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Laboratory and field evaluation of commercial repellent formulations against mosquitoes (Diptera: Culicidae) in Queensland, Australia

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Abstract Laboratory tests of commercial repellent formulations were conducted against *Anopheles farauti* Laveran, *Culex annulirostris* Skuse, *Ochlerotatus vigilax* (Skuse) and *Stegomyia aegypti* (L.). The majority of repellent formulations tested contain *N,N*,-diethyl-*3*-methylbenzamide (also known as diethyl-*m*-toluamide, commonly called deet). Two formulations containing picaridin (1-piperidinecarboxylate acid, 2-(2-hydroxyethyl)-1-methylpropylester, also known as KBR 3023), one containing ethyl butylacetylaminopropionate (EBAP) and two formulations containing essential oils (e.g. Citronella oil) were also tested. In the laboratory tests, repellent formulations containing deet provided the best protection, and picaridin and EBAP also provided good protection. Citronella oil provided only limited protection. Two field trials to compare commercially available repellent formulations containing picaridin and deet against mosquitoes at Redcliffe, Queensland, were conducted. In the first, Autan Repel, containing 9.3% picaridin, RID, containing 10% deet, and Bushman Ultra, containing 80% deet in a gel, were compared. In the second, Autan Repel Army 20, containing 19.2% picaridin, OFF! Skintastic, containing 7% deet, and Aerogard, containing 12% deet, were compared. The predominant mosquito in both tests was *Cx. annulirostris*. Bushman provided >95% protection against all mosquitoes for at least 8 h when tests ceased. The other deet repellents also provided good protection against mosquitoes, with RID providing 5 h, Skintastic 4 h and Aerogard 2 h protection. The Autan repel (9.3% picaridin) provided >95% protection for 3 h, and Autan Repel Army (19.2% picaridin) provided 4 h protection. These studies have shown that commercial formulations of both deet and picaridin provide good protection against *Cx. annulirostris*, an important vector of arboviruses in Australia.

Key words commercial repellents, *Culex annulirostris*, deet, *N*, *N*-diethyl-*3*-methylbenzamide, picaridin.

INTRODUCTION

The use of personal protection measures such as the application of repellents to exposed skin has long been advocated to minimise human contact with vector and nuisance mosquitoes (Gupta & Rutledge 1994). The chemical, *N,N*-diethyl-*3*-methylbenzamide (also known as diethyl-*m*-toluamide, commonly called deet), has been the main active ingredient in repellent formulations since its discovery in 1954. Despite the widespread use of commercial formulations containing deet within Australia (Larson *et al*. 2000), there have been relatively few reports of the response of mosquitoes to commercial repellents published in the scientific literature. Tests of commercial repellents have been commissioned and published in popular magazines (Anonymous 1989, 1995a,b). These studies showed deet repellents were effective against *Stegomyia* (formally *Aedes*) *aegypti* (L.) in the laboratory, and also reported consumer considerations such as the cost per application, the number of applications provided in each container and relative value.

The relatively new chemical, picaridin (1-piperidinecarboxylate acid, 2-(2-hydroxyehtyl)-1-methylpropylester, also known as KBR 3023), has been shown to be an effective repellent against mosquitoes in Malaysia (Yap *et al*. 1998, 2000) and Australia (Frances *et al*. 2002, 2004). In this paper we report laboratory studies to comparatively evaluate the effectiveness of commercial repellents against *Anopheles farauti* Laveran, *St. aegypti*, *Culex annulirostris* Skuse and *Ochlerotatus vigilax* (Skuse). The formulations providing the best overall protection in laboratory tests were subsequently tested in the field against wild populations of mosquitoes in Queensland (Qld), Australia.

MATERIALS AND METHODS

Laboratory studies

Mosquito species. All mosquitoes were obtained from laboratory colonies of *An. farauti*, *Cx. annulirostris* and *St. aegypti*

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(Townsville Strain) held at Australian Army Malaria Institute (AMI), Enoggera, Brisbane. A colony of *Oc. vigilax* was established from eggs provided by Mr Stephen L. Doggett, University of Sydney at Westmead Hospital.

