

1 ***Hepatozoon canis* in three imported dogs: a new tick-borne disease reaching the United**
2 **Kingdom**

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27 **ABSTRACT**

28 An increasing number of non-endemic vector-borne pathogens have been described in dogs
29 imported to the UK in the past two decades. Recently, an outbreak of canine babesiosis in
30 south-east England has raised veterinary awareness with regard to the impact of such diseases
31 on the UK canine population. Canine hepatozoonosis, caused by *Hepatozoon canis* and
32 transmitted by the ingestion of *Rhipicephalus sanguineus* ticks, is widespread in the
33 Mediterranean basin. Herein we describe the first three molecularly confirmed clinical cases
34 of canine hepatozoonosis in dogs imported into the UK. Veterinarians in the UK should be
35 aware of *H. canis* as a potential infection in imported dogs, especially in the face of the
36 expanding distribution of *R. sanguineus* ticks in Europe.

37 **Keywords:** hepatozoonosis, *Hepatozoon canis*, dog, canine tick-borne pathogens, imported
38 disease, UK

39

40 **Introduction**

41 *Hepatozoon canis* (Apicomplexa, Adeleorina, Hepatozoidae) is a tick-borne pathogen that
42 belongs to a diverse group of parasites which includes approximately 340 species that infect
43 a wide range of vertebrates, such as mammals, birds, and reptiles (1). Canine hepatozoonosis
44 was first described in India by a British medical officer in 1905 (2) and since then has been
45 identified worldwide, with *H. canis* and *Hepatozoon americanum*, being of clinical
46 importance for dogs (3). These two species differ in geographical distribution, pathogenicity
47 and definitive invertebrate host (4). *Hepatozoon americanum*, is found in the Southern USA
48 and causes severe, and often fatal, disease whereas *H. canis* is present in tropical and sub-
49 tropical areas globally (5).

50 The life cycle for *H. canis* begins with the ingestion of infected ticks, containing
51 sporulated oocysts, by the canine host. Sporozoites are released in the gut, penetrate the
52 intestinal epithelium, and disseminate via lymphatics or blood vessels to the haemolymphatic
53 tissues (including bone marrow, spleen, and lymph nodes) where they undergo merogony.
54 Merozoites are subsequently released and invade leukocytes (neutrophils and monocytes)
55 forming gamonts. Gamonts are ingested by ticks during blood feeding, undergo a sexual stage,
56 and form oocysts (4, 5). While *Rhipicephalus sanguineus* (brown dog tick) is considered to
57 be the main vector of *H. canis*, other tick species have been confirmed as definitive vectors
58 for this parasite including *Amblyomma ovale* and *Rhipicephalus turanicus* (6, 7).
59 Transplacental infections of *H. canis* have also been reported (8), and a recent case-control
60 study, using structural equation modelling, found that younger dogs are more likely to be
61 infected with *H. canis* compared to adult dogs (9). Interestingly, *H. americanum* may
62 additionally be spread via ingestion of prey containing the cystozoite stages of the parasite.
63 However this mode of transmission has not been evaluated for *H. canis* (4).

64 Clinical signs of *H. canis* relate to the severity of the parasite burden. It frequently
65 causes a chronic sub-clinical infection. Dogs commonly may have a low parasite burden (<1%

66 of neutrophils containing gamonts) and be asymptomatic or show only mild clinical signs,
67 whereas more severe clinical signs including fever, lethargy and emaciation are noted with
68 high parasite burdens (4, 10, 11). In published case reports of dogs suffering from clinical
69 signs of *H. canis*, the percentage of neutrophils containing gamonts varied from 21% to 90%
70 (12-14). The commonly reported periostitis caused by *H. americanum* has also occasionally
71 been reported with *H. canis*, and can be associated with skeletal and muscle pain (8, 14, 15).

72 The most common haematological abnormalities associated with *H. canis* infection
73 include mild anaemia and neutrophilia, while rare extreme leukocytosis (up to $150 \times 10^9/L$
74 leukocytes) can occur with high parasitaemia (12-14, 16, 17). Serum biochemistry
75 abnormalities typically include hyperproteinaemia with hyperglobulinaemia,
76 hypoalbuminaemia, and increased activities of creatine kinase and alkaline phosphatase (4,
77 17).

78 Infection of dogs with *H. canis* has been recognised in Asia (13), Europe (18), the
79 Mediterranean basin (19-21), the Middle East (17, 22), South America (23), and in the
80 southern states of the USA in North America (24). Most recently, *H. canis* was unexpectedly
81 identified for the first time in Queensland, Australia, in an *Ixodes holocyclus* Neumann tick
82 collected from a dog, and the Australian biosecurity authorities are investigating the potential
83 sources of this infection (25). The first known case of canine hepatozoonosis in the UK was
84 presented in 2011 at the European Society of Veterinary Clinical Pathology congress in a dog
85 imported from Ireland (26). Here we further evaluate this case using phylogenetic analysis,
86 and we report two additional clinical cases of this infection imported from Cyprus.

