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Major Article

Cost of intensive routine control and incremental cost of insecticide-treated curtain deployment in a setting with low *Aedes aegypti* infestation

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Abstract

Introduction: Information regarding the cost of implementing insecticide-treated curtains (ITCs) is scarce. Therefore, we evaluated the ITC implementation cost, in addition to the costs of intensive conventional routine activities of the *Aedes* control program in the city of Guantanamo, Cuba. **Methods**: A cost-analysis study was conducted from the perspective of the *Aedes* control program, nested in an ITC effectiveness trial, during 2009–2010. Data for this study were obtained from bookkeeping records and activity registers of the Provincial *Aedes* Control Programme Unit and the account records of the ITC trial. **Results**: The annual cost of the routine *Aedes* control program activities was US$16.80 per household (p.h). Among 3,015 households, 6,714 ITCs were distributed. The total average cost per ITC distributed was US$3.42, and 74.3% of this cost was attributed to the cost of purchasing the ITCs. The annualized costs p.h. of ITC implementation was US$3.80. The additional annualized cost for deploying ITCs represented 19% and 48.4% of the total cost of the routine *Aedes* control and adult-stage *Aedes* control programs, respectively. The trial did not lead to further reductions in the already relatively low *Aedes* infestation levels. **Conclusions**: At current curtain prices, ITC deployment can hardly be considered an efficient option in Guantanamo and other comparable environments.

Keywords: Dengue. Insecticide-treated curtains. Routine vector control. Cost-analysis. Cuba.

INTRODUCTION

Dengue is the most rapidly spreading mosquito-borne viral disease in the world. During the last 50 years, the incidence of dengue has increased 30-fold and the number of affected countries has been increasing steadily. This problem has expanded to rural settings in the last 10 years[1]. Today, approximately 3,6 billion people live in >100 dengue endemic countries[2], and an estimated 284-528 million dengue infections occur annually[3]. It is estimated that 500,000 people with severe dengue require hospitalization each year, and about 2.5% of those affected with dengue die[4]. Additionally, due to the increase in severe cases, dengue has become a leading cause of hospitalization and death in children in several settings[4]. Cuba has been affected by several dengue epidemics; two major epidemics occurred in 1977 and 1981[5]. From 1981 onwards, sporadic and localized outbreaks have been reported in 1997, 2001, and 2006[6].

The *Aedes aegypti* mosquito is the main vector of dengue. The classic vector control approaches to prevent dengue transmission require continuous costly efforts and have been shown to have insufficient effectiveness and sustainability[7] [8] [9] [10]. Recent reports about the potential effectiveness of novel tools, namely insecticide-treated curtains (ITC) and insecticide-treated jar covers, have been published[11] [12] [13] [14] [15] [16]. However, studies regarding the cost of ITC implementation are limited[16] [17] [18]. In order to complement this limited evidence, we aimed to analyze the additional cost for implementing ITC in an environment with low *Aedes* infestation levels and an intensive well-structured *Aedes* vector control program, and the relationship between this cost and changes observed in entomological indices.

METHODS

Context

Guantanamo is a City in the Southeast of Cuba with 223,338 inhabitants (http://www.one.cu/EstadisticaPoblacion/

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EstadisticaPoblacion.asp) who live in approximately 67,000 premises. Mosquito proliferation is favored by interruptions in the water supply that encourage people to store water in a variety of containers[9] [19] coupled with high temperatures (average maximum temperature, 32.1^{0}C), and heavy rain falls (1037.9mm annually)[20] . An intensive routine *Aedes* control program (ACP) that conducts a variety of conventional activities is ongoing. This program has managed to maintain low *A. aegypti* infestation levels at the city level [house indices (HI), 2%]. However, *Aedes aegypti* is continuously present and indices can be much higher at the house block level (HI up to 8%), leading to sporadic outbreaks in 1981[21], 1997, 2001[22], and 2006[23].

During 2009 and 2010, intra-domiciliary adulticiding was intensified in response to an increase of imported dengue cases in Guantanamo. Eventually, the health authorities decided to try using ITCs, which have shown promising results in other countries[11] [13] [14] [15], in order to further decrease vector densities and prevent outbreaks.

A cluster-randomized trial was conducted to evaluate the effectiveness of ITC[24] in Guantanamo city, between 2009-2010 . Twelve circumscriptions were selected among those with the highest mosquito infestation levels in the previous two years; the most decentralized geopolitical unit comprised of about 500 houses. These circumscriptions were randomly allocated to ITC implementation in addition to the routine ACP (n = 6) or the ACP without additional changes (n = 6; control group).

