost after washing in hot water and soap (50, 52).

**Which repellent or pyrethroid?**

Any of the repellents considered safe for skin application may be used to treat clothing. Permethrin has been extensively tested and is still considered the insecticide of choice for clothing treatment (46). Some of the other pyrethroids, e.g. cyfluthrin, may also be suitable but most of the safe pyrethroids degrade quickly in sunlight.

**How to treat clothing**

Clothing can be treated with permethrin by spraying the insecticide from a pressurized can or by soaking in an aqueous emulsion. The recommended dosage for coats, jackets, long-sleeved shirts and trousers is 1.25 g/m² (0.125 mg/cm²) and for short-sleeved shirts it is 0.8 g/m² (0.08 mg/cm²). A pressurized spray containing deet may be more easily available. The recommended dosage for deet is 20 g/m² (2 mg/cm²), or about 70 g of active ingredient for one piece of clothing. Technical-grade deet suitable for the treatment of fabrics by dipping is available as 30% and 95% mixtures with alcohol. Treatment procedures are described on p. 85.

**Treated bedsheets**

People sleeping out of doors in places where the nights are cool, and for whom mosquito nets are unaffordable or impractical, could consider covering themselves
at night with sheets or other fabrics treated with insecticide or repellent. This method has not yet been tested but it can be expected to be as safe and effective as use of treated clothing. For complete coverage of the body in hot climates it would be possible to use thin, open-weave fabrics that allow unobstructed breathing.

**Insect-repellent wide-mesh netting jackets**

Special jackets made of wide-mesh netting, with a hood to protect the head, may provide sufficient protection from biting insects when impregnated with deet or other repellents (Fig. 1.41; 43, 53–56). They are especially suitable for people on brief visits to areas infested with high densities of mosquitoes and other biting insects, as in northern Siberia, Scandinavia and Alaska. Open-mesh material offers the advantages that it can be used in combination with normal clothing or with no clothing beneath and that it is relatively cool.

A disadvantage is that the netting easily gets entangled in dense vegetation; it is most practical in areas with little vegetation. The jackets can be made of strong wide-mesh cotton or a mixture of polyester/cotton or nylon. Mesh jackets sold in Canada and the USA are made of polyester netting containing strands of cotton. Cotton is required to absorb the desired treatment level of 0.25 g of deet per gram of netting (or 10–15 g of deet per m²). The jackets should be stored in an airtight plastic bag when not in use.

**Insect-repellent headnets**

Wide-mesh netting similar to that used in the jackets described above can be employed to protect the head and neck (Fig. 1.42; 57, 58). It is preferably used in combination with a hat or other head covering. The netting allows good visibility and ventilation.

**Insect-repellent bands and anklets**

Many species of bloodsucking insects bite predominantly around the ankles and wrists. Strips of cotton fitted around the extremities and impregnated with a
repellent reduce biting substantially (Fig. 1.43; 18, 59). The cotton strips are about 10 cm wide and 35 cm long and can be provided with buttons and buttonholes or can be elasticized (like sweat bands) so that they remain in place.

The bands are used with a repellent rather than an insecticide because repellent vapour action protects nearby uncovered areas of the body. When not in use, the anklets should be stored in an airtight plastic bag or tin to reduce evaporation of the repellent. The recommended dosage of deet concentrate (95%) for one band is 4 ml, or the band may be saturated in a 30% deet/alcohol mixture. If used for about 2 hours each evening, deet-impregnated bands remain effective for at least 50 days.

**Insect-repellent detachable patches of fabric**

The treatment of clothing can be avoided by using detachable patches of fabric impregnated with repellent. The patches can be attached by, for example, press buttons or Velcro strips. In one study (59), four 15-cm × 15-cm pieces on the front of a shirt and one on the back were found to reduce mosquito bites considerably over a period of more than two months when used twice a week. The patches can be treated by soaking in a 10% solution of deet or DEPA and should be stored in

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**Fig. 1.42**

Headnets impregnated with repellent can be used to protect the head and neck from mosquitoes and other biting insects.

**Fig. 1.43**

Anklets impregnated with repellent stop insects from biting the ankles, feet and lower legs.
airtight plastic bags when not in use. The advantages of the treated patches are that they do not come into direct contact with the skin, they can be removed when clothing has to be washed, and they provide more economical and simpler treatment.

**Insecticide vaporizers**

Unlike repellents, only a few insecticides, such as dichlorvos, have a spatial effect at normal room temperature. However, some insecticides kill or repel insects at a distance through an airborne effect when vaporized with a heating device. Insecticides can also be released into the air as aerosols, for example when sprayed from pressurized spray cans.

Dispensers releasing insecticide into the air help to protect people nearby. Traditionally, plants or wood containing repellent or insecticidal substances have been burned (23, 60). More modern devices include mosquito coils, vaporizing mats, dichlorvos dispensers and aerosol spray cans; these are relatively inexpensive and may protect several people at a time. However, their use is confined to houses and other places with limited ventilation. They may be effective in dense vegetation where the repellent is not too diluted by air movements. The compounds used are mostly quick-acting knockdown insecticides with both a killing and a repellent effect, for instance the allethrins, a group of pyrethroid insecticides. The allethrins are considered to be safe to humans if used properly.

