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Authors: Stephen E. Bienhoff, Dawie J. Kok, Linda M. Roycroft, Elizabeth S. Roberts

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Title

Efficacy of a single oral administration of milbemycin oxime against natural infections of *Ancylostoma braziliense* in dogs

Names of Authors

Stephen E. Bienhoff [a,*], Dawie J. Kok[b], Linda M. Roycroft[a], Elizabeth S. Roberts[a]

Complete postal addresses of affiliations

[a] Novartis Animal Health US, Inc., 3200 Northline Ave, Suite 300, Greensboro, NC 27408, USA

[b] ClinVet International, PO Box 11186, Universitas, Bloemfontein 9321, South Africa

*Corresponding author. Tel.: 336-387-1063; fax: 336-387-1459.

E-mail address: stephen.bienhoff@novartis.com (S.E. Bienhoff).

Abstract

The objective of this randomized, blinded, placebo controlled laboratory study was to confirm the efficacy of a single oral administration of two marketed formulations of milbemycin oxime (Interceptor® Flavor Tabs® and Sentinel® Flavor Tabs®) at a minimum dose of 0.5 mg/kg (0.23 mg/lb) against natural infections of *Ancylostoma braziliense* in dogs. Thirty-six hookworm infected dogs, a minimum of 10 weeks of age and of various breeds and genders were used. Fecal egg counts were done on three separate days prior to treatment for randomization purposes. Dogs were ranked by descending order of the fecal egg count arithmetic means and randomly assigned to either the two milbemycin treatment groups or the placebo control group in blocks of three dogs each, 12 dogs per group. Dogs were dosed according to the product label with blinding maintained by separation of function. Worm counts were done at necropsy 7 days after treatment. Reduction in *A. braziliense* worm counts in the milbemycin groups were compared to the placebo control group using analysis of variance of the *A. braziliense* logarithmic mean worm counts and percent efficacy was based on geometric means. Efficacy was defined as the ability of the test products to significantly ($p \leq 0.05$) reduce parasite load by 90% or greater in treated dogs when compared to adequately infected placebo control dogs. The placebo control group had a geometric mean worm count of 19.2. The Interceptor treated group had a geometric mean worm count of 0.38 representing a 98% reduction in parasite load and the Sentinel treated group had a geometric mean worm count of 0.98 representing a 95% reduction in parasite load. Both reductions were highly significant ($p<0.0001$). In this study, milbemycin oxime, when administered as two marketed formulations at a minimum dose of 0.5 mg/kg (0.23 mg/lb), was efficacious for removing adult *A. braziliense* in naturally infected dogs.

Keywords: Milbemycin oxime, Interceptor®, Sentinel®, Natural infection, *Ancylostoma braziliense*, Dogs

1. Introduction

Ancylostoma braziliense is a pathogenic hookworm parasite of dogs most generally associated with warm and moist climates. Although not as pathogenic as *A. caninum*, heavy infections in young dogs may result in blood loss (Rep, 1980) and hypoproteinemia (Miller, 1968). However, the most significant concern with *A. braziliense* is its ability to cause cutaneous larva migrans in both dogs (Vetter and Leegwater-vd Linden, 1977; Vetter and van der Linden, 1977a; Vetter and van der Linden, 1977b; Bowman et al., 2010) and humans (Brenner and Patel, 2003; Patel et al., 2008; Purdy et al., 2011). Of the hookworm larvae, *A. braziliense* tends to be more invasive by cutaneous penetration and shows the greatest enzyme activity for breaking down structures of the skin (Hotez et al., 1992), thus allowing the larvae to enter by direct contact with intact skin and mucous membranes. Not only has *A. braziliense* been associated with cutaneous larva migrans in humans, but also migration to the lungs (Butland and Coulson, 1985) and oral mucosa (Damante et al., 2011). Even though the parasite is more common in the tropical regions of the world, it has also been reported in non tropical settings (Herbener and Borak, 1988), suggesting the need for control outside the areas typically considered endemic. Therefore, effective control of *A. braziliense* in dogs is important because of its potential pathogenicity in dogs and zoonotic potential for cutaneous larva migrans in humans.