87

88 **Case 1**

89 A 12-year-old, entire male, Beagle, was presented in September 2010 to a veterinary practice
90 in London, UK, having been acquired from a rescue centre in Ireland. There was no clinical
91 history available from prior to the Irish rescue centre and no microchip or tattoo was present.

92 The dog was presented on the 14th of September 2010 (Day 1), was thin but bright and
93 alert. Significant clinical findings included pale mucous membranes, a slightly enlarged
94 prostate (presumed to be benign prostatic hyperplasia), occasional cough, slight nasal
95 discharge and positive tracheal pinch. Haematology results are shown in Table 1. On Day 1,
96 the dog had a mild to moderate, normocytic, normochromic, non-regenerative anaemia. On
97 blood smear examination moderate numbers of neutrophils contained intracytoplasmic
98 elliptical structures (~9-11µm long, ~4-5µm wide) which were clear to lightly basophilic in
99 colour and interpreted as *Hepatozoon* gamonts (Figures 1 and 2). *Hepatozoon* gamonts were
100 noted in approximately 33% neutrophils. Testing for vector borne diseases (VBD; see
101 molecular investigation) revealed infection with *H. canis*. Serum biochemistry revealed only
102 a mild hyperglobulinaemia and mild hypoalbuminaemia. Due to the moderate parasitaemia
103 and mild clinical signs, a diagnosis of hepatozoonosis was made. Treatment was initiated with
104 imidocarb dipropionate (Imizol® Schering-Plough Animal Health, Darmstadt, Germany;
105 6.6mg/kg, by subcutaneous injection, every 14 days) and doxycycline (Ronaxan, Merial,
106 Lyon, France; 10mg/kg orally once daily for 28 days).

107 Haematology on Day 30 revealed an improvement in the anaemia and a borderline
108 monocytosis. Although *Hepatozoon* gamonts were still present in neutrophils (approximately
109 5%), there was reduction in the peripheral parasite burden. Further injections of imidocarb
110 dipropionate were administered (total of four injections). At this time, the dog was castrated
111 for management of the prostatomegaly. Haematology on Day 44 revealed resolution of the
112 anaemia and a mild, novel, neutropenia. No *Hepatozoon* gamonts were encountered during
113 the blood smear examination.

114 Two months later (Day 112) haematology demonstrated recurrence of the borderline
115 anaemia. Very rare *Hepatozoon* gamonts were present in neutrophils (<1%). A final course
116 of two injections of imidocarb dipropionate (6.6mg/kg, subcutaneously 14 days apart) were
117 administered. A final haematology on Day 154 demonstrated continued borderline anaemia

118 with slight regeneration and a mild leukopenia. No *Hepatozoon* gamonts were encountered
119 on examination of peripheral blood smears and on buffy coat preparations. This finding was
120 supported by conventional PCR analysis for *Hepatozoon* spp. which was negative. Monthly
121 ectoparasitic prevention was recommended for the dog. The dog was doing clinically well
122 until the end of 2011 after which time clinical follow up was unavailable.

123

124 **Case 2**

125 A five-month-old, entire male, cross-breed, clinically healthy dog was imported into the UK
126 from a rescue centre in Paphos, Cyprus (Day 0); the day before travelling it had been treated
127 with fipronil and (S)-methoprene spot-on (FrontlineCombo®, Merial, Lyon, France). The dog
128 presented to a veterinary practice in Leicester, UK on the 7th of September 2014 (Day 1) due
129 to lethargy and presence of tick infestation. Fipronil spray (Frontline® Spray 0.25% w/v
130 Cutaneous Spray Solution, Merial) was applied, visible ticks were manually removed and
131 disposed of without any further identification. EDTA blood was collected for VBD testing,
132 which revealed infection with *H. canis*.

133 The dog's lethargy resolved spontaneously on Day 2. Due to financial limitations, the
134 foster owner declined further investigations and treatment. On Day 22, automated
135 haematology and serum biochemistry parameters were unremarkable. However, blood smear
136 and buffy coat examinations revealed the presence of low numbers *Hepatozoon* gamonts in
137 neutrophils (approximately 8%) (Table 2). Imidocarb dipropionate (6.6 mg/kg, by
138 subcutaneous injection, 14 days apart) was administered on Days 22 and 36. On Day 36, the
139 dog remained well but low numbers of *Hepatozoon* gamonts were still visible on blood smear
140 examination (<1%) and PCR was positive. Another six injections of imidocarb dipropionate
141 (6.6 mg/kg, subcutaneously) were administered weekly. On Day 85 the parasitaemia was not
142 apparent on blood smear examination, but PCR remained positive. Monthly ectoparasitic

143 prevention was recommended. One and three years following treatment completion, the dog
144 was described as healthy by the owner via telephone communication.

