Review Article

Indian J Med Res 136, November 2012, pp 739-749

Need for an efficient adult trap for the surveillance of dengue vectors

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Received August 12, 2011

The emergence and re-emergence of arboviral diseases transmitted by *Aedes aegypti* and *Ae. albopictus* continue to be a major threat in the tropics and subtropics. Associations between currently used indices and dengue transmission have not been proven to be satisfactorily predictive of dengue epidemics. Classical larval indices in dengue surveillance have limited use in assessing transmission risk and are a poor proxy for measuring adult emergence. Besides, collection of larval indices is labour intensive and plagued by difficulties of access particularly in urban settings. The re-emergence of dengue disease in many countries despite lower immature indices has warranted the need for more effective indices in dengue vector surveillance and control. Reliable and highly useful indices could be developed with the help of efficient and appropriate entomological tools. Most current programmes emphasize reduction of immature *Ae. aegypti* density, but it is of little value because its relation to transmission risk is weak. More attention should be paid to methods directed toward adult rather than immature *Ae. aegypti*. Collection of sufficient numbers of adult mosquitoes is important to understand disease transmission dynamics and to devise an appropriate control strategy. Even though, use of certain traps such as BG-Sentinel traps has been attempted in monitoring *Ae. aegypti* population, their utility is limited due to various setbacks which make these insufficient for entomological and epidemiological studies. Thus, there is an urgent need for the development of an ideal trap that could be used for adult vector surveillance. The present review critically analyzes the setbacks in the existing tools of entomological surveillance of dengue vectors and highlights the importance and necessity of more improved, more sensitive and reliable adult trap that could be used for surveillance of dengue vectors.

Key words Adult trap - *Aedes aegypti* - dengue vector surveillance - entomological indices

Introduction

Arboviral diseases such as dengue, dengue haemorrhagic fever (DHF), chikungunya fever transmitted by *Aedes aegypti* and *Ae. albopictus* are emerging and resurging in different parts of world and are posing a great threat to mankind. Dengue viruses have evolved rapidly as they have spread worldwide, having genotypes associated with increased virulence[1]. Dengue incidence has increased 30-fold with increasing geographic expansion to new countries and, in the present decade from urban to rural settings[2,3]. An estimated 50 million dengue cases occur annually and approximately 2.5 billion people live in countries that are endemic for dengue[2]. The disease burden is high, with more than 500 million cases each year and this requires immediate action[4]. In the absence of vaccination and effective drug, vector control has been considered an important tool in the prevention and control of DHF, dengue and chickungunya virus infection[2]. Despite various vector control measures, emergence and resurgence of these diseases continue to be a major threat in the tropics and subtropics[5]. The vectors of these diseases breed in a variety of habitats and many of these habitats are inaccessible to effective control measures. Though source reduction is considered to be a viable and affordable method of controlling the breeding of these vectors, it has not ensured desired elimination. Further, during rainy seasons, when there is an increase in the number of containers in and around human dwellings, it is difficult to go for source reduction and it would be cumbersome for frequent emptying of tyres and other innumerable breeding sources of *Ae. aegypti* and *Ae. albopictus* around the domestic environs[6,7]. The vectors are highly resilient as these are capable of shifting their breeding habitats very frequently. Evolution of these species of vectors clearly indicates that they can breed anywhere and in anything with little water and other minimum requirements for the survival of their immature. Though they are basically tree-hole breeding mosquitoes, they have acquired many traits to survive in nature from sylvatic to peri-domestic and domestic habitats. *Ae. aegypti* mates, feeds, rests, and lays eggs in and around human habitation[8]. There is no reason why they can not multiply in large numbers. They can easily return after source reduction measures and establish in any area[9].

Reducing the density of the dengue vectors to low levels is the only presently available measure for preventing dengue transmission[2]. However, reducing the vector density to a minimum threshold may not always necessarily result in low level of transmission in the case of dengue because a single vector can transmit the disease to many persons by its day biting, anthropophagic, interrupted and multiple feeding behaviour and a single virion may be sufficient to produce a patent infection in the human host[10]. Further, larviciding, insecticide spraying or elimination of domestic water containers through community involvement is labour intensive and often difficult to sustain[9].