Insecticide vaporizers protect against mosquitoes and biting flies by:

- preventing them from entering a room (deterrent effect);
- irritating and disturbing them after contact (excito-repellent effect) and preventing them from biting;
- paralysing or killing them (insecticidal effect).

**Mosquito coils**

Coils (Fig. 1.44) are among the most popular and widely used insecticide vaporizers because they are easy to use, effective (61–66) and inexpensive. Once lit, coils
smoulder at a steady rate for 6–8 hours, steadily releasing insecticide into the
air.

Originally, mosquito coils consisted of a mixture of pyrethrum powder (see
box), a combustible filling material, such as sawdust, and a binder, such as starch.
Some of the synthetic pyrethroids, especially knockdown agents like the allethrins,
are now commonly used in coils. They are more effective and more easily obtain-
able than pyrethrum (61). DDT is an ingredient of some brands of coil in China
but is ineffective when used in this way (61). To make the smoke more acceptable
the coil sometimes incorporates a fragrance. The shelf-life of coils is at least three
years if they are packed in paper or plastic and stored in boxes, protected from light
and moisture.

Pyrethrum

The pyrethrum plant (Chrysanthemum cinerariaefolium) contains several active
substances (pyrethrins) that are toxic to insects. The active material can be extracted
with a solvent from the dried flowers (Fig. 1.45) and stems and has commonly been
used in sprays for quick knockdown of flying insects. Dried pyrethrum flowers,
ground to a powder, or the extract obtained from them, are used to produce anti-mos-
quitos and coils. However, because of the uncertainty of supplies and the intro-
duction of more effective synthetic pyre-

throids, the use of pyrethrum has declined.

How to use

The coil is placed on a suitable stand and the free end is lit. A metal stand is
normally provided in a box of coils. The stand ensures that the coil does not touch
or rest on a surface, which might cause it to go out or to set fire to nearby
flammable objects. When used indoors, coils mounted on stands should be placed
on a fireproof base, such as a saucer or plate and as low as possible in the
immediate vicinity of the people to be protected.

The coils should be lit just before mosquitos become active. One coil is
sufficient for a normal bedroom (35 m³). In confined areas such as a closed tent or
a small closed room, the smoke may cause irritation to the eyes and lungs. For
larger spaces, several coils should be placed at different points. If rooms are
ventilated or if the coils are used outdoors it is important that they are upwind of
the people to be protected.

If lit in the evening, a coil can provide protection until early morning. However,
a strong draught in a room with an open door or windows, or windy conditions
outdoors, may significantly speed up the rate of burning while dispersing the
insecticide and diluting its effect. For better protection a coil should be used
during the early evening hours indoors (or a repellent should be applied to exposed skin or clothing outdoors) and a mosquito net should be used indoors during the remaining part of the night.

**Coil holders**

The efficacy, convenience and safety of coils can be improved by placing them in special containers or holders. Holders may prolong the burning time by up to 20%. Holders also protect the burning coil from wind and rain, and prevent flammable objects from making contact with it. Various models of coil holder are widely available in Asia (Fig. 1.46). They can also be easily made from used cans with the metal stand soldered to the bottom. The can itself is perforated with small holes in the side and top.

**Portable coil holder**

People working in forested areas where there is not much wind (woodcutters, rubber-tappers, plantation workers, gold-miners) can obtain some protection from biting mosquitoes and phlebotomine sandflies by attaching one or two smouldering coils in special holders to their belts (Fig. 1.47). Each coil is kept in place between two pieces of metal or non-flammable fibre glass gauze. The advantages of coil holders over skin repellents are that they are cheaper, do not elicit any skin reactions when used frequently, and are not washed off by perspiration.

![Fig. 1.46](image)

Commercially available coil holders. The holders are commonly used in Asia, especially in crowded rooms. They improve the performance, convenience and safety of smouldering mosquito coils.
**How to make coils**

Coils can be made cheaply from an insecticide and a flammable base material (67).

**Ingredients**

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>% by weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.3% pyrethrum powder</td>
<td>20–40</td>
</tr>
<tr>
<td>Water-soluble glue (starch gel)</td>
<td>25–30</td>
</tr>
<tr>
<td>Filler (coconut shell flour, sawdust, jute)</td>
<td>30–40</td>
</tr>
<tr>
<td>Fungicide (benzoic acid, sodium dehydroacetate)</td>
<td>0.2–0.5</td>
</tr>
</tbody>
</table>

More effective alternative insecticides are (+)-allethrin (0.2–0.3%) and (+)-trans-allethrin (0.10–0.15%). If one of these is used the quantity of filler is increased to 60–80%. To regulate burning, commercially produced coils often contain potassium nitrate. The sawdust particles have to be of the correct dimensions, otherwise the coil does not burn well. This has to be determined by trial and error. Mix the ingredients thoroughly and add an equal weight of water to produce a uniform and homogeneous paste. Compress the mix in a mould of the desired shape and place on a rack to dry. A suitable mould can be carved out of a piece of wood. If the device is meant to burn for many hours a coil shape is the most convenient. For shorter periods (3–4 hours) it is possible to give it the shape of a long thin stick.