145

146 **Case 3**

147 An adult, neutered female, Poodle cross, clinically healthy dog was imported into the UK
148 from a rescue centre in Paphos, Cyprus (Day 0); the day before travelling it had been treated
149 with fipronil and (S)-methoprene spot-on. The dog presented to a veterinary practice in the
150 Midlands, UK on the 10th of August 2015 (Day 1) due to anorexia, lethargy and presence of
151 ticks which were manually removed and disposed of without any further identification. EDTA
152 blood was collected for blood smear examination and VBD testing. On Day 1, the dog had a
153 mild neutrophilia and on blood smear examination, moderate numbers of neutrophils
154 (approximately 40%) contained *Hepatozoon* gamonts. Testing for VBD revealed infection
155 with *H. canis* (Table 3). Due to the moderate parasitaemia and mild clinical signs, a diagnosis
156 of hepatozoonosis was made. Treatment was initiated with imidocarb dipropionate (6.6
157 mg/kg, by subcutaneous injection, 14 days apart, for 8 weeks) and doxycycline (10 mg/kg,
158 orally once daily, for 28 days).

159 On Day 60 the dog was reported to be clinically healthy by the veterinarian and no
160 *Hepatozoon* gamonts were noted on blood smear examination; however, the dog remained
161 PCR positive for *H. canis*. It was subsequently lost to follow-up and no further clinical
162 information was available for this case.

163

164 **Travel history**

165 All cases reported here were dogs imported to the UK. The dogs in Cases 2 and 3 were
166 imported from Cyprus, a European Union (EU) member island state situated in the eastern
167 Mediterranean basin (35°10'N and 33°22'E) with a temperate climate. The predominant tick
168 species found in Cyprus is *R. sanguineus* (27, 28) and a recent study has found that clinically

169 healthy dogs from the area of Paphos have a PCR prevalence of 45% for *H. canis*, 20% for
170 *Mycoplasma haemocanis*, 3% for *Anaplasma platys* and 1% for *Ehrlichia canis* (9).
171 According to the Ministry of Agriculture, Rural Development and Environment of the
172 Republic of Cyprus 8244 dogs travelled from Cyprus to the UK in the years 2015, 2016 and
173 2017 with the numbers increasing each year
174 ([http://www.philenews.com/koinonia/eidiseis/article/536613/steilame-10-850-adespotoys-](http://www.philenews.com/koinonia/eidiseis/article/536613/steilame-10-850-adespotoys-skyloys-sto-exoteriko-pinakas)
175 [skyloys-sto-exoteriko-pinakas](http://www.philenews.com/koinonia/eidiseis/article/536613/steilame-10-850-adespotoys-skyloys-sto-exoteriko-pinakas)).

176 Both Cases 2 and 3, fulfilled all the requirements set by UK's pet travel scheme
177 (PETS) for entering the country, that includes microchip identification, rabies vaccination 21-
178 days prior to arrival into the UK, and tapeworm treatment administration by a certified vet
179 between 5-days and 24-hours prior to arrival into the UK ([https://www.gov.uk/take-pet-](https://www.gov.uk/take-pet-abroad)
180 [abroad](https://www.gov.uk/take-pet-abroad)). Despite not being a requirement since January 2012, both dogs received acaricide
181 treatment 24-hours prior to for entry into the UK, and yet attached ticks were noted upon
182 arrival.

183 Case 1 did not have a microchip or a tattoo, making it difficult to trace its movements
184 and determine where it became infected with *H. canis*. Both Ireland and UK were
185 considered unlikely countries for acquiring *H. canis* infection as it has not previously been
186 documented in either of these countries and the main vector, *R. sanguineus*, does not appear
187 to be endemic in Ireland or the UK (29, 30). The most common tick encountered in both
188 Ireland and the UK is *Ixodes ricinus*, which has not been shown to be a vector for *H. canis*
189 (29-31). It was considered most likely that Case 1 became chronically infected with *H.*
190 *canis* in an endemic area, most likely in Southern Europe, possibly in Cyprus (9), France
191 (32), Greece (33), Italy (34), Portugal (35) or Spain (36) and then entered Ireland, either
192 prior to the introduction of PETS or illegally (37). Another possibility, considered less
193 likely, was infection following ingestion of a tick in Ireland that had previously fed on a
194 dog infected with *H. canis*.

195

196 **Molecular investigation, sequencing and phylogenetic analysis**

197 For all three cases DNA was extracted from 100 µL of EDTA-blood using a commercial kit
198 (NucleoSpin® Blood, Machery-Nagel, Germany) according to the manufacturer's
199 instructions. For the VBD testing, previously described conventional PCR assays , were used
200 to detect infection with *Ehrlichia/Anaplasma* spp. (38) and *Hepatozoon* spp. (39), and
201 quantitative PCR assays were used to detect infection with *Leishmania* spp. (40), *Babesia*
202 spp.(41), “*Candidatus Mycoplasma haematoparvum*” and *M. haemocanis* (42). For each PCR
203 assay, appropriate positive and negative controls were included.