Chemicals. Commercial repellents were purchased from retail outlets in Brisbane. The following commercial repellent formulations were used:

1 Autan Repel, Insect Pump Spray, 125 mL, containing 92.8 g L^{-1} picaridin, Bayer Australia Ltd, Pymble, New South Wales (NSW).

2 OFF! Skintastic, Personal Insect Repellent Spray, 200 mL, containing 68.75 g L^{-1} *N,N,*-diethyltoluamide and 27.9 g L^{-1} Di-*N*-Propyl-isochomeronate, SC Johnson Wax, Lane Cove, NSW.

3 RID, Low Irritant in a pump action spray, 175 mL, containing 100 g L^{-1} *N,N*-diethyl-*m*-toluamide, 20 g L^{-1} *N*-octyl Bicycloheptene Dicarboximide, 10 g L^{-1} Di-*N*-propyl Isochomeronate and 1 g L^{-1} Triclosan, Thorley Laboratories, Salisbury, Qld.

4 Aerogard Personal Insect Repellent Spray, Low Irritant, 135 mL, containing 126.35 g L^{-1} Diethyltoluamide and 26.76 g L^{-1} Di-*N*-Propyl Isochomeronate, Reckitt Benckiser, Ermington, NSW.

5 Bushman Ultra, Insect repellent 75 g, containing 800 g L^{-1} Diethyltoluamide in a gel, North Qld Laboratories P/L, Cairns, Qld.

6 Bite Blocker Insect repellent, 120 mL, contains plant oils (including 2% Soybean Oil), made by Consep, Bend, Oregon, USA, but made in Canada.

7 Avon Skin-So-Soft Bug Guard, 100 mL, containing 0.865 g L^{-1} citronella Oil, Avon Products Pty Ltd, Brookvale, NSW.

8 Avon (Skin-So-Soft) Bug Guard Insect Repellent, 100 mL, containing 75 g kg^{-1} ethyl butylacetylaminopropionate (EBAP), Avon Products Pty Ltd, Brookvale, NSW.

The following repellent formulations and standards were also used. These products contain similar active ingredients to the commercial brands, but cannot be purchased in Brisbane:

1 3% deet, containing 3% *N,N*-diethyl-*m*-toluamide (Fluka, Switzerland) in absolute ethanol.

2 Army Insect Repellent Personal, 75 g, containing 346 g kg^{-1} Diethyltoluamide in a gel, made by Colbar (Aust) Pty Ltd, Hampton Park, Victoria, for the Australian Defence Force (ADF).

3 Extended Duration Repellent Formulation (EDRF), 2 fl. ounces, containing 31.58% *N,N,*-dietyl-*m*-toluamide and 1.75% other isomers of deet, in a polymer, made by 3M Consumer Specialties Division for the Unites States Army.

4 20% Citronellal, containing 20% citronellal (3,7-dimethyl-6-octenal, Sigma, St Louis, MO, USA) in absolute ethanol.

5 Autan Repel Army 20, containing 191.2 g L^{-1} picaridin in ethanol, made by Bayer (Aust.) Ltd, Pymble, NSW, for the ADF.

Test procedures. The methods described by Frances *et al.* (1998) were used. For each test, 100 nulliparous females (6–9 d old) were placed into a screened wire cage ($30 \times 30 \times 30$ cm). Tests were conducted by exposing untreated and treated forearms to the mosquitoes. A surgical glove was worn during each test to prevent biting on the untreated hand. Each test consisted of two parts. First, an untreated forearm was exposed in the cage for 15–30 s, and the number of probing mosquitoes recorded. Probing mosquitoes were blown from the arm before any blood was taken. Immediately thereafter, the forearm was removed and the repellent formulation to be tested was applied evenly to the same forearm (between the wrist and elbow). The repellent container was weighed before and after repellent application. After drying for 2 min, the treated forearm was exposed to the bites of mosquitoes in the same test cage initially for 5 min, and then for 5 min at 30 min intervals for *An. farauti* and 60 min intervals for the other three species until three bites were recorded, terminating the test. The tests were terminated after 6 h if three bites were not recorded.