**Fig. 1.47**

A rubber-tapper with a special portable coil holder attached to his belt.
Repellent ropes

A cheaper alternative to mosquito coils has been developed in India (68): ropes soaked in a solution of a suitable insecticide, when burnt, produce a smoke that kills and repels mosquitoes and biting flies. The recommended material, widely available in India, consists of jute fibres, is about 0.9 cm in diameter and weighs about 28g/m. Esbiothrin was used in India, but other insecticides used in mosquito coils would also be suitable. A 1.2-m impregnated rope will burn for 10–12 hours if hung indoors from a ceiling. The ropes are preferably burned inside cylinders of wire mesh to prevent them from making contact with flammable materials.

How to impregnate ropes:

If esbiothrin is used for impregnation the recommended dosage is 1 ml/kg: 1 ml of technical-grade esbiothrin is dissolved in 1.15 litres of kerosene, and a 1-kg jute rope is dipped into the solution until saturated. The rope is dried in the shade and stored in a box or bag until required.

Vaporizing mats

Where electricity is available, small electric heating plates can be used to vaporize volatile insecticides from mats (Fig. 1.48). This popular method has the advantage over coils that no visible smoke is produced. The mat is often a porous paper pad measuring $35 \times 22 \times 2$ mm, impregnated with an insecticide. The mats are packed in foil to prevent evaporation of the insecticide before use. The insecticides are usually allethrin pyrethroids, e.g. bioallethrin, esbiothrin and esbiol, which are considered to be safe to humans but have a rapid killing and repellent effect on mosquitoes and biting flies (62, 69).

The mats contain an indicator dye that changes colour from blue to white in about the same time that it takes for the insecticide to evaporate. If used in a room of about 35 m$^3$, a mat containing, for example, 40 mg of $(+)$-allethrin or 20 mg of $(+)$-trans-allethrin will last for 8–10 hours. However, towards the end of the period less insecticide will be released. In larger rooms more than one mat, or mats containing more insecticide, should be used.

Several types of electrical heater are sold with the mats. All have a flat pad-like resistance unit (5 to 6 watt) mounted in a ventilated plastic case. Some models are directly plugged into a power point. The heater normally produces a temperature of 160 °C between the mat and the heater and 125 °C on the upper surface of the
mat. A mat temperature of about 145 °C is needed for vaporizing the insecticide. Some heaters on the market do not achieve this temperature and therefore do not vaporize the insecticide sufficiently. A heater takes about 30 minutes to reach its operating temperature.

**Electric liquid vaporizer**

This device is a technological improvement on vaporizing mats. The insecticide is evaporated by an electric heater through a porous wick from a reservoir bottle containing the liquid (Fig. 1.49). The liquid insecticide lasts for up to 45 periods of 8–10 hours. Many models are controlled by a switch and have a pilot lamp.

This method is more convenient and more effective than the mat heater because the amount of insecticide released remains constant over time, but for the moment it is more expensive.

**Dichlorvos dispenser**

Dichlorvos is a volatile liquid whose vapour is highly toxic to flying insects. Liquid dichlorvos impregnated into a special absorbent material, such as polyurethane, slowly evaporates without the need for a heating device. A dispenser usually consists of a piece of polyvinyl chloride plastic or a resin saturated with liquid dichlorvos, mounted in an open plastic support (Fig. 1.50). Some dispensers are strips measuring 5 × 25 cm, while others have the shape of a small box. They are sealed in an airtight package to avoid premature vaporization of the insecticide.

The dispenser in its plastic support is placed at a height of 1–2 m above the floor or is suspended from the ceiling. Most models contain sufficient dichlorvos to treat a room of 15–30 m³ for 1–2 months. A strong draught will shorten the period of effectiveness. The advantages of this method are the long period of effectiveness and the lack of a need for electricity, making it especially suitable for use in rural houses, tents or caravans.

The continuous exposure of young children and sick or elderly people to dichlorvos in poorly ventilated rooms should be avoided. Some reports suggest
that continuous exposure to dichlorvos may have caused health problems in a few people.

**Pressurized spray cans**

Pressurized cans provide a convenient method of spraying insecticidal aerosols in rooms, on mosquito nets, vehicles and so on, to obtain rapid knock-down of mosquitoes and other flying insects. The spray cans contain a concentrate of the insecticide in an organic solvent or water together with a liquefied or compressed gas propellant. Pyrethrum used to be the common ingredient in many different brands of aerosol sprays. Today, however, the synthetic pyrethroids and to a lesser extent the carbamates (propoxur and bendiocarb) and organophosphorus compounds (dichlorvos) are the main active ingredients. The spray may contain a “knock-down” agent to give a rapid effect, a slow-acting agent that actually kills the insect, and a synergist—usually piperonyl butoxide—to increase the activity of the ingredients. In view of worldwide concern about the use of chlorofluorocarbons, which may affect the ozone layer of the atmosphere, most brands now contain other propellants.

The spray can is operated by briefly pressing a valve incorporating a nozzle on top of the container. The spray can be directed against flying or crawling insects or sprayed into a room (Fig. 1.51). Rooms should then be kept closed for about 15 minutes in order to kill as many insects as possible. The hiding and breeding places of cockroaches, fleas, lice and bedbugs can be sprayed directly from a distance of about 20 cm.