Economic study

Perspective and analytic horizon: a cost-analysis study was conducted concurrently with the trial. We studied the cost of the routine ACP activities and ITC implementation from the point of view of the ACP. The analytic horizon was two years (i.e., 2009-2010).

Description of Aedes control activities: the activities of the routine ACP have been described in detail elsewhere[23] [25] . In short, the activities consisted of entomologic surveillance and source reduction through monthly inspection of all premises, larviciding with temephos in water-holding containers, selective adulticiding (indoor and outdoor fogging with pyrethroids) when *Aedes* foci are detected, providing health education, and enforcing mosquito control legislation through the fines.

The ITCs (PermaNet, Vestergaard Frandsen, Lausanne, Switzerland) used in this study were white, 2 by 2m, with long-lasting 55mg/m^2 deltamethrin impregnation and ultraviolet protection. The ITCs were implemented through the ACP in six clusters in an average of 512 premises (range, 400-703 premises) totaling 10,101 inhabitants. Implementation, which occurred in 2009, consisted of two phases: preparation and distribution .

In the preparation phase, the ITCs were purchased, shipped to Guantanamo, and stored in the warehouse of the Provincial ACP Unit . Two training sessions were held with the vector control workers who were selected to distribute ITCs in the study clusters and the managerial and quality control staff of the ACP. Fifteen meetings were held in the selected communities to explain and discuss the study purpose and the use of ITCs. Afterwards and during preparation phase, ACP technicians visited each household in the intervention clusters to further explain the study, obtain informed consent and negotiate where the curtains would be placed. Up to a maximum of 3 ITCs were offered, which was equal to the number of rooms in a typical house. The technical criteriafor slecting places to hang ITC (optimal sites from an entomological perspective) were reconciled with family preferences. The families generally perceived that the bedroom and living room areas had the most mosquitos and preferred the ITCs to be hung by windows, door openings, or on the wall. A booklet with answers to frequently asked questions about ITCs was distributed to each family.

Costing: data regarding ACP resource utilization and cost for all activities were thoroughly collected from bookkeeping records, activity registers of the Provincial ACP Unit, and from the accounts of the ITC trial.

The costs were classified according Johns, 2003[26]. The ACP routine activity costs were stratified by larval and adult control and further divided into recurrent and capital costs. The larval and adult control costs included labor [reported in person-day full-time equivalent (FTE), number of hours worked divided by 8], larvicides or insecticides, other consumables (i.e., fuels, office and computer consumables, and protective clothing and shoes), and operations (i.e., utilities, transport, meals, maintenance, and rent). Recurrent costs were obtained by multiplying the number units of resources consumed by the corresponding market price. Capital costs included costs for transport, furniture, and equipment. Capital means were annuitized[27] at 3% discount rate for the assumed average useful length of life[28] using 20% scrap value and market price replacement cost. The capital costs were estimated by multiplying the annual depreciation of the assets by the usage time.

For ITC implementation, we distinguished between the cost of using existing ACP resources that were now devoted to ITC implementation and the additional cost incurred. Based on previous findings, ITCs were assumed to last for 2 years[18] [29] and were treated as capital goods. Expenditure for ITC implementation will be incurred bi-annually and in order to compare with the annual costs of the routine ACP activities, we annuitized all corresponding cost items to obtain the annual equivalent cost (annuity factor of 1,9701, corresponding to 3% discount rate, 2 years of useful life, and 0% scrap value). Costs not directly related to mosquito control (i.e., administrative cost of the ACP at municipal and provincial managerial levels) were allocated directly[27].

All costs were collected in Cuban Peso (CUP), the national currency, calculated at 2009 prices and converted to US$ using the official exchange rate of 1 CUP = US$1 for goods and 10 CUP = US$1 for salaries, according to Rodriguez [30] .

Outcome: in the intervention study[24], the HI at circumscription level during an 18-month period after ITC distribution was used as the outcome measure. The adjusted HI rate ratios, based on the initial level, of intervention vs. control clusters were calculated by fitting a generalized linear random effect regression model with a negative binomial link function.

Ethicals considerations

The study was approved by the ethical committee of the Institute of Tropical Medicine *Pedro Kouri*, Havana, by

the Provincial Health authorities of Guantanamo and by the Institutional Review Board of the Institute of Tropical Medicine, Antwerp. Community leaders approved the intervention, and informed consent was obtained from each household included in the study. The ITC material was approved by the World Health Organization Pesticide Evaluation Scheme for bed net use. The ITCs were purchased from the study budget and freely distributed to the population. The study was conducted in accordance to the Helsinki Declaration of 1964 and subsequent revisions.