Weaknesses of the existing entomological indicators include a lack of representation of dengue vector burden and a lack of correlation between different indicators[11-13]. Number of eggs laid in ovitraps cannot be used as reliable data and extrapolation of the number of eggs to the adult population in an area is not always meaningful. Associations between existing indices and dengue transmission have not proven to be satisfactorily predictive of dengue epidemics[14]. Evaluation of adult control measures could be done only by collecting adult vector mosquitoes and not by eggs or immature. At present, there is no effective method for collecting sufficient numbers of adult females of *Ae. aegypti*.

Though Cuba and Singapore have demonstrated successful dengue control by vertically orienting and incorporating source reduction, space spraying, health education and law enforcement, the re-emergence of dengue despite lower immature indices has warranted the need for more effective indices for dengue vector control[15-17]. Effective prevention depends on effective entomological surveillance tools and there is an urgent need for new and innovative approaches for a sustainable vector control[18]. It has been realized that ineffective methods and inferior technology are to be identified so as to replace better performing alternatives for the control of dengue vectors[19]. In resource limited settings, vector control must maximize both efficacy and efficiency. Surveillance is fundamental for setting goals and evaluating success. Reliable surveillance tools for dengue vectors are greatly needed. An inexpensive and effective *Ae. aegypti*-specific adult trap would be a significant surveillance breakthrough, and could also allow for virus testing. Development of a cost-effective, field-appropriate method for estimating adult *Ae. aegypti* densities should be a priority. An effective adult trap would be less intrusive than current *Ae. aegypti* household surveys, require less labour, benefit from and allow for more complete coverage both spatially and temporally besides benefit from an effective lure or attractant[20]. The need of the hour is to produce tools to provide more efficient outbreak detection and to prevent vector population outbreaks in space and time. This review critically analyzes the setbacks in present tools of entomological surveillance of dengue vectors and highlights the importance and necessity of more improved, more sensitive and reliable adult trap that could be used for surveillance of dengue vectors.

Immature indices

(i) Larval indices: House or premises index (HI, percentage of houses positive for immature), container index (CI, percentage of containers positive for immature), Breteau index (BI, number of positive

containers per 100 houses) and Stegomyia larval index (SI, number of positive containers to the number of people living in the area) are the most widely used larval indices[21]. Stegomyia indices were developed to monitor the progress of vector eradication efforts and to protect *Ae. aegypti*-free zones from re-infestation[22]. The house or premises index has been used most widely, but it neither takes into account the number of containers with immature mosquitoes nor the production of adults from those containers. The container index provides information on the proportion of water-holding containers that contain >1 immature mosquito; it does not account for variation in density or adult productivity. The Breteau index establishes a relationship between positive containers and houses, but it also fails to account for adults produced from containers. BI is an indicator of prevalence rather than abundance[23]. A variety of alternative indices have been proposed since 1971, which attempted to account better for adult productivity[12,24-26]. In general, many of these indices were discontinued because of the requirement of high degree of sampling.

All these indices are empirical as these are the estimates of frequency and not actual numbers and their critical thresholds have never been determined for dengue fever transmission. Though some of these indices have been effectively used in the prevention of yellow fever transmission, their utility has not yet been well established in the case of dengue disease[27]. Among these indices, Breteau index is considered the best as it is more qualitative and has more epidemiological significance[28]. However, this index and also the other indices seem to have virtually no correspondence with the actual number of pupae per hectare or per person and do not indicate the number of adults produced from each container. It has been realized from the experiences in Singapore and Cuba that reduction of larval indices would not result in the interruption of dengue virus transmission. Therefore, appropriateness of the larval indices has been questioned[29-30].