Space sprays have a very short residual effect: once the aerosol has settled out of the atmosphere insects can again enter the area with impunity. Furthermore, the active ingredients (commonly (+)-allethrin or (+)-trans-allethrin) are rapidly degraded by light. An advantage of short-lasting insecticides is that they do not leave any toxic residues on beds, furniture or other surfaces. This method works best in screened spaces and can be repeated daily or several times a day.

The spray can is under pressure and should not be exposed to direct sunshine or temperatures over 50 °C. Most sprays contain the flammable substances propane or butane and should not be directed at fires or smouldering objects, e.g. cigarettes.
Water-based aerosol spray

Water-based aerosol sprays have recently been developed and are claimed to offer the following advantages over oil-based aerosols: they leave no oil residues or stains on surfaces, do not produce an unpleasant smell or an irritant effect, and are not flammable. However, the droplets of oil-based aerosols are usually finer and more effective. The cans must be shaken well before use.

Spray gun

Before the invention of the pressurized disposable spray can, a hand-compressed spray pump was commonly used. This spray pump has a reservoir which can be filled with a solution of pyrethrum or other insecticide (Fig. 1.52). It is cheaper to use a spray gun than to buy pressurized spray cans. However, the droplets in the aerosol from a spray can are finer, stay in the air longer and are usually more effective. Spray guns are nowadays used mainly against crawling insects.

Spray guns and the liquids to fill them are commercially available in some countries. The liquids can be based on equal parts of kerosene and alcohol, to which are added a small quantity of one or two quick-acting insecticides and a perfume.

An example of a standard insecticide mixture is:
Bioallethrin 0.1%
Permethrin 0.5%
White spirit (or pure alcohol) 49.7%
Kerosene 49.7%

Propoxur and dichlorvos are among the many other insecticide mixtures that can be used.

Electronic buzzers
Battery-operated electronic devices that produce a high-pitched buzz have been widely sold as mosquito repellents. Some manufacturers have claimed that they simulate the sound of a male mosquito and that this sound is repellent to mated females. Others claimed that the buzzers simulate the sound of the dragonfly, thus inducing mosquitos to fly away. However, several independent scientific investigations in different countries have convincingly demonstrated that these electronic gadgets provide no protection from biting mosquitos (70, 71). An apparently positive test by producers was faulty in design. In the United Kingdom some companies have been fined for making unsubstantiated claims in their advertisements for buzzers.

Protection measures in hammocks
Hammocks are used in many parts of the world for sleeping and resting. They are often used in jungle areas and offer the following advantages over other sleeping places:

— they are not easily accessible to crawling insects, scorpions, snakes and other small animals;
— they are well ventilated and suitable for use in hot climates;
— they provide dry sleeping places and are not in contact with damp soil;
— they are light and easily folded and are therefore easy to transport.

However, they do not protect the user from flying insects. Mosquitos often settle and feed where the body touches the lower part of the hammock (Fig. 1.53). At night the use of hammock mosquito nets (see p. 79) can offer protection but during daytime the use of nets is often considered inconvenient for various reasons, among them poor visibility and reduced ventilation.
Suggestions for protection in the absence of a mosquito net

- Application of a volatile repellent such as deet to the lower part of the hammock at a dose of about 20 g/m². The repellent persists for only a few days and some mosquitos may try to feed from above.
- Placing a burning mosquito coil close to the hammock. If used in a coil holder it is safe to place the smouldering coil under the hammock.
- A method that provides longer-lasting protection is the impregnation of the whole hammock or the lower part of it, using a sponge, with a quick-acting pyrethroid insecticide. Mosquitos making contact with the treated part of the hammock are killed or incapacitated. Because of the thickness of the hammock material this method requires a relatively high dose of insecticide (1.5 g of permethrin or more per m²).
- A more economical method, requiring far less insecticide and probably equally effective, is that of protecting the lower surface of the hammock with an impregnated piece of netting or cloth (Fig. 1.54). This material can be loosely attached to the hammock with a few pins or with stitches. It should be attached close to the hammock so that mosquitos are more likely to settle on it and be killed. However, the netting should not touch the hammock except where it is pinned or stitched on, because this would enable some mosquitos to feed before being killed. The advantages of using removable material are that it is easily impregnated, can be removed when the hammock is washed, and can be stored in an airtight box when not in use.
Mosquito nets

Mosquito nets (Fig. 1.55) have been in use since very early times to protect people against bloodsucking insects at night; they also help to protect against other creatures, such as spiders, cockroaches, beetles, lizards, snakes and rats. When made of thicker opaque sheeting they also protect against cold and dust, and provide privacy.

Mosquito nets normally have a mesh size of 1.2–1.5 mm, which is sufficiently small to prevent mosquitos from entering. Very small insects, however, such as phlebotomine sandflies and biting midges may enter. Only opaque sheeting, very fine-mesh jersey netting (mesh size less than 0.2 mm), and impregnated netting (see p. 82) offer protection against these insects. In hot climates, poor ventilation through fine-mesh netting is a serious disadvantage. The wider the mesh size the better the ventilation, but if the mesh is more than 2 mm most mosquitos can enter.

Netting materials

Traditional netting materials are linen, raffia (palm fibre) and hemp. Nets are now made of cotton or synthetic fibres (nylon, polyester or polyethylene). The quality of a mosquito net depends on the thickness and strength of the threads and on the production process. The threads in a mosquito net can be woven or knitted (Fig. 1.56). A disadvantage of woven nets is that the threads can slide over each other, thus creating enlarged holes through which mosquitos can pass. However, in woven nets made of stiff, polyethylene fibres this does not seem to be a problem.