Field studies

Field site. Tests were conducted at the edge of forest at Redcliffe Airport in February–March 2004. This site is located approximately 30 km north of Brisbane, Qld.

Chemicals. Commercial repellents were purchased from retail outlets in Brisbane.

The following commercial repellent formulations were used in Test 1:

1 Autan repel, containing 9.3% picaridin.

2 RID, containing 10% deet.

3 Bushman Ultra, containing 80% deet in a gel.

The following commercial repellent formulations were used in Test 2:

1 Autan Repel Army 20, containing 19.2% picaridin.

2 OFF! Skintastic, containing 7% deet.

3 Aerogard, containing 12% deet.

Test procedures. Four adults (mean age 30.5 years) participated in the study, and each wore a long sleeved shirt, buttoned at the wrist, long trousers, and running shoes without socks. A mesh jacket (Bugout, Wautosa, WI, USA) was worn over the head and arms, surgical gloves on the hands, and the legs of the trousers were rolled to the knee to expose only the lower legs to biting mosquitoes.

The repellents and 100% ethanol (control) were spread evenly by the volunteers over each lower leg from the base of the knee to the ankle, according to label instructions. The amount of repellent applied was determined by weighing the container before and after application. The amount of repellent per cm^2 varied among volunteers due to leg size differences. The approximate application area ($A = 1/3(a + b + c) \times h$) was calculated from measurements of leg length (h, knee to the ankle) and circumference (a – just below the knee, b – the calf, and c – the ankle).

Two field tests were conducted. In the first test (Test 1) conducted over four nights, repellent formulations were applied

at 14:00 h on each day, 2 h before the start of each test at 16:00 h. Repellent treatments were assigned randomly by rotation so that each participant tested a different treatment on each of the 4 d. Participants entered the test area, sat in predetermined positions approximately 5 m apart, and collected all mosquitoes biting in the next 10 min, followed by a 50 min break. Mosquitoes were captured using aspirators and placed into cups. This procedure was repeated hourly for 7 h, so that seven biting collections were made by each volunteer. In the second test (Test 2) conducted over four nights, repellent formulations were applied at 17:00 on each day, 2 h before the start of each test at 19:00 h. Collections were made in the same manner as Test 1, except that only six hourly collections were made.

The totals at each of the hourly time points were determined for the controls and for each repellent group. These totals then were summed and percentage protection was calculated at each time point by comparing the number of bites for controls against the number of bites for repellent-treated test participants using Abbott's formula (Abbott 1925). Percentage protection, defined as the number of bites received by an individual in a treatment group relative to that of the control, was calculated as (control − treatment)/control × 100. Comparison of repellent efficacy was made among the three treatment groups using a two-way analysis of variance (ANOVA) for two factors. The treatment factor, type of repellent, was studied at three levels with repeated measures made during a second factor time. Time was measured in hours after repellent application and studied at seven levels in Test 1 and six in Test 2. The restriction on randomisation of the treatments within a block (i.e. day) resulted in two error terms for this design. Because the data were expressed as percentages (percentage protection), an arcsine transformation was performed on values before statistical analysis.

RESULTS

Laboratory studies

There were differences in the amount of repellent applied to the test forearm, with a mean application rate of 2.66 mg cm^{-2} (Table 1). There was variable protection provided according to the type and concentration of active ingredient in the repellent formulation (Table 1). There were significant differences in the protection provided by repellent formulations against mosquitoes (two-way ANOVA $F_{12,94} = 25.9$, $P < 0.001$). The formulations containing deet (Bushman, ADF, EDRF, Rid, Aerogard, and OFF! Skintastic), Bite Blocker and Avon Bug Guard provided the best protection in these tests. The two Autan formulations and 3% deet provided less protection, while 20% Citronellal and Avon Skin So Soft Bug Guard provided the least protection. The mean protection that was provided against the four mosquito species was also significantly different (two-way ANOVA $F_{3,94} = 56.4$, $P < 0.001$) with the protection provided against *An. farauti* significantly shorter than provided against the other species. Protection was significantly longer against *St. aegypti*, and best against *Oc. vigilax* and *Cx. annulirostris*.