(ii) Pupal indices: As an alternative to larval indices, pupal indices have been developed to reflect the risk for transmission more meaningfully[26]. Advantages of using pupae as a measure of *Ae. aegypti* abundance are that absolute counts of pupae are feasible in most domestic environments,well-characterised pupa mortality and the number of pupae/person is positively correlated with the number of adults mosquitoes/person[27,28].

Pupal demographic survey (PDS) of *Ae. aegypti* has been designed to identify the important containers that support the breeding of *Ae. aegypti* so as to estimate its abundance and productivity. This methodology may be considered a practical tool to assess *Ae. aegypti* pupae/person when a sequential sampling scheme is used. Pupae per person index (the average number of pupae per person in the community, PPI) has been considered as potentially one of the important and appropriate parameters in determining the risk of dengue virus transmission and directing control operations[31-33]. Once the most productive containers are identified, targeted control of dengue vectors becomes more affordable and feasible. At the same time, targeted vector control can help to minimize the use of chemicals that may be costly and have other long-term health and environment impacts[32].

The strength of correlations between pupa and adult populations depends on season, year, or geographic location. Shifts in the productivity of key containers are becoming a commonplace with respect to season, geographical location, availability of water, and cultural habits of the people[34,35]. Large water drums, tyres, buckets and cement tanks supported >70 per cent pupae during rainy season whereas >80 per cent pupae were reported from drums and cement tanks in dry season. Large cement water basins are also reported to support >84 per cent pupae[31]. Thus the most productive containers may vary from season to season in the same locality. Targeting the most productive domestic containers, control efforts may be streamlined to have the greatest impact on reducing the adult *Ae. aegypti* population locally. This would result in the significant reduction in the incidence of dengue[36-38].

The PDS has got several important limitations. Time, manpower and sampling variations are the major limitations of pupal index. Collecting individual pupae from large containers and proper identification of co-existing *Aedes* species in the same container is laborious and time consuming[30]. So, greater precision is required to validate vector thresholds in accordance with variations in herd immunity, virus movement and temperature in the field. Large sample sizes are essential to overcome sampling problems associated with temporal and spatial variation in *Ae. aegypti* pupa production. There are ample chances that actual thresholds would likely to be higher than the conservative thresholds developed by using sequential plans in pupal democratic survey, especially in highly endemic areas[37]. The container types with the highest production of *Ae. aegypti* pupae usually vary from place to place[39,40]. In such as lower infestation areas, PPI in combination with the level of seroprevalence could be used to better predict dengue outbreak risk. Further, it has not yet been demonstrated that at which frequency the pupal demographic surveys have to be repeated (once per year? or less or more often?) and how long after the observation period. These issues are to be essentially addressed so as to consider PDS in dengue vector surveillance.

Combination of key premises and key containers with the pupal indices revealed that container productivity and the risk of disease transmission based on the number of people living in each house or per hectare may serve as an improved indicator for vector control and dengue suppression programmes[36]. Therefore, it has been suggested that cardinal points and key premises approaches should be combined and vector control programmes should target the most protective containers in key premises in order to reduce dengue transmission levels[40].

Ovitrap indices

Development of accurate methods to estimate adult population of *Ae. aegypti* is very important to evolve an effective control strategy. But collection of sufficient numbers of adult females of *Ae. aegypti* resting indoors as well as outdoors is very difficult. So oviposition traps (OTs) were developed to estimate the number of females in an area through the number of eggs laid in OTs. Ovitrap surveys could be considered a sensitive and an efficient technique for detecting and monitoring *Aedes* populations at low densities and where the BI values are very low. Further, the OTs are safe, economical and environment-friendly surveillance tools[41].

Ovitraps were first used for surveillance in 1965 and subsequently these were demonstrated to be superior to larval surveys[42,43]. These were recommended for the surveillance of *Aedes* vectors and subsequently shown to be a useful sampling device in determining *Ae. aegypti* distribution and seasonal fluctuation[44] and in evaluating the efficacy of aerial ultra low volume (ULV) malathion application and source reduction[45,46]. OTs were also used to assess changes in the vector breeding (*Ae. aegypti* to *Ae. albopictus* or vice versa) and to determine the presence or absence of breeding populations of *Ae. aegypti* in locations where control measures were considered. In addition, when large numbers of wild *Ae. aegypti* larvae and adults are required for laboratory tests; OT provides a simple way to obtain substantial quantities of eggs. OT is used extensively in Singapore as a tool to detect, monitor and control *Aedes* populations. OT gives an approximate gauge of the adult population in an area and acts as an early warning signal to prevent any impending dengue outbreaks[47].