204 *Hepatozoon* spp. PCR amplicons were purified using a commercial kit (ExoSAP-IT,
205 Affymetrix, USB, Cleveland, Ohio, USA) according to the manufacturer's instructions, and
206 the DNA sequenced using forward and reverse primers. The derived sequences were
207 assembled using MacVector v15.5.4 (MacVector Inc, Cambridge, UK). DNA sequences were
208 deposited in the European Nucleotide Archive. The derived sequence from Case 1
209 (LS453286) yielded 100% identity to an existing 18s rRNA gene for *H. canis* (AF418558)
210 over 625 bp. The derived sequences from Cases 2 and 3 (LS453287 and LS453288) yielded
211 99% identities to an existing 18s rRNA gene for *H. canis* (KX818220) over 625 bp and 577
212 bp respectively. Sequences obtained in this study were aligned using ClustalW to selected
213 18S rRNA gene sequences from *Hepatozoon* spp. found in GenBank and a phylogenetic tree
214 was subsequently generated (Figure 3). All *H. canis* sequences compared clustered into two
215 clades, separate from *H. felis*, with Cases 2 and 3 separate from Case 1. It was not possible to
216 predict the origin of Case 1's *H. canis* using available sequence data.

217

218 **Discussion**

219 These three cases highlight the risk of introducing non-endemic diseases, such as *H. canis*
220 infection, into the UK through dogs being imported from, or having a travel history to,

221 countries where *H. canis* is endemic. Furthermore, they illustrate the spectrum of
222 clinicopathological changes which *H. canis* infected dogs present with, as well as the
223 diagnostic and treatment options available.

224 All cases had mild clinical signs that developed shortly after arrival, thus potentially
225 the transportation stress may have aided the development of clinical hepatozoonosis from a
226 prior sub-clinical infection (43). Only Case 1 displayed mild abnormalities on its haematology
227 and biochemistry. Despite the high parasite burden (approximately 33%) a neutrophilia was
228 not observed. Indeed, a transient neutropenia was present on Day 44. It is unknown if this was
229 related to therapy resulting in the removal of parasitized neutrophils, or whether there was
230 underlying inflammation resulting in neutrophil consumption. Dogs with a high parasite
231 burden may be at an increased risk of secondary infections. Immune compromise can occur
232 for multiple reasons. Neutrophils which contain gamonts have reduced myeloperoxidase
233 activity (44), and have been reported to be deficient in oxidative bactericidal capacity (45).
234 The mild non-regenerative anaemia noted in this case was attributed to anaemia of
235 inflammatory disease, despite the lack of an inflammatory leukogram. The anaemia did
236 improve with treatment; however, a borderline anaemia still remained on the final
237 haematology. Also, in Case 1 there was a mild hyperglobulinaemia and hypoalbuminaemia,
238 as with other reported cases of canine hepatozoonosis due to *H. canis* (4, 17). The
239 hypoalbuminaemia most likely was due to an acute phase protein response or developed in
240 compensation to the hyperglobulinaemia, and the hyperglobulinaemia likely reflected chronic
241 inflammation. The timing of clinical presentation of all 3 dogs would suggest that they
242 became infected during summer when *R. sanguineus* is most abundant and there is increased
243 risk of pathogen transmission (46). Therefore, veterinarians should be aware that dogs
244 imported to UK, or having a travel history to, countries where *H. canis* is endemic during
245 summer or early autumn are more likely to have acquired this pathogen compared to dogs

246 imported during the winter or spring. Still, given the existence of chronic subclinical infection
247 with *H. canis*, it is possible that dogs imported all year round could develop clinical signs.

248 Blood smear examination was the most important diagnostic step in order to identify
249 the *Hepatozoon* gamonts and establish the infection in these three cases. The morphology of
250 the gamonts alone cannot distinguish infecting species and given the different prognosis and
251 treatment recommendations, PCR and sequencing were performed (4). Interestingly, none of
252 the three cases presented here were found to be co-infected with other vector-borne pathogens
253 that have frequently been reported in *H. canis*-infected dogs, such as *A. platys*, *E. canis*, or *L.*
254 *infantum* (21). These other vector-borne pathogens are common in the canine population of
255 Cyprus (9, 19, 47) and for Cases 1 and 3 there were clinical concerns initially for *E. canis* co-
256 infection, thus doxycycline was administered. Interestingly, the highest PCR prevalence
257 (37.9%) recorded for *Hepatozoon felis* in cats has been reported in Cyprus, and *H. felis*
258 infected cats are 12 times more likely to be co-infected with *Leishmania infantum* compared
259 to the cats that are PCR negative for *H. felis* (48, 49).