Synthetic nets usually cost less and are less likely to rot than cotton nets. Inexpensive nets of cotton, nylon or polyester often contain starch, which gives a less flimsy, more attractive appearance. The starch dissolves when the nets are washed.
Some terms for characteristics of netting material

**Mesh:** the number of holes per square inch. For example, mesh 156 has $12 \times 13$ holes per square inch (see Fig. 1.56).

**Mesh size:** the size of the openings in a net. It is determined by the number of holes per square inch (the mesh) and the thickness of the threads with which the netting is made. The mesh size recommended for most tropical countries is between 1.2 and 1.5 mm.

**Denier:** an indication of the weight (and therefore the strength) of the thread. It is defined as the weight in grams of 9000 metres of a single thread. Commonly used mosquito net threads have a denier between 40 and 100 but denier 40 is easily torn and 70 or more is recommended.

**Strength:** an indication of the pulling strength of a thread, expressed in grams per denier. If 1 metre of 40 denier thread breaks with a load of 160g, the strength is 4g per denier.

**Monofilament/multifilament fibre:** the thread of a mosquito net consists of one or more fibres. A nylon or polyester fibre is multifilament (consisting of many filaments), while polyethylene fibres are monofilament.

**Sheeting border:** nets are often provided with a strong border of cotton sheeting or synthetic jersey. This protects the net from wear due to daily tucking in of the net under the mattress. If the border is wide enough (30 cm) the extra material will also reduce bites from insects that may make contact with the lower part of the net whilst the occupant is asleep.

**Ceiling:** fine-meshed jersey or other opaque material is often used as a ceiling for the net to prevent dust from falling through.

**Colour:** white material is most commonly preferred but other colours are available. In a white net it is easier to see any mosquitoes that have entered. A darker colour may be preferable because nets are less likely to appear soiled.
Mosquito net models

Mosquito nets are produced in different sizes and shapes. A net should cover the sleepers completely and should be sufficiently spacious for them to avoid contact with the fabric. Sufficient length is needed so that the net can be tucked in under the mattress or sleeping mat. Various models have been developed for specific circumstances. They differ in convenience for daily use, and prices vary widely. The method of suspension is an important consideration.

Rectangular net

This is the most popular and practical model, normally used over a bed or sleeping mat. It is suspended from four or more loops along the upper edges. This model can be provided with an overlapping entrance flap of about 60 cm on one of the long sides to facilitate entering or leaving without pulling out the part of the net tucked in under the mattress (Fig. 1.57). Care should be taken to ensure that the overlap is properly closed to keep mosquitoes out.

Dimensions vary: most nets have a height of about 150 cm and a length of 180–190 cm. A single-size net has a width of 70–80 cm, contains about 9 m² of netting material, and is used to cover one person on a single bed or sleeping mat. Double nets with a width of 100–110 cm (10–11 m² of netting) and family-size or large double nets with a width of 130–140 cm (12–13 m² of netting) are used for larger beds. Extra-large nets with a width of 180–190 cm (14–15 m² of netting) are used for very large beds and where several family members sleep together on a sleeping mat in one room. The optimal size depends on sleeping habits and available space.

Very large nets are sometimes used by groups of people (e.g. in Mauritania) who spend the early evening hours together. These nets are used in shelters that provide shade during daytime but do not have walls.

Special supports for rectangular bednets

Indoor supports Where it is customary to rearrange and use beds for seating during daytime, nets should be supported using detachable poles or mosquito net supports attached to the ceiling or wall (Figs. 1.58 and 1.59).
Fig. 1.58  
A support system for a rectangular net which enables quick and easy overhead storage during the day. The components can be made of bamboo, wood or plastic.

Fig. 1.59  
A support system for a rectangular net which can be used indoors or outdoors (adapted from 72).
Fig. 1.60
Flexible wooden poles can be placed in a crossed position at the ends of the bed with the lower ends tied or attached to the legs of the bed. The poles and net are easily removed during daytime.

Outdoor supports Where people habitually sleep outdoors during the hot season nets are best supported by a frame that can be easily detached from the bed (Fig. 1.60) (72).

Circular net
Circular, or conical, nets are often preferred because they can be hung from a single support (Fig. 1.61). The top is suspended by a loop attached to a sleeved hoop of rattan or plastic. The nets are mostly available in double size. Compared with the rectangular net, more care has to be taken to avoid contact between the body and the net, which would allow mosquitos to feed.

Fig. 1.61
A circular net suspended from a single support.
**Wedge-shaped net**

Wedge-shaped nets are available only in single size. They are much cheaper than rectangular bednets because only about half the netting material is needed. The head end is suspended by a loop attached to a sleeved wooden bar. It can be hung from any suitable fixing point above the head of the bed or sleeping place. The foot end, which is made of thick material so that mosquitos cannot feed on the feet, must be firmly tucked under the mattress or otherwise secured (Fig. 1.62). Because of its small volume when folded and because it can be suspended from a single point, the wedge-shaped net is convenient for travellers and campers.