Setting OTs in public areas could serve as an alternative method of vector detection[17]. OT data have reported to be more sensitive than the traditional *Stegomyia* indices in detecting low population[48]. Historically, ovitraps have provided useful data on the spatial and temporal distributions of *Ae. aegypti* and other container inhabiting mosquito species[49]. Placement of OT depends of the flight range of the *Aedes* species and usually the OTs are placed at a distance of 100-250 meters from each other. Size of OT and height from which the OT is suspended has significant effect on oviposition behaviour of dengue vectors[50,51]. This has also reduced the chances of predation and disturbances due to animals and human. Different types of oviposition substrates have been attempted to enhance the quantity of eggs laid in OT[6,52,53].

The OT indices such as ovitrap premises index (*i.e.*, percentage of premises observed with at least one ovitrap positive), ovitrap positive index (OPI) and egg density index (EDI) indicate the extent and intensity of vector prevalence. OTs were considered to have greater operational control with the potential of cost reduction, methodology standardization and fast identification of infestation[11]. OT was later modified as an autocidal or lethal OT (LOT) which could kill both ovipositing adults and larvae emerging from the eggs laid[54]. Deltamethrin treated LOTs have been reported to kill 89 per cent of *Ae. aegypti* adults and produced more than 99 per cent larval mortality during 1-month field trials[11]. Thus, LOT could also be used as a supplementary control device in dengue vector control programmes. Alternatively, a "sticky ovitrap (SOT)" was also developed by replacing the ovistrip with an adhesive that trapped mosquitoes[55,56], which allowed for rapid identification of specimens and for arbovirus screenings[57,58]. A combination of lethal ovitraps and sticky ovitraps in North Queensland, Australia showed that significantly more number of females could be collected[59].

Ovitraps can give insight into relative changes in the adult female populations but these do not provide estimation of *Ae. aegypti* population densities[7]. When applying this ovitrap index for surveillance, one must be aware of that an ovitrap error may come from the competitive deposition probability with other natural ovipostion sites for female mosquitoes and it varies from site to site. Another disadvantage of using OT is the chances of predation by snails and cockroaches if the exposure period is long[60]. Another important drawback in OT is the requirement of large number of vector control officers to maintain these traps. The "skip oviposition behaviour" of *Ae. aegypti* is a problem along with other problems in the field such as predation in OTs, disturbance of OTs by animals and man may pose problems in interpreting the data derived from ovitraps[61,62]. It has been reported that low numbers of mosquitoes collected with lethal ovitraps are not sufficient for virus isolation and the efficiency of the trap is hampered by many factors in the field[63]. Even though ovitraps are useful in monitoring changes in oviposition activity over time, comparison between areas is not reliable because the availability of larval habitats in different settings will differ. Further, it can be misleading to monitor and interpret ovitrap data over time in a given area where vector control interventions include source reduction measures[47]. Another possible pitfall of using ovitraps in dengue prevention programmes is that ovitraps *per se* may produce vectors if they hold water longer than the developmental duration of the immature mosquitoes[64]. Treatment of methoprene pellets in ovitraps has been suggested to overcome this problem to prevent mosquito production[65].