RESULTS

The total absolute annual expenditure and cost per household (p.h.) of the routine ACP activities in Guantanamo City were US$1,137,701 and US$16.80, respectively (**Table 1**). Labor, consumables, larvicides, and insecticides were the main cost drivers. Approximately, 54.4% of the ACP cost (US$9.14p.h.) per year was for imported goods (i.e., larvicides, insecticides, fuels, protective clothing, computer and office material, spare parts, and capital goods). Approximately, 60.8% (US$10.21p.h.) and 39.2% (US$ 6.59p.h.) of the cost of routine ACP activities were used for larval to adult mosquito control. Salaries were found to be the predominant cost driver for larval control, which corresponded to the labor-intensive nature of this activity (0.20 FTE p.h. per year). This activity further consumed 0.90kg of Abate®(Company Farmex SA, Lima, Peru) p.h. per year at a price of US$1000.00 per ton. The major cost for routine ACP using adult control consumables was the fuel used in fogging (4,56L of fuels p.h. per year at an average price of US$0.65/L) followed by insecticides (0.086L p.h. per year at an average price of US$9.42/L) and labor (0.03 FTE p.h. per year) **(Table 1).**

We purchased 6,714 ITCs at US$2.54 (cost-insurance-freight-price) per curtain, which were distributed to 3,015 households (**Table 2**). The initial ITC coverage (inmidiatelly after finishing the distribution) reached 98.4%, and an average of 2.22 curtains were provided for each household. The total cost of ITC implementation was US$22,937.86. The average cost per ITC distributed was US$3.42, and the cost per household in the study clusters was US$7.50 **(Table 2).**

Approximately, 74.3%, 14.5%, and 10.1% of the total costs were attributed to curtain purchase, consumables, and labor, respectively. Furthermore, 5.6% of the total cost was used for preparing the distribution of the ITC (preparation phase). The average time spend p.h. for fixing the ITCs was 15.8 min [95% confidence interval (95% CI), 13.4-18.4 min; range, 5-28 min]. The annualized cost per ITC distributed and p.h. of ITC implementation was US$1.74 [US$3.42/1,9701 (**Table 2**) and US$3.80, respectively (**Table 3**)].

The annualized cost of ITC implementation represented 23% (US$3.80/16.80) of the total annual cost of all ACP routine activities and 57.6% (US$3.80/6.59) of the cost of its activities for adult-stage *Aedes* control (**Table 1** and **Table 3**). Furthermore, the additional total annualized cost was US$9,773.87 (US$19,255.50/1.9701), which was 19% (US$3.19/16.80) of the routine ACP cost and 48.4% (US$3.19/6.59) of the routine cost for adult-stage control.

The HI rate ratios during the 18-month observation period after ITC distribution were not significantly different between intervention and control clusters (1.15; 95% CI, 0.57-2.34)[24]. The annualized incremental cost of US$3.19p.h. for ITC implementation did not result in a further reduction in entomological indices. Therefore, the use of ITCs in addition to the ACP is a non-efficient option.

TABLE 1

Annual total per inhabitant and per household costs (US$) of the routine *Aedes* control program activities, Guantanamo, Cuba, 2009.

Activity/cost item	Annualcost total	Annual cost per inhabitant	Annual cost per household	Subtotal %	Total %
Larval control					
Recurrent					
labor	413,693	1.85	6.11	59.8	36.4
larvicides	78,747	0.35	1.16	11.4	6.9
other consumables	83, 126	0.37	1.22	12.0	7.3
operations	93,779	0.42	1.39	13.6	8.2
Capital	22,339	0.10	0.33	3.2	2.0
Sub total	**691,684**	**3.09**	**10.21**	**100.0**	**60.8**
Adult control					
Recurrent					
labor	53,229	0.24	0.79	12.0	4.7
insecticides	54,481	0.24	0.80	12.2	4.8
other consumables	292,083	1.31	4.32	65.5	25.6
operations	17,115	0.08	0.25	3.8	1.5
Capital	29,109	0.13	0.43	6.5	2.6
Sub total	**446,017**	**2.00**	**6.59**	**100.0**	**39.2**
Total	**1,137,701**	**5.09**	**16.80**	**100.0**	**100.0**

TABLE 2

Structure output and unit costs for insecticide-treated curtain implementation, Guantanamo, Cuba, 2009.