260 Imidocarb dipropionate has been described as the drug of choice for treatment of
261 hepatozoonosis caused by *H. canis* (4). However, as in Cases 2 and 3, imidocarb dipropionate
262 has been described as being ineffective in eliminating *H. canis* infection, despite repeated
263 administration over a period of eight months to three naturally infected dogs (34). In all of
264 our three cases, treatment resulted in a decrease in the peripheral parasite burden, and eventual
265 absence of *Hepatozoon* gamonts on blood smear examination, and a negative *Hepatozoon*
266 spp. PCR result on blood in Case 1. As PCR was not performed on haemolymphatic tissues,
267 complete elimination of the infection could not be confirmed for Case 1. Complete
268 elimination of the parasitaemia is difficult to determine on examination of peripheral blood
269 smears alone. This is also supported by a published case report of a dog in Japan described as
270 having a positive blood PCR for *H. canis* 242 days after diagnosis, despite an absence of
271 gamonts on peripheral blood smear examination (13). In the absence of a more effective

272 treatment, imidocarb dipropionate currently remains the drug of choice (6.6 mg/kg,
273 subcutaneously 14 days apart) to manage clinical hepatozoonosis due to *H. canis*, and the
274 prognosis is considered good (4).

275 We recommend that *H. canis* positive dogs receive regular and effective ectoparasitic
276 prevention to prevent onward transmission and to minimise the risk of acquiring co-infections
277 with other vector-borne pathogens, and that they are not used as blood donors. Repeat blood
278 smear and buffy coat examinations, as well as PCR's would be advised every 6-months to
279 monitor for parasitaemia, and treatment initiated if clinically warranted (e.g. lethargy, weight
280 loss, pyrexia) alongside a positive PCR result or blood smear examination. Administration of
281 immunosuppressive or chemotherapeutic agents should be avoided if possible, but if
282 necessary, more frequent monitoring of parasitaemia can be performed.

283 *Hepatozoon* species have been previously reported in the UK from pine martens
284 (*Martes martes*) in Scotland (50), wild red squirrels (*Sciurus vulgaris*) in the Isle of Wight
285 (51) and most recently in ticks infesting cats from south-east England for *H. felis* and from
286 Wales for *Hepatozoon silvestris* (52). Additionally, a letter to Veterinary Record by Skeldon
287 et al. described a case of *H. canis* infection in a dog imported into the UK from Cyprus (53).
288 Due to clinical deterioration that dog was euthanised and no further diagnostic tests were
289 performed.

290 At the moment the risk of *H. canis* becoming an endemic infection in the canine
291 population of UK is low since the current climate does not favour the survival of the main
292 vector *R. sanguineus* (54). However, if climate changes progress to establishing suitable
293 conditions for these ticks, then *H. canis* could potentially become endemic in UK especially
294 in the face of the expanding distribution of *R. sanguineus* ticks in northern Europe (55). The
295 recent outbreak of canine babesiosis in UK (56) has raised awareness of the risks associated
296 with dog importation and the Public Health England's Tick Surveillance Scheme's
297 (<https://www.gov.uk/guidance/tick-surveillance-scheme>) data analysis revealed that dogs

298 travelling from Cyprus and Spain may result in *R. sanguineus* tick importation (57).
299 *Rhipicephalus sanguineus* ticks can survive and establish populations within houses in the
300 UK where canine hosts are present, and could transmit *H. canis* to other canine hosts within
301 such environments (57). Additionally, other potential vector ticks that have not yet been
302 investigated may transmit *H. canis*. In south Hungary, an area considered free from *R.*
303 *sanguineus* ticks, canine hepatozoonosis has been reported, so *Dermacentor marginatus* and
304 *Dermacentor reticulatus* ticks that are present there have been considered as possible *H. canis*
305 vectors, although this has not been confirmed (58). *Dermacentor reticulatus* ticks are present
306 in parts of the UK such as western Wales and south-west England, but in small numbers (29)
307 so, the overall risk of *H. canis* transmission in the UK is thought to be very limited.

308 These findings, alongside the identification of various non-UK endemic infectious
309 pathogens in imported dogs has sparked discussion of altering the current PETS following the
310 Brexit referendum (59). Possible reintroduction of a requirement for acaricide treatment of
311 dogs by a veterinarian 24-hours prior to entry into the UK has been considered as a measure
312 for reducing the risk of tick importation in the UK. Still, it is questionable whether it would
313 be effective as demonstrated by Cases 2 and 3 that, despite receiving acaricides prior to
314 travelling, both dogs were still found to be infested with ticks upon arrival. A modification of
315 this scheme for acaricide treatment of dogs 48-72 hours, followed by examination by a
316 veterinarian 24 hours, prior to entry into the UK, to document an apparent absence of ticks
317 could also be discussed. Implementing stricter requirements, for example a 10-day quarantine
318 facility stay and extensive infectious agent screening such as those in existence in Australia
319 ([http://www.agriculture.gov.au/cats-dogs/step-by-step-guides/category-3-step-by-step-](http://www.agriculture.gov.au/cats-dogs/step-by-step-guides/category-3-step-by-step-guide-for-dogs)
320 [guide-for-dogs](http://www.agriculture.gov.au/cats-dogs/step-by-step-guides/category-3-step-by-step-guide-for-dogs)), could also be explored.