Milbemycin oxime is a macrocyclic lactone that is efficacious against infections of *A. caninum* (Blagburn et al., 1992; Niamatali et al., 1992), but no studies have been done specifically investigating effectiveness against *A. braziliense*. We hypothesized that milbemycin oxime would be over 90% efficacious when administered as a single treatment to dogs infected with *A. braziliense*.

2. Materials and methods

The study was a randomized, blinded, placebo controlled laboratory study using naturally infected dogs conducted in compliance with GCP (VICH GL9), South African animal welfare regulations, as stipulated in the "National Code for Animal Use in Research, Education, Diagnosis and Testing of Drugs and Related Substances in South Africa". The protocol was submitted to the ClinVet Animal Ethics Committee (CAEC), the composition of which was in compliance with the National Code, for approval. In addition, the protocol was reviewed and approved by the Novartis Animal Health US, Inc. Institutional Animal Care and Use Committee.

2.1. Animals

Thirty-six hookworm infected dogs (21 males and 15 females), a minimum of 10 weeks of age and of any pure or mixed breed were randomly assigned to cages at the beginning of acclimation. Animals were purchased from owners who were fully informed of the nature of the study. Each dog was identified by a unique number on a collar tag. All purchase contracts indicated each animal's origin and procurement records traceable to each animal by identification number. Individual dog pens were marked with corresponding animal identification numbers. Potential infection with *A. braziliense* was assessed by fecal egg counts (presence of hookworm eggs) for three consecutive days prior to inclusion in the study. A sample of dogs from a specific source were acquired for necropsy purposes to confirm the presence of *A. braziliense*. Other than intestinal parasitism, dogs were clinically healthy as determined by a general physical examination and clinical pathology review. Dogs were acclimated at least 7 days prior to treatment and were observed at least once daily up to the time of treatment.

2.2. Housing

Dogs were housed individually. Room temperature was monitored and exercise was conducted according to facility standard operating procedures, as appropriate. Animals were acclimated at least seven days prior to treatment and were observed at least once daily up to the time of treatment and then twice daily until euthanasia. A commercially available high quality complete canine diet which provided the nutritional requirements for the age of dog used in this study was offered *ad libitum* to each dog. Water was also available *ad libitum*.

2.3. Randomization

Fecal egg counts were done using the McMaster technique (Henriksen and Aagaard, 1976) on three separate days prior to treatment for randomization purposes. Dogs were ranked by descending order of the fecal egg count arithmetic means and randomly assigned to treatment in blocks of three dogs each (one dog to each treatment group), 12 dogs per group. Randomizations were performed in two replicates (phases), with each replicate group containing 18 dogs. The randomization process was applied independently within each replicate. Counts were recorded as hookworm eggs per gram of feces (epg) with subsequent determination of arithmetic means by a statistician.

2.4. Blinding

Blinding was accomplished by separation of function. Individuals responsible for general health observations, clinical observations, or examination of dogs at necropsy for adult *A. braziliense* worms did not know the allocation of dogs to treatment. Only the statistician and individuals responsible for drug administration were aware of treatment assignments until analyses.

2.5. Procedures

All dogs were fasted overnight before the day of treatment to encourage food intake prior to dosing and treatment was administered within approximately 30 min after feeding. Dogs received either a single oral administration of the marketed formulations of milbemycin oxime (Interceptor® Flavor Tabs® or Sentinel® Flavor Tabs®; Novartis Animal Health US, Inc.) according to the label at a minimum dose of 0.5 mg/kg (0.23 mg/lb) or a placebo (Pet-Tabs®; Virbac Animal Health, Inc.). Observations for adverse clinical signs were done on each dog within 1 h (± 15 min) prior to treatment and again at 1, 4, 8 h (± 15 min) and 24 h (± 1 h) after treatment. Seven days after treatment each dog was administered a lethal intravenous dose of euthanasia solution (Euthapent®; Kyron Laboratories [Pty] Ltd) in the same order as treatment group assignment for assessing adult worm counts in the intestinal tract. The dose of euthanasia solution was based on the body weight determined on the day of euthanasia. Dogs were fasted 12 h immediately prior to euthanasia in order to decrease the amount of material in the intestinal tract. The abdominal cavity was opened along the ventral midline and double ligatures were placed at the cardia of the stomach and at the distal rectum prior to removal of the gastrointestinal tract from the abdominal cavity. The stomach was opened along the greater curvature and the contents collected in a suitable container. The mucosa was thoroughly scrubbed, rinsed with water and the washings combined with the gastric contents. The mucosa was inspected and any attached parasites were removed and preserved in 10% formalin or other suitable preservative. In a similar manner, the small and large intestines were opened along their entire length and the contents and mucosa were collected, thoroughly rinsed with water and the scrapings/washings from the mucosa were combined. The mucosa was inspected and any attached parasites were removed and preserved in 10% formalin. The gastric and intestinal