From the results of the laboratory studies, only deet (four formulations) and picaridin (two formulations) were selected for field testing. The formulations used in the field tests were readily available in retail outlets in Brisbane during the period of these studies. The Avon Bug Guard formulation (containing 7.5% EBAP) provided good protection against mosquitoes in laboratory tests, but the formulation was purchased after the commencement of field tests. This is the only repellent available in Australia containing this new active ingredient, and assessment of the efficacy of the formulation against mosquitoes in field tests is warranted.

Table 1 Mean protection time for forearms treated with commercial formulations against four species of mosquitoes in the laboratory

Formulation	Mean rate of repellent application† (mg cm^{-2} ± SE)	Mean protection time‡ (±SE) for each mosquito species (min)			
		Anopheles farauti	*Stegomyia aegypti*	*Culex annulirostris*	*Ochlerotatus vigilax*
Autan Repel	3.23 ± 0.13ab	80 ± 36.1 ($n = 3$)	<5 ($n = 3$)	220 ± 40 ($n = 3$)	>360 ($n = 2$)
Autan Repel Army	3.39 ± 0.15a	10 ± 10 ($n = 3$)	90 ± 17.3 ($n = 4$)	>360 ($n = 4$)	>360 ($n = 2$)
OFF! Skintastic	2.79 ± 0.10bc	30 ($n = 3$)	240 ± 34.6 ($n = 3$)	>360 ($n = 3$)	>360 ($n = 2$)
Rid Pump Spray	2.24 ± 0.09c	70 ± 20 ($n = 3$)	140 ± 40 ($n = 3$)	>360 ($n = 3$)	>360 ($n = 2$)
Aerogard Pump Spray	2.90 ± 0.18ac	60 ± 17.3 ($n = 3$)	180 ± 69.3 ($n = 3$)	320 ± 40 ($n = 3$)	>360 ($n = 1$)
EDRF	2.54 ± 0.27c	70 ± 10 ($n = 3$)	>360 ($n = 2$)	>360 ($n = 3$)	>360 ($n = 2$)
ADF	2.00 ± 0.13c	200 ± 20 ($n = 3$)	325.7 ± 25.7 ($n = 7$)	>360 ($n = 3$)	>360 ($n = 2$)
Bushman	2.92 ± 0.01ac	>360 ($n = 2$)	>360 ($n = 2$)	>360 ($n = 2$)	>360 ($n = 2$)
Bite Blocker	2.21 ± 0.10c	90 ($n = 3$)	280 ± 20 ($n = 3$)	>360 ($n = 2$)	>360 ($n = 1$)
Avon Bug Guard	2.35 ± 0.07c	130 ± 20 ($n = 3$)	100 ± 20 ($n = 3$)	>360 ($n = 3$)	>360 ($n = 2$)
Avon Skin-So-Soft Bug Guard	2.73 ± 0.18bc	50 ± 36.1 ($n = 3$)	<5 ($n = 3$)	100 ± 20 ($n = 3$)	<5 ($n = 3$)
Standards					
Citronellal (20%)	2.86 ± 0.07ac	<5 ($n = 3$)	60 ($n = 3$)	200 ± 20 ($n = 3$)	80 ± 20 ($n = 3$)
Deet (3%) in ethanol	2.62 ± 0.11c	60 ± 34.6 ($n = 3$)	40 ± 20 ($n = 3$)	320 ± 20 ($n = 3$)	280 ± 20 ($n = 3$)

†Means followed by the same letter are not significantly different using one-way ANOVAR and Student–Newman–Kuels test ($P > 0.05$). ‡Time until three bites recorded.

Mean probing rate on untreated arm: *An. farauti* 7.1 ± 0.5/15 s ($n = 38$), *St. aegypti* 9.3 ± 0.6/15 s ($n = 42$), *Cx. annulirostris* 3.1 ± 0.2/30 s ($n = 38$) and *Oc. vigilax* 4.5 ± 0.5/15 s ($n = 27$).

ADF, Australian Defence Force; EDRF, Extended Duration Repellent Formulation.