Adult indices

Only adult female mosquitoes are responsible for disease transmission and it would be more appropriate if control measures are directed towards adults rather than against other life stages of vector mosquitoes. Although the ultimate objective should be to prevent disease, most current programmes emphasize reduction of immature *Ae. aegypti* density, which is of little value because of its weak relation with transmission risk[66]. One of the major problems for dengue vector control programmes is to efficiently and effectively estimate and monitor adult mosquito frequency, distribution, and density. This information is fundamental for assessing risk of disease transmission and for evaluating the impact of vector control strategies. Further, greater emphasis should be placed on relative abundance of adult vectors in relation to human serotype-specific herd immunity, introduction of unique viruses, mosquito-human contact and weather. The most appropriate spatial scale for assessing entomological risk is the individual household[10].

In nature, adult *Ae. aegypti* population densities are relatively low compared to most other mosquito species and difficult to estimate and this makes routine adult surveillance problematic[10,67]. Adult mosquito indices generally used are house density index (HDI), biting rate index (BRI) and net index (NI). Indoor resting collection of *Ae. aegypti* adults usually yields less numbers and even with skilled laboures, it would be possible to catch less than 50 per cent of the existing vectors[7]. For vector control programmes, use of vector surveillance traps is an attractive alternative to the traditional labour-intensive household surveys. Ideal characteristics of an adult trap would include low cost, ease of distribution, species exclusivity, a consistent sampling profile, and independence from electric power. An adult trap would benefit from an effective lure or attractant. *Ae. aegypti* adult surveillance programmes should include two components. Rapid assessment of abundance of adults to allow for targeting particular areas for vector control operations and evaluations, and routine collection over several months to provide a measure of population dynamics in relation to dengue virus activity[68].

Antennae of mosquitoes are used to detect CO_2 released from a person's lungs and chemical odours produced by human skin. The compound eyes accompanied by light sensitive simple eyes are used for spotting movement of the host particularly during day time. The maxillary palpus is sensitive to heat helping the mosquitoes to locate warm-blooded host and pinpoint capillaries. These facts are to be meticulously considered while designing an efficient adult trap for collecting host seeking dengue vectors[69].

Sticky traps collected significantly more *Ae. aegypti* and *Ae. albopictus* females than did backpack aspirators when located outdoors[70]. A "double sticky trap" has been developed and evaluated which collected significantly more adults than the standard sticky trap[71]. Sticky trap may be an inexpensive method to collect adult *Ae. aegypti* as it does not need any electricity and can be be left unattended for up to seven days. But the major limitation is that it targets only oviposting females rather than host-seeking ones and its efficacy will be reduced by nearby natural oviposition sites[56].

LOT may reduce adult *Ae. aegypti* populations but its efficacy is lower in the presence of alternative breeding sources[72]. LOTs could not represent the adult population as a whole as these collect only the gravid population and so it cannot be claimed to be a good tool for population estimation of *Ae. aegypti*.

But data collected by efficient adult traps that collect indoor resting mosquitoes of all abdominal conditions could be used for population estimation of the targeted vector. Adult traps have been evaluated under different field conditions and found to have good potential for monitoring *Aedes* populations[73-76].

The efficiency of six traps *viz.*, Mosquito Magnet Professional trap, Fay-Prince trap, Standard surveillance trap, CDC Wilton trap, Mosquito Magnet-X trap and Mosquito Magnet Liberty trap were compared on the collection of *Ae. albopictus*, the Mosquito Magnet Liberty proved better followed by Mosquito Magnet-X and Mosquito Magnet Pro. The study claims that these traps are better than CDC surveillance traps in terms of their long term use with little attendance and maintenance. However, these commercial traps are more expensive[77].

The most effective adult *Ae. aegypti* collecting methodology is the backpack aspirator[67]. The advantage of this method is that it could collect all gonotrophic stages of female as well as male *Ae. aegypti* but it is labour-intensive and not suitable for routine use because collections require diligence, skill, consistency of effort and free access to the most private parts of the home. So the BG-Sentinel trap was considered for evaluation in different field conditions[78-80].

Based on trapping efficiency, both the BG-Sentinel trap and backpack aspirator were claimed superior to CO_2 baited EVS trap[79]. An important advantage of BG-Sentinel trap is that it can be considered as an acceptable alternative to human landing/biting collections in the surveillance of adult host-seeking dengue vectors. In a comparative study between the BG-Sentinel and a sticky ovitrap for gravid females, the BG-Sentinel proved to be more efficient and sensitive tool to measure the density of *Ae. aegypti* populations[81].