contents and rinsing fluids were washed over appropriately sized sieve(s) and any material that retained in the sieve(s) was preserved in 10% formalin.

2.6. Ancylostoma braziliense identification

Worm recovery and identification was performed by appropriately trained and experienced individuals. Prior to examining the preserved worms and washings, formalin was removed by sedimentation and/or washing. Recovered worms were examined microscopically, identified to genus and species based on characteristics of the buccal plates. The number of adult *A. braziliense* recovered from each dog was recorded along with the number of other adult worms recovered from each dog.

2.7. Statistical analyses

Twelve dogs were randomized to each group to increase the probability of having at least six dogs adequately infected in the placebo control group indicating an adequate test. The individual dog was the experimental unit. Efficacy was determined on the basis of the percent reduction in adult worm counts in the treated groups compared to the placebo control group. Arithmetic and geometric means of all *A. braziliense* counts were calculated.

Percent effectiveness was calculated using the following formula:

$$\text{Percent Effectiveness} = 100 * ((c_c - c_t) / c_c)$$

where: c_c = geometric mean number of adult *A. braziliense* in the control group and c_t = geometric mean number of adult *A. braziliense* in the treatment group. There were separate calculations for each treatment group. Since the calculation of the geometric mean involved taking the logarithm of the *A. braziliense* count of each animal, a "1" was added to the *A. braziliense* count for every animal in every group since there were *A. braziliense* counts equal to zero. This constant (1) was subtracted from the resultant calculated geometric mean prior to

147 calculating percent effectiveness. Percent effectiveness based on ≥ 90% reduction in *A.*
148 *braziliense* worm burden was calculated using geometric means. All analyses were performed
149 on logarithmic means using SAS/STAT® software (Version 9 of the SAS System for Windows,
150 SAS Institute Inc.) and all hypotheses were tested at a two-sided 0.05 level of significance.
151

152 **3. Results**

153 Of the 36 dogs enrolled in the study, 21 were male and 15 were female (Placebo = 5 males
154 and 7 females; Interceptor = 8 males and 4 females; Sentinel = 8 males and 4 females). Dogs
155 treated with Interceptor or Sentinel received a mean milbemycin oxime dose of 0.57 ± 0.08 and
156 0.57 ± 0.05 mg/kg, respectively. All dogs were reported as being over 10 months of age and the
157 weight ranged from 10.3 to 46.8 kg two days prior to dosing (weight used to determine dose).
158 There were no significant differences in body weights between treatment groups. Breeds
159 represented were variable and included purebred and mixed Alsatians (German Shepherds),
160 South African Boerboels, Border Collies, Chihuahuas, Dachshunds, Dobermans, Greyhounds,
161 Labradors, Maltese, Ridgebacks, Rottweilers and Terriers. Adult worms other than *A.*
162 *braziliense* that were identified during necropsy included *Ancylostoma caninum*, *Uncinaria*
163 *stenocephala*, *Trichuris vulpis*, *Toxocara canis*, *Toxascaris leonina*, *Dipylidium caninum*, *Taenia*
164 spp. and *Echinococcus granulosus*. Efficacy against these parasites was consistent with label
165 indications.

