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Topical and spatial repellent bioassays against the Australian paralysis tick, *Ixodes holocyclus* (Acari: Ixodidae)

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Abstract The Australian paralysis tick, *Ixodes holocyclus*, is the cause of significant human morbidity. Bites from the tick may result in paralysis, allergic reactions that can include anaphylaxis and death, mammalian meat allergies and the transmission of infectious agents. In recent years, there have been a number of papers published on the microbiome of the species, but to date, there is no published research on *I. holocyclus* management or personal protection options to prevent the bite from the species. The study herein focused on the latter; the use of repellents for the prevention of bites from *I. holocyclus*. Five personal repellents were tested along with coconut oil, and a citronella patch and wristband. These were all tested for repellency in a laboratory assay over the time intervals of 15 min, 1, 2, 3 and 4 h post application. The personal repellents included the active ingredients of picaridin (9.3%), DEET (11.5%), lemon eucalyptus (36.0%), a combined formulation of citronella and tea tree oil (28.4%) and an extract of *Andrographis paniculata* (30% w/v). The coconut oil was 30% v/v. The citronella patch contained 120 mg/patch, whereas the citronella wristband contained 750 mg/band. Two spatial repellents were also tested in the laboratory for repellency and toxicity against *I. holocyclus* and tested for toxicity in the field. These included OFF!® Clip-On™ (metofluthrin 312 g/kg) and Thermacell® (allethrin 219.7 g/kg). For the personal repellents at 4 h, there was no statistical difference in repellency between the formulations of picaridin, DEET and lemon eucalyptus, with over 84% repellency recorded for all. Thus, these would be the personal repellents recommended for preventing tick bites. The citronella patch produced 100% repellency over 4 h; however, as this type of product is known to only provide protection close to the patch, it is not recommended for routine use. For the spatial repellents, both produced significant repellency and toxicity in the laboratory, but failed to produce any tick mortality in the field, and their use cannot be recommended. This is the first published study investigating personal and spatial repellents for the prevention of tick bite from *I. holocyclus*.

Key words *Andrographis paniculata*, citronella, coconut oil, DEET, lemon eucalyptus, OFF!® Clip-On™, picaridin, Thermacell®.

INTRODUCTION

Tick bites and the transmission of tick-borne pathogens continue to be a global public health concern (Jongejan & Uilenberg 2004). The Australian paralysis tick, *Ixodes holocyclus*, is the species most commonly responsible for causing tick-related human morbidity in Australia (Doggett 2004).

This species occurs along the eastern coastal strip of the country and has a seasonal pattern in the activity of its various stages. The larvae are most common during the autumn months, the nymphs during the winter and the adults in the spring (Eppleston *et al*. 2013). The tick is less active in the hot summer months where it over-summers as the egg stage (Eppleston *et al*. 2013; Barker & Walker 2014). As the common name suggests, the tick can induce paralysis, and some 20 human deaths occurred before the development of an effective anti-venene (Doggett 2004). The paralysis is induced by a toxin (known as 'holocyclotoxin') that occurs in the tick saliva that is injected during blood feeding. As the adult female injects larger volumes of saliva, it is this stage that poses greatest risk of paralysis (Doggett 2004). Every year, more than 1000 companion animals are affected with paralysis caused by *I. holocyclus* (Hall-Mendelin *et al*. 2011; Eppleston *et al*. 2013; Mullins *et al*. 2016). Furthermore, the tick saliva can induce allergic reactions, which can be from mild to severe, including anaphylaxis with occasional death (Brown & Hamilton 1998; Rappo *et al*. 2013). Allergic reactions in humans are now considered more significant, and are far more common, than paralysis (Rappo *et al*. 2013; van Nunen 2018). The tick itself can attach to various sites of the body, such as the conjunctiva, making removal very challenging (Teong *et al*. 2015). It also poses a risk to travellers, and there are a number of reports of overseas visitors returning home and finding an attached *I. holocyclus* (Pietzsch *et al*. 2013; Pek *et al*. 2016). Proper tick removal is now considered key to minimising complications from allergic reactions associated with tick bite (Taylor *et al*. 2019).

Around 10 years ago, a syndrome initially known as 'red meat allergy' was recognised in patients bitten by *I. holocyclus* (van Nunen *et al*. 2009). The patients developed symptoms including gut pain, bloating, diarrhoea and occasional anaphylaxis following the consumption of meats of mammal origin, including pork, lamb, bovine, whale and guinea pig. For this reason,

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