Field studies

The average area of the collectors' legs that was protected was 2164 cm^2 (range 1798–2450 cm^2) and the amount of repellent applied to the collectors' legs is shown in Table 2. There was no statistical differences in the amount of repellent applied to the collectors' legs (one-way ANOVA $F_{5,18} = 0.64$, $P = 0.68$). A total of 740 mosquitoes were collected during Test 1 and the main species collected were *Cx. annulirostris* (49.9% of collection), *Verrallina* Marks sp. no. 52 (20.7%) and *Oc. vigilax* (15.9%) (Table 3). The overall mean biting rate of all mosquitoes on ethanol-treated (control) volunteers was 21.2 bites per 10 min (Table 4). The mean number of mosquitoes collected throughout the collection period was fairly uniform, except for a distinct dusk peak recorded at 19:00 h resulting in significantly more mosquitoes (two-way ANOVA $F_{6,18} = 6.9$, $P < 0.001$) and *Cx. annulirostris* (two-way ANOVA $F_{6,18} = 5.8$, $P = 0.002$) collected during the fourth hour of collection. There were no differences in the mean number of mosquitoes collected in the other periods (Table 4).

A total of 335 mosquitoes were collected during Test 2 and the main species collected were *Cx. annulirostris* (58.8% of collection) and *Oc. vigilax* (22.1%) (Table 3). The overall mean biting rate of all mosquitoes on ethanol-treated (control) volunteers was 11.3 bites per 10 min (Table 4). The mean number of mosquitoes collected throughout the collection period was fairly uniform and there were no differences in the mean number of all mosquitoes (two-way ANOVA $F_{5,15} = 1.9$, $P = 0.16$) and *Cx. annulirostris* (two-way ANOVA $F_{5,15} = 0.9$, $P = 0.53$) collected each hour.

Table 2 Mean (±SE) application rate of repellents to the lower legs of volunteers at Redcliffe, Queensland, February–March 2004

Repellent formulation	Test number	Mean ± SE application rate (mg cm^{-2}, $n = 4$)
Autan Repel (9.3% picaridin)	1	1.95 ± 0.26
RID (10% deet)	1	2.12 ± 0.32
Bushman (80% deet)	1	1.59 ± 0.35
Autan Army 20 (19.2% picaridin)	2	1.71 ± 0.15
Skintastic (7% deet)	2	1.75 ± 0.12
Aerogard (12.4% deet)	2	1.69 ± 0.20

During Test 1 the percentage protection provided by the three repellents against all mosquitoes was significantly different ($F_{2,36} = 8.1$, $P = 0.006$, Fig. 1). Bushman provided >95% protection for at least 8 h when tests ceased, and provided significantly better protection than Autan Repel which provided >95% protection for 3 h, and RID which provided >95% protection for 5 h. There was no difference between Autan Repel and RID. During Test 2 the percentage protection provided by the three repellents against all mosquitoes was also significantly different ($F_{2,30} = 8.6$, $P = 0.007$, Fig. 1). Both Autan and Skintastic provided >95% protection for 4 h, significantly greater than Aerogard, which provided 2 h protection.

DISCUSSION

The laboratory tests have shown that both *Cx. annulirostris* and *Oc. vigilax* are very sensitive to repellents containing deet.

Table 3 Mosquito species and overall number collected in two repellent tests at Redcliffe Airport, Queensland, February–March 2004

Mosquito species	Number collected (%)	
	Test 1	Test 2
Anopheles amictus	2 (0.3)	0 (0)
Anopheles annulipes	1 (0.1)	1 (0.3)
Coquillettidia xanthogaster	0 (0)	6 (1.8)
Culex annulirostris	369 (49.9)	197 (58.8)
Culex sitiens	10 (1.4)	8 (2.4)
Mansonia uniformis	5 (0.7)	5 (1.5)
Mucidus alternans	33 (4.5)	6 (1.8)
Neomelaniconion lineatopenne	7 (0.9)	1 (0.3)
Ochlerotatus notoscriptus	26 (3.5)	0 (0)
Ochlerotatus procax	1 (0.1)	0 (0)
Ochlerotatus vigilax	118 (15.9)	74 (22.1)
Ochlerotatus vittiger	11 (1.5)	26 (7.8)
Ochlerotatus sp. unidentified	0 (0)	4 (1.2)
Verrallina funerea	4 (0.5)	1 (0.3)
Verrallina Marks sp. no. 52	153 (20.7)	6 (1.8)
Total	740	335