Structure output	Unit costs
Inhabitants (n)	10,101
Households (n)	3,061
Clusters (n)	6
Average of premises per cluster (n)	512
Person preparing distribution* (n)	60
Hours worked for distribution preparation (n)	1,578
ITCs distributed (n)	6,714
Households covered at distribution (%)	98.4
Households covered at 24 months (%)	97.4
Average of ITCs distributed per household (n)	2.22
Median of ITCs distributed per household (n)	3
Persons supporting distribution**(n)	50
Total of hours worked to support distribution (n)	6,397
Cost per curtain distributed (US$)	3.42
Cost per inhabitant (US$)	2.28
Cost per household (US$)	7.50
Cost per household covered at distribution (US$)	7.61

ITC: insecticide-treated curtain; **n:** number; **%:** percentage; **US$:** United States dollar. *Community meetings, informed consent and training. **Control workers to prepare curtains and cut wire for hanging, drivers, and management quality assurance.

DISCUSSION

The annual cost p.h. for conducting routine, intensive, and conventional *Aedes* control activities by the ACP in Guantanamo was a substantial US$16.80. The additional annual cost for deploying ITCs was 19% of this overall cost and 48.4% of the routine cost for adult vector control.

Dengue is not endemic in Cuba, but occurs in small, localized outbreaks years (1981, 1997, 2006) apart[6]. *Aedes* at immature-stage infestation levels were used as a surrogate measure of dengue transmission in the trial[23], which is a limitation when evaluating the effectiveness and cost-effectiveness of ITC implementation. Furthermore, the program perspective, rather than the societal perspective, was used in this study because the community did not incur any costs.

Despite these limitations, we have provided information regarding the cost of ITC implementation in an environment with an intensive well-structured ACP. We applied the methodology that was previously used in Venezuela and Thailand[17] and an accepted non-official rate to convert salaries from the national currency to US$, which provides a realistic picture of the total costs and relative weight of imported goods and enhances the comparability of our results.

The cost of routine dengue vector control programs varies according to the mix, frequency, and attained coverage of activities and differences in program structure, wage rates, different insecticides used, and dengue epidemiology. Therefore, it is difficult to make international comparisons of their cost. Costs are also hindered by different costing approaches and frequent failure to report important details, such as quantities of resources consumed. However, the Cuban routine ACP is among the most expensive programmes worldwide. Our estimate of the cost of ACP was at the upper bound of annual cost p.h. reported previously, which ranged from US$0.60 in Cambodia, over US$1.89 in Thailand, US$2.14 in Philippines, US$2.19 in Venezuela, US$4.40 in Panama, and US$4.90 in Colombia, and up to US$31.74 in Kenya and US$31.75 in Mexico[16] [17] [25] [31] [32] [33]. The main cost drivers for the conventional control activities in Guantanamo were salaries, supplies for chemical control, and the cost for chemicals. This seems common to all ACPs. However, the Cuban program invests heavily in larval control activities, consisting of 60% of the overall expenditure, while other national programs mainly focus on adult *Aedes* control, which is less labor intensive[17] [32]. Unfortunately, recent international publications do not explicitly separate the cost shares of these activities, which impedes a quantitative comparison.

We were only able to compare our results regarding the cost of ITC implementation with estimates of ITC implementation from Venezuela[17], Guatemala[18], and Colombia[16]. Using a similar costing methodology, the costs p.h.in Guantanamo and Venezuela were found to be similar (US$7.50 vs. 6.95). However, the cost per curtain distributed was higher in Guantanamo than in Venezuela (US$3.42 vs. 1.90, respectively) This can be attributed to the interplay between more intensive ACP activities in Cuba to involve the community and to distribute ITC compared to that in Venezuela, higher purchase prices (US$2.54 vs. 1.46) for larger curtains, and higher coverage [i.e., smaller household sizes and less curtains distributed p.h. on average (2.22 vs. 4.66)]. However, the ITC cost was the major cost driver. In a study in Guatemala[18], the direct costs of distributing an average of 3 ITCs p.h. and a few insecticide-treated drum covers and treating the most productive containers with temephos and eliminating disposable items was US$5.30p.h. Staff costs were attributed to 69% of the total cost; however, the ITC cost was not included in this estimate or reported separately. In Colombia, the cost of implementing ITCs followed by insecticide-treated drum covers was US$48 p.h.[16]. From the data provided, it can be estimated that about US$29 was spent on distributing an average of 3.3 curtains p.h.; this extremely high cost has not been fully explained.