166 Of the 12 dogs in the placebo control group, seven had more than 20 *A. braziliense* isolated
167 at necropsy and 10 had more than five isolated at necropsy (range 10 to 100) indicating the
168 presence of an adequate infection in the study dogs. Statistically, both milbemycin treatment
169 groups had significantly ($p < 0.0001$) fewer *A. braziliense* isolated at necropsy when compared to

the placebo control group. All surviving *A. braziliense* were isolated from the small intestines. The calculated efficacy based on geometric means was 98% for the Interceptor® group and 95% for the Sentinel® group (**Table 1**). Despite careful and frequent observations of the study animals, no adverse events, abnormal clinical observations, or abnormal health observations were observed during the study. In addition, there were no statistically significant differences in body weight change between groups.

4. Discussion

Macrocyclic lactones have excellent antihelmintic activity and have been shown to be effective against hookworm infections in dogs and cats (Anderson and Roberson, 1982; Blagburn et al., 1992; Niamatali et al., 1992; Nolan et al., 1992; Six et al., 2000). Milbemycin oxime is a macrocyclic lactone that is efficacious against infections of *A. caninum* (Blagburn et al., 1992; Niamatali et al., 1992), but no studies have been done specifically investigating effectiveness against *A. braziliense,* as has been done for other compounds (Robinson et al., 1976; Anderson and Roberson, 1982). In this study, we specifically investigated the effectiveness of a single oral administration of milbemycin oxime in two commercial formulations (Interceptor® Flavor Tabs® and Sentinel® Flavor Tabs®) at a minimum dose of 0.23 mg/lb (0.5 mg/kg) against natural infections of *A. braziliense* in dogs. We hypothesized that milbemycin oxime would be over 90% efficacious when administered as a single treatment. Naturally infected dogs from South Africa were used as *A. braziliense* is known to be endemic to this area (Verster, 1979; Minnaar and Krecek, 2001; Minnaar et al., 2002).

The study design was based on the known life-cycle of *A. braziliense* and is routinely used to determine the efficacy of anthelmintics in well controlled laboratory settings. Thirty-six clinically healthy dogs (other than intestinal parasitism) of various breeds and body weights that were a minimum of 10 weeks of age were used and were representative of the general dog population present in South Africa. Statistically, both of the milbemycin oxime treatment groups had significantly ($p < 0.0001$) fewer *A. braziliense* isolated at necropsy when compared to the placebo control group with reductions ranging from 94.91% (Sentinel) to 98.02% (Interceptor) from a single administration. Taken together, these results confirm that all requirements for an adequate test of efficacy were met in this study.

No adverse events were reported nor were there any significant reductions in body weight observed indicating milbemycin oxime in these formulations was well tolerated, which is consistent with previous studies that have shown milbemycin oxime is safe when administered orally for control of nematode parasites (Ide et al, 1993).

5. Conclusion

This study demonstrates milbemycin oxime, when administered in the commercial formulations of Interceptor® Flavor Tabs® and Sentinel® Flavor Tabs® at a minimum milbemycin oxime dose of 0.5 mg/kg (0.23 mg/lb), is efficacious for the removal and control of adult *A. braziliense* in dogs.

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Conflict of interest

The study was funding by Novartis Animal Health Inc. Global Technical Services. Logistics and technical support, including the design of the study, statistical analyses, interpretation of results and writing the manuscript was done by Novartis Animal Health US, Inc. New Product Development. Three of the authors are employees of Novartis Animal Health US, Inc. who manufactures Interceptor® Flavor Tabs® and Sentinel® Flavor Tabs®. Dawie Kok was contracted by Novartis Animal Health US, Inc. to conduct the study.

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304

304 **Tables**

305 **Table 1.** *Ancylostoma braziliense* geometric mean counts, percent efficacy and statistical

306 significance by treatment group.

Treatment Group	Geometric mean	Arithmetic mean	% Efficacy†	p-value
Placebo Control	19.227	35.500	NA	NA
Interceptor® Flavor Tabs®	0.381	0.583	98.02	<0.0001*
Sentinel® Flavor Tabs®	0.979	2.167	94.91	<0.0001*

307 * Statistically significant at $p \leq 0.05$ when geometric means were compared to Placebo

308 † Percent efficacy based on geometric means

309