Table 4 Mean (±SE) number of all mosquitoes and *Culex annulirostris* biting per 10 min on untreated (control) volunteers during hourly collections†

Time after repellent application (h)	Test 1		Test 2	
	All species ($n = 591$)	*Culex annulirostris* ($n = 299$)	All species ($n = 272$)	*Culex annulirostris* ($n = 172$)
2	2.3 ± 1.9a	0.5 ± 0.5a	8.8 ± 2.2a	5.3 ± 2.7a
3	3.0 ± 2.7a	0.8 ± 0.5a	13.5 ± 7.2a	10.0 ± 7.4a
4	8.3 ± 7.3a	0.5 ± 0.5a	7.3 ± 3.0a	4.5 ± 3.5a
5	62.0 ± 15.0b	34.5 ± 12.0b	4.5 ± 2.5a	2.5 ± 1.9a
6	17.0 ± 5.8a	5.3 ± 3.1a	16.0 ± 3.9a	9.0 ± 4.4a
7	26.3 ± 6.1a	13.8 ± 3.1a	18.0 ± 7.0a	11.8 ± 7.2a
8	29.0 ± 13.8a	16.0 ± 14.6	–	–

†Means in each column followed by the same letter are not significantly different using two-way ANOVAR and Student–Newman–Kuels test ($P > 0.05$).

Test 1, repellent applied at 14:00 h; Test 2, repellent applied at 17:00 h.

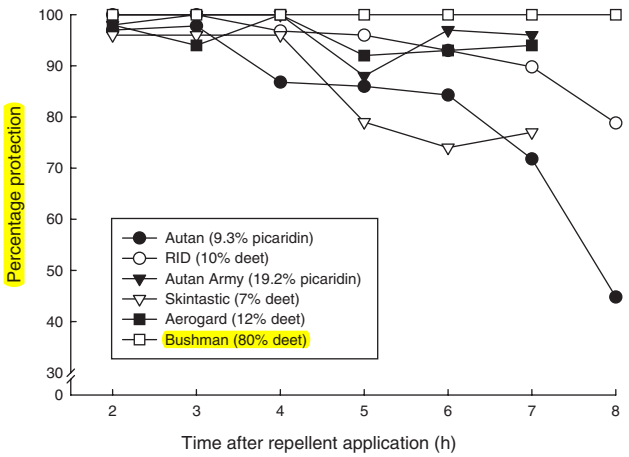

Fig. 1. Percentage protection provided by six commercial repellents against all mosquitoes at Redcliffe, Queensland, in February–March 2004.

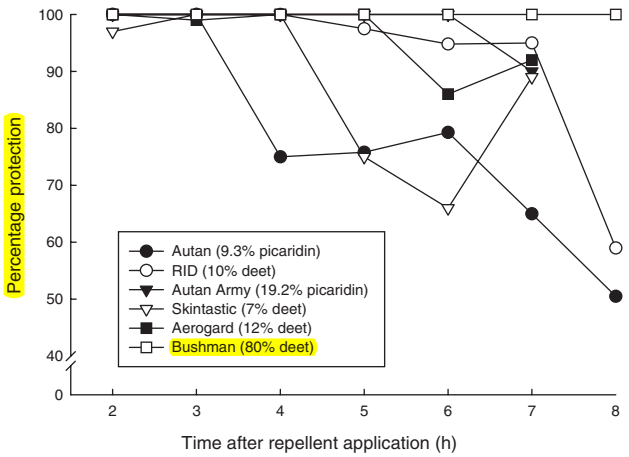

Fig. 2. Percentage protection provided by six commercial repellents against *Culex annulirostris* at Redcliffe, Queensland, in February–March 2004.