The annualized cost of ITC deployment to control adult stages of *Aedes* was much lower in Guantanamo, but still high compared to the annual overall cost of the ACP and very high relative to the routine cost for adult vector control. Efficient ITC implementation depends on the incremental effectiveness (given the incremental costs) of ITCs as a control method in addition to routine activities or the potential to reduce the scope and scale (and hence reduce the cost) of routine adult vector control activities while maintaining the same overall effectiveness.

TABLE 3

Cost per inhabitant and per household (US$) of insecticide-treated curtain implementation, Guantanamo, Cuba, 2009*.

Activity	Cost item	Cost				Cost per inhabitant (per household)	Annualized cost p.i.** (per household) (2009-2010)
		existing resources	additional resources	total	(%)		
Purchase of curtains	6,714 curtains distributed	0.00	17,041.50	17,041.50	(74.3)	1.69 (5.57)	0.86 (2.83)
Preparation							
community meetings, negotiation with families, and informed consent	184.5 p.d.*** Health sector and RACP labor	349.21	0.00	349.21	(1.5)	0.03 (0.11)	0.02 (0.06)
	Consumables	190.00	500.00	690.00	(3.0)	0.07 (0.23)	0.03 (0.11)
training	12.8 p.d.* Health sector and RACP labor	180.00	0.00	180.00	(0.8)	0.02 (0.06)	0.01 (0.03)
	Consumables	0.00	68.00	68.00	(0.3)	0.01 (0.02)	0.00 (0.01)
Sub-total preparation		**719.21**	**568.00**	**1,287.21**	**(5.6)**	**0.13 (0.42)**	**0.06 (0.21)**
Distribution							
	629.4 p.d. RACP labor (drivers control workers)	1,306.35	0.00	1,306.35	(5.7)	0.13 (0.43)	0.07 (0.22)
	170.3 p.d RACP labor (management and quality assurance)	473.80	0.00	473.80	(2.1)	0.05 (0.15)	0.02 (0.07)
	Consumables	945.00	1,634.00	2,579.00	(11.2)	0.26 (0.84)	0.13 (0.43)
	Capital	250.00	0.00	250.00	(1.1)	0.02 (0.08)	0.01 (0.04)
Sub-total distribution		**2,975.15**	**1,634.00**	**4,609.15**	**(20.1)**	**0.46 (1.51)**	**0.23 (0.76)**
Total		**3,694.36**	**19,243.50**	**22,937.86**	**(100.0)**	**2.27 (7.50)**	**1.15 (3.80)**

US$: United States dollar; **p.d.:** person days; **RACP:** routine *Aedes* control program; **FTE:** full-time equivalent. *All data are rounded to the next digit. **Cost per inhabitant (per household) divided by the annuity factor 1.9701 (see Methods). ***Person days (8 h/day) FTE.

Unfortunately, the evidence regarding incremental ITC effectiveness is rather scarce and conflicting. Approximately, the entomological indices were reduced by 50% in settings with modest investment in conventional vector control actions and high *Aedes* infestation levels, such as Venezuela[11] and Thailand[15], which was conditional on an ITC coverage of 50%. However, in another study in Venezuela[11], no difference in the pupae per person index was observed between ITC and control areas. Furthermore, Lenhart[14] could not demonstrate any effect in entomological indices in a later study in Thailand. In Colombia, Quintero et al.[16] report a significantly decreased Breteau index up to 6 weeks after ITC implementation, but no effect on the pupae per person index. In our economic study, based on the results from the trial in Guantanamo[24], there was no incremental effect of ITC in addition to the ACP. This could be explained by the already low vector infestation levels and/or the intensive routine vector control activities.

Currently the deployment of ITCs in addition to existing conventional ACP activities is definitely not an option in Guantanamo or comparable environments. ITCs that partly substitute for residual insecticide spraying could possibly be advantageous if they could sufficiently reduce annual operational costs. However, the effectiveness of ITC deployment in such a scenario remains unknown. It is difficult to predict how ITCs could substitute for specific vector control activities in the vast majority of dengue endemic countries where the current p.h. investments in *Aedes* control are at least three or four times lower than ITC implementation costs. However, substantially lower curtain prices could possibly make ITCs a more attractive option[17] depending on the relative effectiveness of the different (adult) *Aedes* control tools. Furthermore, making ITCs palatable for niche application in transmission hot spots or closed public spaces, such as hospitals, where their barrier function can be better exploited to reduce human vector contact.

Currently, ITC deployment at current curtain prices should hardly be promoted in Cuba. However, given the low *Aedes* infestation levels, the incremental cost effectiveness ratio will certainly lie beyond the willingness to pay for an additional unit of benefit and health policy makers will be reluctant to substitute a tool of uncertain effectiveness for a relatively successful strategy.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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