ZumbaTM and BG-SentinelTM traps were evaluated for their efficacy in collecting host seeking mosquitoes against Miniature light trap and CDC Fay-Prince trap baited with BG-lure and CO_2. BG-Sentinel trap baited with lure and CO_2 collected seven times more of *Ae. albopictus* than CDC-Miniature and Fay-Prince trap[80].

It has been demonstrated that BG-Sentinel traps are capable of collecting mostly unfed females of *Ae. Aegypti/Ae. albopictus*, and their efficacy in collecting gravid females is not compromised. Further, it is more pronounced towards the collection of males rather than female besides its poor performance during dry season and in sylvatic habitats[79,82]. Though BG-Sentinel trap is more efficient in collecting *Ae. aegypti* females than a backpack aspirator, both are too laborious to permit daily mosquito collection in dengue-endemic areas[74]. Adultrap and MosquiTRAP have been developed recently and their efficiencies are being compared with aspiration and other methods[76,83,84]. A recent study claims that Prokopack aspirator is more advantageous than the CDC Backpack aspirator in the field[85].

MosquiTRAP has been shown to be an effective and reliable device for trapping gravid *Ae. aegypti* when a larval survey could not detect the presence of this species[80]. Still these traps need to be evaluated through a longer time series and under different levels and patterns of infestation[86]. AdulTrap being as efficient as backpack aspirators has higher sensitivity towards collecting *Ae. aegypti* gravid females. Though MosquiTRAP collects more females of *Ae. aegypti* than AdulTrap, it has a serious disadvantage of acting as a breeding site for dengue vectors. However, it has been suggested for use in assessment of risk classification of dengue fever[87].

The fact that none of these methods is as informative or amenable to large-scale sampling as the most significant contribution to dengue surveillance would be development of an operationally feasible technique to monitor adult female *Ae. aegypti* population densities.

Discussion & conclusion

Surveillance of dengue vectors is a measure of vector population density that may be predictive of dengue epidemics. Since eradication is not feasible, the goal of public-health preventive measures, in the absence of a vaccine, is to maintain the population density of dengue vectors that should be too low to support sustained viral transmission. The global reliance on source reduction for the past 50 years may appear logical for the control of dengue vectors but it does not work in most countries at risk and the disease is more prevalent now than at any time in history[8]. Classical larval indices in dengue surveillance have limited use in assessing transmission risk and are a poor proxy for measuring adult emergence[88].

Minimum entomological thresholds for dengue are usually low and dynamics in the relationship between mosquito density and human infection are complex. It has been suggested that the vector-population densities required for epidemic transmission are lower in regions with low herd immunity[76]. Therefore, there is an urgent need for rigorous field-based evaluations of the relationships among the available *Ae. aegypti* indices, virus transmission and disease. Further, new rapid and inexpensive methodologies are essentially needed for assessing risk.

The experience in Singapore has clearly indicated that the existing immature indices are not sufficient to detect and prevent dengue outbreaks[17]. Pupal indices are considered to be simple, logical and appropriate as the number of pupae/person is positively correlated with the number of adult mosquitoes/person. But collection of pupal indices is labourious, time-consuming and cost prohibitive besides sampling variation. Further, large sample sizes are essential to overcome sampling problems associated with temporal and spatial variation in *Ae. aegypti* pupal production[13].

Transmission is affected only by adult mosquitoes and estimation of adult density via extrapolation of eggs laid in ovitraps may not be always appropriate. We should pay more attention to methods directed towards collection of adults rather than immature *Ae. aegypti*. Ovitraps do not provide estimates of *Ae. aegypti* population densities but these can give insights into relative changes in the adult female populations. Further, bias in ovitrap sampling usually occurs in competition with natural oviposition sites. Further, collection of female mosquitoes of all gonotrophic stages is also epidemiologically and entomologically significant.