In general, formulations containing the higher concentrations of deet, Bite Blocker and Avon Bug Guard provided the best protection in these tests. The two Autan (picaridin) formulations and 3% deet were slightly less effective, while Citronella oil provided only short-term or no protection. Avon Bug Guard (containing EBAP) is the only repellent available in Australia containing this new active ingredient, and assessment of the efficacy of the formulation against mosquitoes in field tests is warranted.

There are reports in the medical literature concerning the adverse effects of deet repellents on humans. Qiu *et al*. (1998) reviewed the safety of deet and reported severe adverse events associated with skin exposure. These included several cases of encephelopathy and three deaths over a 20-year period. The deaths involved two 6-year-old children and a 17-month-old infant, and were believed to be the result of excessive and prolonged external use of deet repellents. The majority of adverse events in adults range from mild skin irritation to contact urticaria. Recent studies have investigated the safety

Table 5 Summary of protection provided by various commercial repellents against mosquitoes in field trials

Repellent formulation	Hours of >95% protection against mosquitoes	
	All mosquitoes	*Culex annulirostris*
Autan (9.3% picaridin)	3	3
RID	5	5
Bushman	>8	>8
Autan (19.2% picaridin)	4	6
Skintastic	4	4
Aerogard	2	5

of deet repellents and concluded that there is very little risk of serious adverse effects provided that the product is used appropriately and not excessively for prolonged periods (Osimitz & Grothaus 1995; Goodyer & Behrens 1998; Qiu *et al*. 1998). However, due to possible toxicity and potential for misuse, the use of repellents containing less than 50% deet is recommended (Goodyer & Behrens 1998). In the current study, Bushman Gel (80% deet) provided the best protection against mosquitoes in field tests. However, formulations containing lower concentrations of deet (RID, Skintastic and Aerogard) provided 2–5 h protection against all mosquitoes and 4–5 h protection against *Cx. annulirostris* (Table 5, Fig. 2). Autan Repel (containing 9.3% picaridin) provided 3 h protection against all mosquitoes and also against *Cx. annulirostris* (Table 5). Therefore, in areas and situations where optimal protection is needed, the use of Bushman gel or more frequent re-application of other formulations may be advocated. However, in areas where the density of mosquitoes is relatively low and individuals are only exposed to mosquitoes for relatively short periods of time (2–3 h), formulations with lower concentrations of deet or picaridin would be adequate.

The repellent formulations tested were purchased in the Brisbane area. Deet formulations are the most commonly sold in supermarkets and pharmacies. Formulations containing essential oils can be purchased at weekend markets and small independent stores. The formulation and application method of repellents can also have an influence on the effectiveness of the product. Therefore, for comparative reasons, primarily pump action spray formulations were selected for testing. Repellents are also formulated in a variety of application methods and types including lotions, gels, roll-ons and 'wipes'.

There have been relatively few studies of the response of Australian mosquitoes to repellent formulations. Many of the previous studies have been conducted to evaluate simple solutions of active ingredients (Frances *et al*. 1998). Earlier studies have shown the response of individual species to deet, including *An. farauti* s.s. Laveran (Frances *et al*. 1998), *Oc. vigilax* (Frances 1987) and *Verrallina lineata* (Taylor) (Frances *et al*. 2002).

Culex annulirostris is an important vector of Japanese encephalitis (van den Hurk *et al*. 2003), Ross River Virus (Russell 2002) and Barmah Forest Virus (Russell 1995), in Australia. The potential for the introduction of exotic mos-

quito-borne diseases, for example, West Nile virus (WNV), into Australia is a continuing threat (Russell & Kay 2004). Prior to the arrival of WNV into the USA in 1999, Herrington (2003) noted that the most frequently cited behaviour by people living in four US states to take action against being bitten by mosquitoes was the use of insect repellent on the skin and clothing. The use of mosquito repellents and other personal protection measures is the first line of protection against mosquito-borne disease, and should be encouraged in the community. The response of natural populations of *Cx. annulirostris* to repellent chemicals was reported recently (Frances *et al.* 2004), and results of the current field studies support the conclusion that repellents containing deet and picaridin provide good protection against this important vector of arboviruses in Australia. These data should be used to advise the public that the use of repellents provide good protection against nuisance mosquitoes and vectors of arboviruses, especially *Cx. annulirostris*.

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