321 In the era of increased canine international travel, UK veterinary surgeons and
322 diagnosticians should be aware of *H. canis* infection. Dogs with a travel history from endemic

323 countries, especially from Southern Europe, are advised to be molecularly tested for
324 *Hepatozoon* spp. alongside other VBD and blood smear evaluation.

325

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329

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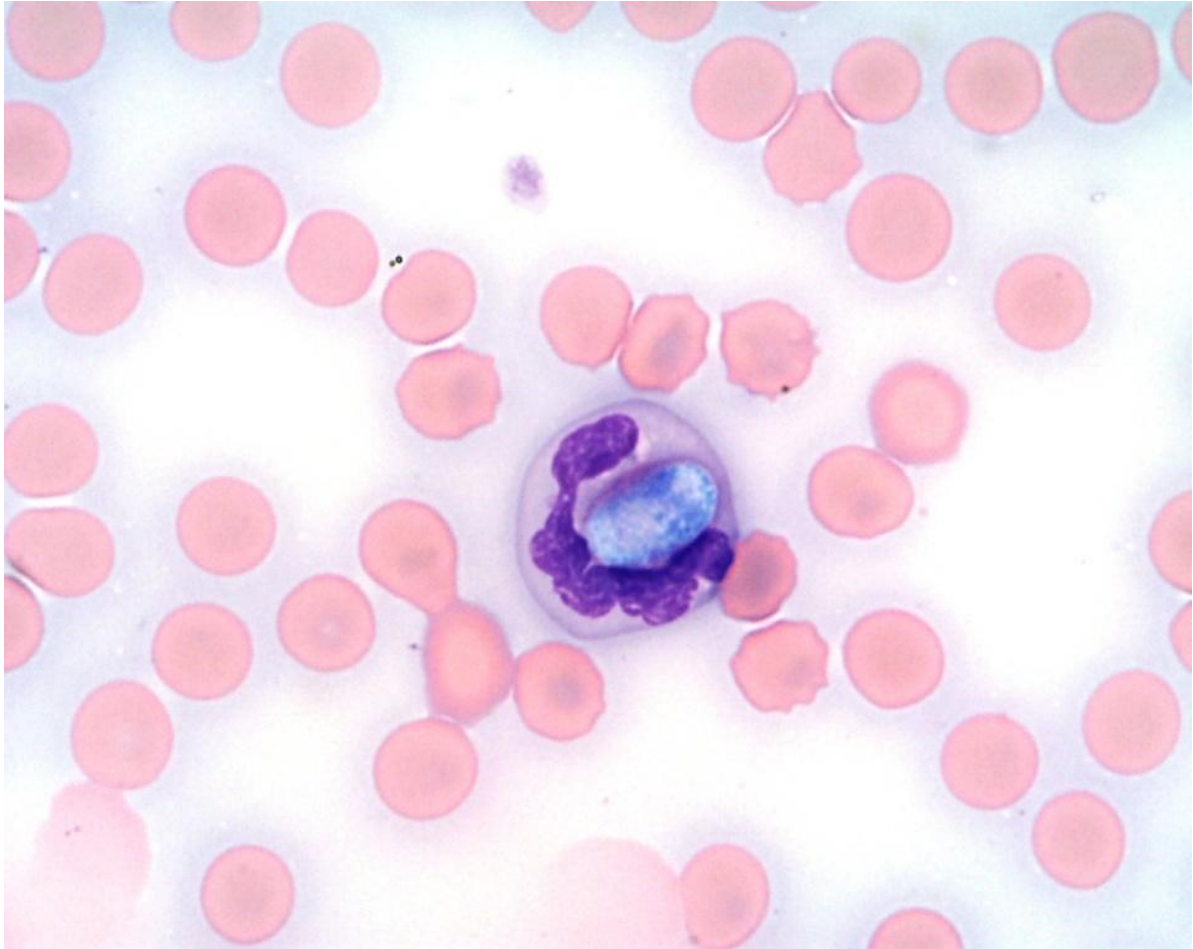
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483 **Figure Legends**

484 **Figure 1.** Case 1, Day 1 blood smear: Neutrophil containing a *Hepatozoon canis*
485 gamont in the cytoplasm. 100x oil; Modified Wright's stain.