Adult control measures including insecticidal fogging during emergencies cannot be continued for a longer time. Thus, there is a need for an efficient adult trap that could be used for both surveillance and control. It would be more advantageous if the traps are developed for targeting mosquitoes of all gonotrophic stages that would give more information on the decline of transmission than targeting larval or only a particular sub-population of adults.

Development of a cost-effective, field-appropriate tool to estimate adult *Ae. aegypti* densities should be a priority. An efficient adult trap would be less intrusive, less laborious, allow for more complete coverage both spatially and temporally besides low cost, with ease of distribution, species exclusivity, a consistent sampling profile, and independence from electric power.

The adult traps that are being advocated for use in the surveillance of dengue vectors are not satisfactory. Though BG-Sentinel traps are claimed to be more efficient than other existing traps in the collection of dengue vectors, these collect mostly unfed females and frequently males outnumber the total collection. A trap that attracts primarily nulliparous mosquitoes is unlikely to collect many arbovirus infected mosquitoes and any infection rate calculated from nulliparous mosquitoes will lead to underestimation of true infection rate. The number of mosquitoes collected by a backpack aspirator is extremely dependent of operator's motivation and skill[84]. Though MosquiTRAP is better than Adultrap and backpack aspirator, it has the serious disadvantage of acting as a breeding site for dengue vectors. The trap that is claimed to collect a particular sub-population of the concerned vector species may not be adequately useful for forcasting the impending outbreak or for evaluating the impact of a control strategy. A simple, efficient and unbiased adult trap specific for collecting all sub populations (*e.g.* the one seeking host for feeding, seeking shelter for resting after feeding, seeking habitat for egg laying) of *Ae. aegypti*/*Ae. albopictus* needs to be designed and evaluated and such a tool could be reliably useful in the surveillance of dengue vectors. Among several adult mosquito traps available for other species, backpack aspirator may be used only for certain preliminary entomological investigations of dengue outbreak as it delivers representative samples of the vector population but it can not be used for routine surveillance owing to its cost, weight, non-extendable nature of the suction hose and limited availability.

Currently novel control strategies such as manipulation of *Ae. aegypti* in the adult stage using bacterial endosymbiont, *Wolbachia* and release of transgenic males with a dominant lethal gene demand adult sampling tools to measure changes in population size, structure (age, sex ratio) and ultimately the success of the programme[89,90].

Based on the existing knowledge on the behaviour of dengue vectors, an efficient comprehensive adult trap may be developed to collect different sub-populations of dengue vectors by incorporating various components in the trap for attracting, resting, ovipositing and knocking down of mosquitoes. The trap should not require any power to operate and it should be easily used by householders and volunteers. It should be useful a both indoor and outdoor situations. Mosquito collections from such a comprehensive trap would provide alternative and and less labour-intensive abundance measure for assessing risk of dengue virus transmission and success of dengue vector control programmes. Operational feasibility of using such a comprehensive trap specific for dengue surveillance includes continuous operation, unbiased by collector's expertise, non-requirement of electric power, local availability of the components of the trap and acceptability by the householders. Further, such a trap may also be useful to study the dispersal, longevity, resting and ovipositing behaviour of the dengue vectors with respect to indoor and outdoor environments, blood meal identification, and virus isolation and to assay for insecticide resistance alleles. Most of the outdoor resting and oviposition sites of dengue vectors occur in peridomestic environment and it would be possible to earn acceptability and co-operation from the neighbours in fixing and mainaining the traps. Above all, such a trap could be an alternative to indoor and outdoor resting collection.

To conclude, there is an urgent need for the development of an efficient comprehensive adult trap. Trap index derived from such a trap could be effectively used along with other indices such as key premises index, key container index and pupal indices for routine surveillance, mapping the risk areas, forecasting epidemics and monitoring the impact of mosquito control strategies.

Acknowledgment

Authors thank Dr P. Jambulingam, Director, Vector Control Research Centre (ICMR), Puducherry, for encouragement and support.

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