**Self-supporting nets**

These nets are available in small sizes. Usually marketed for the protection of food from flies, they are also used to protect babies and infants (Fig. 1.63). Because the nets are self-supporting they are easy to set up indoors and outdoors.

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**Fig. 1.62**
A wedge-shaped net.

**Fig. 1.63**
Two self-supporting nets used to protect babies and infants. The collapsible “umbrella” net (left) is commercially available. The other model (right) is also collapsible and consists of U-shaped pieces of wire; it is easy to make.
Camp bed with protective cover

A collapsible camp bed with a self-supporting cover has been developed for use by workers in rainforest areas, for instance gold-miners in the Amazon region. The cover is a detachable part of the bed and consists of waterproof (polypropylene) sheeting with built-in ventilation openings of mosquito gauze and a door of mosquito netting closed with a zipper (Fig. 1.64). It is more comfortable than a hammock with a mosquito net, but it is also more expensive and more bulky.

Mosquito nets for hammocks

Special mosquito nets are available for hammocks; these are similar to rectangular bednets but have sleeves for the hammock ropes at each end. In some areas these nets are made from opaque cotton cloth which offers privacy, provides additional protection from the cold and is more sturdy. To prevent mosquitoes from entering, the nets can be left hanging down to touch the ground.

If the ground surface is dirty or if there is a need to prevent small animals from climbing up the net, it can be closed by pulling up one side under the hammock with strings and tucking the other side into it. The sleeves are tightly closed around the hammock ropes by means of strings. The net is suspended from four points, as shown in Fig. 1.65, or from two points if horizontal pieces of wood are used in the roof to keep the two long sides apart. In the latter case the net is suspended from a single string tied between the two hammock rope ends.

Unfortunately, the net is often tight around the hammock, and direct contact between the body and the net or between the lower part of the hammock and net may occur, enabling mosquitoes to feed. To avoid this a larger net should be used.

A special military or expedition model for use in jungle areas has the netting attached to the sides of the hammock. At the two ends the hammock is extended with pieces of wood. It is covered by a waterproof roof. Entry is via an opening with a zipper. To prevent mosquitoes biting from below, the hammock is made of impenetrable material which also provides insulation from the cold. However, in hot climates these nets trap sweat, making them uncomfortable to lie in.
Instructions for use of mosquito nets

Any holes developing in the net should be mended as soon as possible. It is important to use a net sufficiently large to cover the entire bed or sleeping place, so that contact between the body and the netting is avoided and mosquitos cannot bite through the net.

In some areas it is customary for several people, especially children, to share one net. This may result in overcrowding, and parts of people’s bodies may protrude from the net during the night (Fig. 1.66). A bigger net or an extra one could be used to prevent overcrowding. Alternatively, the net can be impregnated with an insecticide to repel or kill mosquitos before they land on the unprotected skin.

A net can be closed by:

— tucking it in under the mattress or sleeping mat;
— lowering it around the sleeping place until it makes complete contact with the floor; a border of heavy material ensures good contact, or weights can be put on the border or inserted in the hem to keep it in place.

The net should be let down before darkness falls. Mosquitos that manage to enter can be killed by swatting or by spraying with insecticide before the people concerned go to sleep.
Open floor with slits
Sometimes mosquitos enter a net from underneath. This problem often occurs in stilt houses with bamboo floors or containing beds with mattresses made of woven string. Sleeping mats can give protection when used with the mosquito net tucked underneath. However, mosquitos may continue to feed through openings in mats that are too thin. A quick-acting safe insecticide on the mat or string mattress may prevent this. This will also help to kill bedbugs. More permanent protection can be obtained by the use of an impenetrable surface under the sleeping mat or the bed. Cloth or plastic sheeting may well serve this purpose.

Obtaining a net
Bednets are widely available in different models, sizes and qualities. They can also be made locally from a length of netting material. The advantage of local manufacture is that quality, design and shape can be chosen to suit personal preferences. Opaque sheeting nets can be made from locally available textiles used in clothing manufacture. Open netting is commonly available as curtain material. Any type of strong opaque sheeting can be used for the borders, ceilings and suspension loops. The seams to which the loops are attached should be reinforced. The durability and effectiveness of cheap factory-produced net can be improved by adding a border to its lower edge.

Problems with mosquito nets
The protection provided by mosquito nets will be reduced if they are not used properly or holes are left unrepaired. In addition, contact may occur with the net during sleep, allowing mosquitos to bite through the net. Furthermore, hungry mosquitos may remain in the room and feed when the occupant leaves the net. They may also be diverted to unprotected people sleeping in the same room (Fig. 1.67).
Individual or community protection with untreated nets

If a small number of people in a community use mosquito nets, they will probably benefit because hungry mosquitoes can easily find an alternative blood-meal nearby on unprotected people or domestic animals. However, if all inhabitants of a community use nets and there are no attractive domestic animals to feed on, hungry mosquitoes are likely to persist until (1) they find holes in nets, (2) they find places where they can feed through nets, or (3) occupants leave nets. In this situation, the use of nets may not result in a reduction of malaria in a community (73, 74). On the other hand, diverted hungry mosquitoes can easily obtain blood-meals if there are animals on which they can feed (75). In areas where malaria transmission is low or moderate this may be sufficient to reduce malaria among community members.