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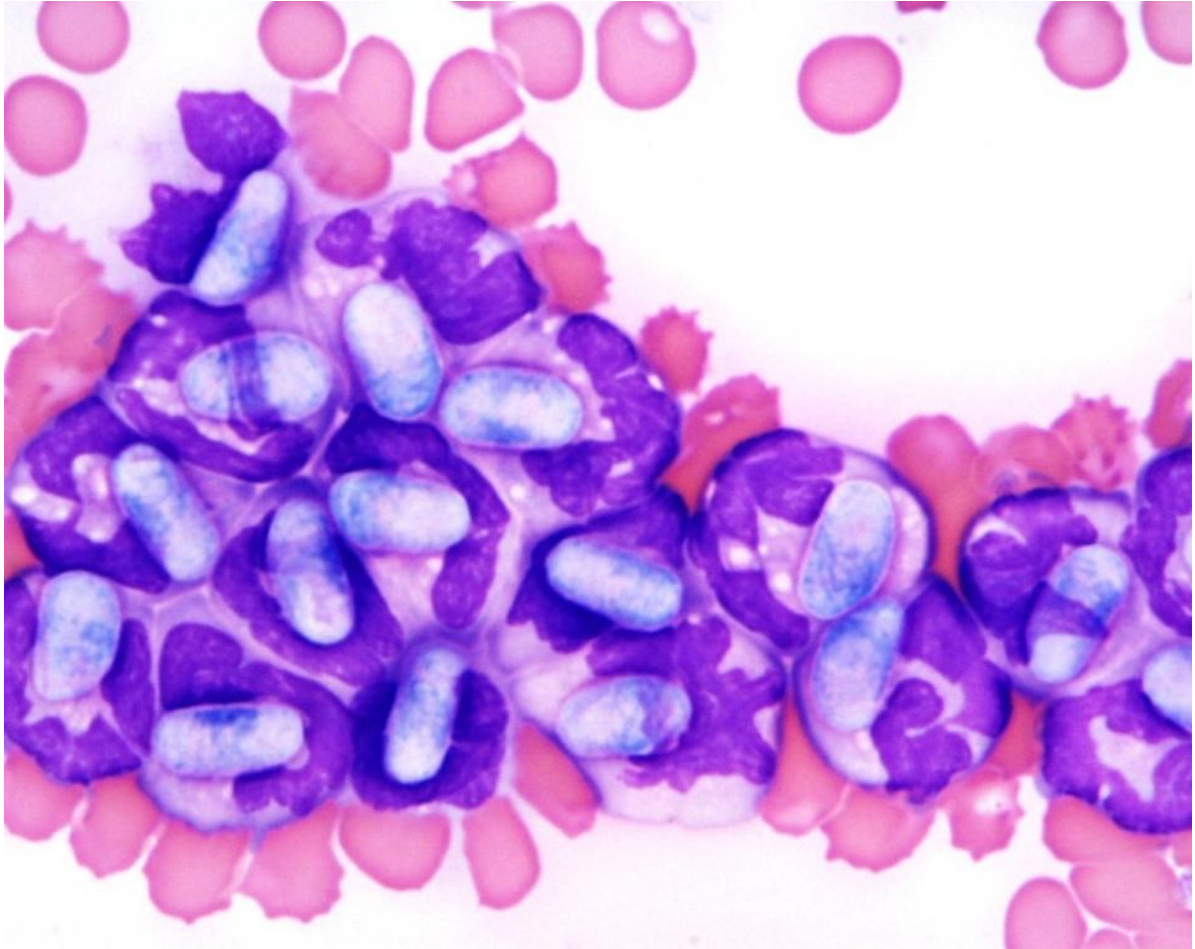
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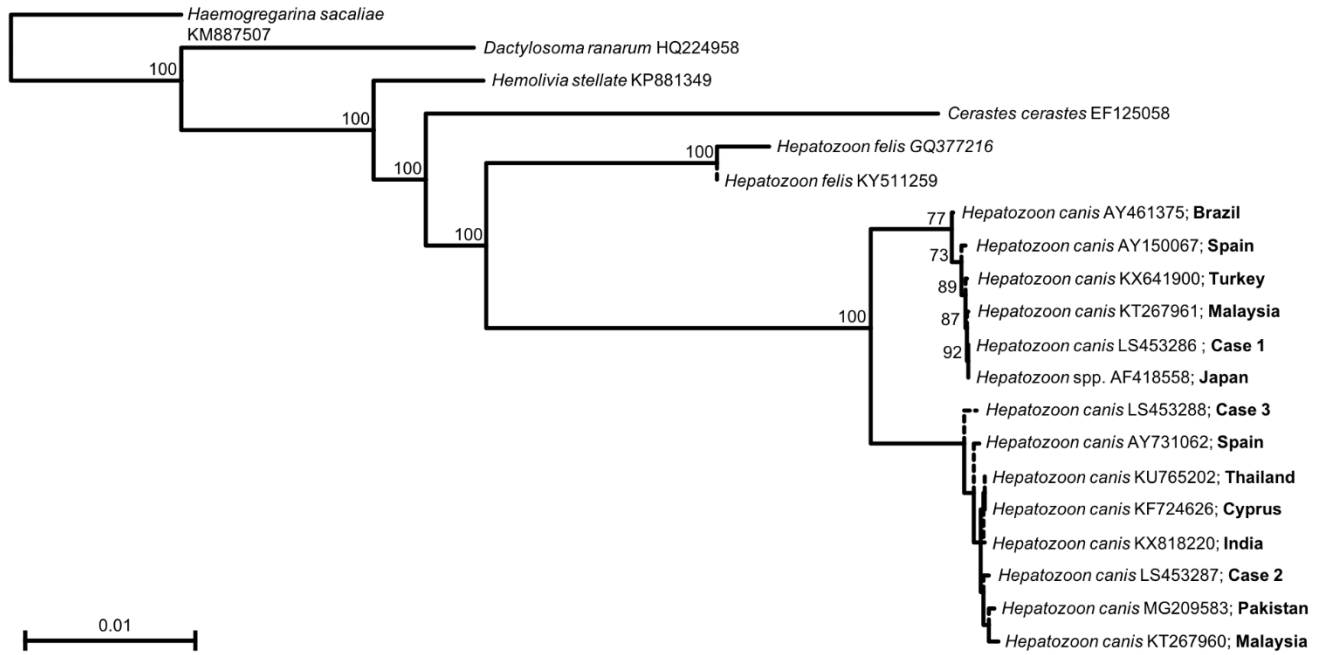
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495 **Figure 2.** Case 1, Day 1 blood smear: Neutrophils on the feathered edge containing
496 numerous *Hepatozoon canis* gamonts in the cytoplasm. 100x oil; Modified Wright's
497 stain.