Insecticide-treated mosquito nets

The above-mentioned problems of standard mosquito nets can be solved by impregnating them with a quick-acting pyrethroid insecticide (74, 76–78) which irritates or kills mosquitoes on contact, preventing them from finding openings (Fig. 1.68). An impregnated net with holes that are not too large is as effective as an undamaged net (79–81). Insecticide treatment thus extends the useful life of a net. Mosquitoes that land on an impregnated net and attempt to feed through it on
part of the body in contact with the net are likely to be killed (44). The behaviour of a mosquito that survives contact with the insecticide is so disturbed that it is unlikely to attack again (79, 80, 82, 83). People without a net and sleeping near someone with a treated net may receive some protection from bites (79). A person leaving such a net during the night or in the morning runs a reduced risk of being bitten.

Insecticide-treated nets serve as human-baited traps when somebody is sleeping inside by attracting and killing mosquitoes and other biting insects.

These factors make the widespread use of treated mosquito nets particularly important in the control of malaria. When employed by all members of a community the practice kills many *Anopheles* and reduces the chance that any will live long enough to transmit malaria parasites. People outside their nets early in the night or before dawn, or people not using nets, thus receive some protection against the risk of infection (84–88).

Treated nets can also be used to protect the most vulnerable groups in a community, such as pregnant women, children and old and sick people, from infection with malaria or other insect-borne diseases. Young children, going to sleep early, receive most protection (89).

The use of impregnated bednets may lead to the disappearance or reduction of other pests that are sensitive to the insecticide used, such as bedbugs, head lice, chicken ticks and houseflies (90, 91). The nets are probably also effective against fleas and triatomine bugs.
Which nets can be treated?

All types of bednet are treatable, including old nets with holes and nets of synthetic or natural fibre. However, multifilament nets are better than monofilament nets at holding the insecticide. The insecticide particles are easily dislodged from monofilament nets by abrasion or washing. For more information on the insecticides that can be used and on how nets should be impregnated see p. 85.

Control of malaria in a community with treated nets

Insecticide-treated bednets have been successful in reducing the number of malaria infections in villages where the transmission of malaria is low or moderate, for instance in China and the Gambia (88, 92). In villages where the transmission of malaria is intense (holoendemic malaria), community use of impregnated mosquito nets was found to have little impact on the number of infected people. However, people received 90–95% fewer infective bites from malaria-carrying mosquitoes, and were apparently better able to overcome the disease and to develop immunity (76, 85, 93–96).

Alternative materials for treatment

Other materials, such as fabrics of wide-mesh netting and bed curtains made of loose single-strand fibres, can also act as a physical barrier to the entry of insects, if treated with insecticide.

Wide-mesh nets

Treated nets with a mesh size slightly less than the wing span of a flying insect will force it to land before passing through, and on contact with the net it will be killed or repelled (97–102). Treated netting with a mesh size of approximately 4 mm protects against most mosquito species (81) and a mesh size of 2 mm would probably be effective against biting midges and sandflies (103). Such nets allow good ventilation in hot climates.

The advantages of wide-mesh nets (74) include:

- increased ventilation in hot and humid climates;
- reduced cost, even though stronger fibre is required;
- weight and volume when folded are less, making the nets easy to distribute and practical for travellers and nomadic people.

The disadvantages of such nets are:

- the nets offer no protection once the insecticide has lost its activity; prompt re-treatment is particularly important with this type of net;
- wide-mesh nets are more easily torn than standard nets;
- they are not yet commercially available but can be made out of curtain or other wide-mesh netting material.

Bed curtains

In areas where bednets are too expensive an alternative may be to use curtains made of locally available fibres (Fig. 1.69) or strings hung around the bed. To offer
A cheap alternative to mosquito nets may be bed curtains made of locally available fibre material treated with an insecticide. A roof is not essential as mosquitoes generally fly low. Curtains offer considerable protection but are not as effective as treated bednets.

Suitable materials include fibres from polypropylene or jute sacks. Sacks should be cut open and unpicked to obtain a loose arrangement of fibres. Flammable material (e.g. sisal) should not be used.

Treating fabrics with an insecticide

The impregnation of fabrics with an insecticide is simple: an emulsion is made in water, and the material to be impregnated is soaked in it and allowed to dry. After drying, the insecticide remains attached to the fibres.

Insecticides

Many well known insecticides, e.g. DDT, are not suitable for the treatment of fabrics because they act too slowly and allow insects to make contact and escape before they pick up a lethal dose. Moreover, many insects have developed resistance to a number of insecticides. The synthetic pyrethroids do not have these disadvantages. They are quick-acting and highly toxic to insects. In addition, they are considered to be generally safe to humans at the recommended dosages. They are also relatively safe for the environment because of their quick breakdown in the soil.

Pyrethroid insecticides are available as solutions, usually called emulsifiable concentrates. These can be mixed with water, producing a milky liquid. Oil-in-water emulsion formulations have been made specially for the treatment of fabrics; they give good adherence of the insecticide to the fabric material and do not produce an unpleasant odour during treatment. Pyrethroids can also be obtained as wettable powders or suspension concentrates, also known as flowable concentrates, but these formulations are less suitable for treating fabrics since they are more easily dislodged. This reduces the period of effectiveness and the dislodged particles may cause irritation of the skin. A number of photostable pyrethroids are available, of which only permethrin, cyfluthrin, deltamethrin and lambda-cyhalothrin have been tested for their efficacy and safety in the treatment of mosquito nets. Permethrin and flumethrin have been tested for the treatment of clothing.

Further information on insecticides is available on request from Division of Control of Tropical Diseases, World Health Organization, 1211 Geneva 27, Switzerland.
Pyrethroids for treatment of fabrics

Not all pyrethroid insecticides are suitable for the treatment of fabrics. To be suitable, a pyrethroid must remain effective in the fabric for at least several weeks, be resistant to sunlight and safe. The first-generation pyrethroids, such as the natural pyrethrins (pyrethrum), the allethrins and phenothrin, are unsuitable because they decompose rapidly when exposed to daylight. The second- and third-generation pyrethroids are much more stable and are therefore suitable (104).

**Permethrin**

Permethrin is commonly used for agricultural and public health purposes and is widely available. It is the most commonly recommended insecticide for the impregnation of bednets and clothing. It has proved to be highly effective in pest control, and there are no reports of adverse side-effects.

**Deltamethrin**

Deltamethrin is commonly used in agriculture and public health and is widely available. This pyrethroid is used extensively in China for the impregnation of bednets. It is more than 30 times as powerful as permethrin. Recommended dosages are much lower than for permethrin but this is compensated by a higher price per unit weight. The toxicity to domestic animals and humans is higher than that of permethrin, but formulations contain less active ingredient. There have been complaints about an irritant effect during the impregnation procedure. People sleeping under dry nets do not usually experience any side-effects but this may depend on the fibre material of the net and the insecticide formulation. A burning sensation of the face has been reported by people sleeping under polyethylene nets treated with a flowable formulation of deltamethrin (C.F. Curtis, unpublished observations, 1990) and by people sleeping under cotton nets treated with deltamethrin wettable powder (105).

**Lambdacyhalothrin**

This insecticide has been developed recently and is increasingly used for public health purposes. It is widely available for agricultural use. In general its properties are similar to those of deltamethrin. It is reported that lambdacyhalothrin causes nasal irritation to some people sleeping under freshly treated nets, even when these are dry. Reports demonstrating its prolonged insecticidal effectiveness have recently become available (93, 106) and more trials are under way.

**Cyfluthrin**

This product is used in agriculture and public health and is widely available. It is more toxic to insects than permethrin but less toxic than lambdacyhalothrin and deltamethrin. No side-effects have been reported but testing has been very limited so far (G. Hesse, personal communication). A special oil-in-water emulsion is available which gives better adherence to fibres than the emulsifiable concentrate formulation and does not produce an odour or irritant effect during treatment.

**Other pyrethroids**

The toxicities of cypermethrin, flumethrin and alphacypermethrin range between those of permethrin and deltamethrin. However, these insecticides have not yet been fully tested for efficacy and safety in the treatment of mosquito nets or clothing.
Optimal combination of mosquito net materials and pyrethroids

For the same insecticidal effect, nets made of cotton fibre need to be impregnated with 3–5 times as much permethrin or lambdacyhalothrin as those made of nylon fibre \((107, 108)\). This may be because in cotton fibres much of the insecticide is contained in the hollow spaces inside the fibres where it is unavailable to mosquitos. Nylon fibres are not hollow and most of the insecticide remains on the outer surface, where landing mosquitos pick it up on their legs. However, with deltamethrin there seems to be no difference in effectiveness between cotton and nylon \((77, 108)\).

Before a choice of material is made the local availability of materials should be investigated. The choice will then depend on a comparison of costs and technical considerations.

Recommended dosages

The recommended dosages of insecticide per quantity of fabric are usually given in grams of active ingredient per square metre \((\text{g/m}^2)\) or in milligrams of active ingredient per square centimetre \((\text{mg/cm}^2)\) \((1 \text{ g/m}^2 = 0.1 \text{ mg/cm}^2)\).

If impregnated with the same mixture of insecticide, a square metre of thick fabric absorbs much more insecticide than a similar area of thin open-weave fabric. However, some of the insecticide is not available on the surface, having penetrated inwards. Higher dosages of insecticide per unit area of thick fabric are presumably needed to provide a toxic resting surface equivalent to that obtained on the thinner fabrics (Table 1.3).

The duration of activity of an insecticide would normally be expected to be longer with a higher dosage. However, if a fabric is washed regularly it may be advisable to treat it with a lower dosage after each wash.

The more potent pyrethroids may be more economical because of the lower dosages needed. However, prices per unit weight of these insecticides are higher than that of permethrin and the choice will depend on local availability and prices.

Table 1.3

<table>
<thead>
<tr>
<th>Fabric</th>
<th>Dose (g/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Permethrin</td>
</tr>
<tr>
<td>Wide-mesh netting (more than 2mm)</td>
<td>0.10–0.25</td>
</tr>
<tr>
<td>Standard mosquito mesh (1.5mm)</td>
<td>0.20–0.50</td>
</tr>
<tr>
<td>Cotton cloth (sheeting, shirts)</td>
<td>0.70–1.20</td>
</tr>
<tr>
<td>Thick fabrics, jackets, trousers</td>
<td>0.65–1.25</td>
</tr>
</tbody>
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