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508 **Figure 3.** Phylogenetic tree constructed using the neighbour-joining program, corrected
 509 for nucleotide substitutions by the Kimura-2 parameter model, in MacVector. The data
 510 set was resampled 1000 times to generate bootstrap percentages. The country of origin
 511 is indicated in bold letters for *H. canis* sequences.



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525 **Table 1** Serial haematology and molecular results from Case 1 (days from initial diagnosis)

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Parameter	Day 1	Day 30	Day 44	Day 112	Day 154	Reference Interval	Units
RBC	4.2	5.0	5.2	4.4	4.7	5.5 – 8.5	x10 ¹² /L
HGB	9.8	11.8	12.4	10.6	11.2	12.0 – 18.0	g/dL
HCT	30.0	35.0	37.0	35.0	38.0	37.0 – 55.0	na
MCV	70.8	69.7	70.6	80.1*	81.5*	60.0 – 77.0	fL
MCH	23.2	23.7	23.9	24.1	23.9	19.5 – 24.5	p/g
MCHC	32.7	34.0	33.8	30.1	29.4	31.0 – 37.0	g/dL
WBC	8.0	7.4	8.0	7.3	4.9	6.0 – 17.1	x10 ⁹ /L
Neutrophils	5.5	3.3	2.6	4.3	3.0	3.0 – 11.5	x10 ⁹ /L
Lymphocytes	1.3	1.9	2.9	2.0	1.6	1.0 – 4.8	x10 ⁹ /L
Monocytes	0.8	1.8	1.4	0.7	0.2	0.2 -1.5	x10 ⁹ /L
Eosinophils	0.4	0.4	1.1	0.4	0.2	0.0 – 1.3	x10 ⁹ /L
Polychromasia	Abs.	Mild	Mild	Abs.	Mild	na	na
Platelets	114**	249	282	111**	187	150 - 900	x10 ⁹ /L
<i>Hepatozoon</i> spp. PCR	Pos.	na	na	na	Neg.	na	na
<i>Hepatozoon</i> gamonts on blood smear ⁺	~33%	~5%	Neg.	<1%	Neg.	na	na

527 Haematology analyses were performed with Cell-DYN 3500 Haematology Analyser (Abbott, Chicago,
528 Illinois, United States).

529

530 Abnormal findings are denoted by bold font.

531 +: % of neutrophils containing *H. canis* gamonts on the monolayer

532 *: *In vitro* swelling

533 **: Moderate platelet clumping, platelet numbers adequate on blood smear examination.

534

535

536 Abbreviations: *RBC* red blood cells; *HGB* haemoglobin; *HCT* haematocrit; *MCV* mean corpuscular volume;
537 *MCH* mean cell haemoglobin; *MCHC* mean corpuscular haemoglobin concentration; *WBC* white blood cell;
538 *Abs.* absent; *Neg.* negative; *na* not applicable; *pos.* positive

539

540 **Table 2** Serial blood smear and molecular results from Case 2 (days from initial presentation)

541

Parameter	Day 1	Day 22	Day 36	Day 85
<i>Hepatozoon</i> spp PCR	na	na	Pos.	Pos.
<i>Hepatozoon</i> gamonts on blood smear ⁺	na	~8%	<1%	Neg.

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543 Abnormal findings are denoted by bold font.

544 +: % of neutrophils containing *H. canis* gamonts on the monolayer

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546 Abbreviations: *na* not applicable; *Pos.* positive; *Neg.* negative

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551 **Table 3** Serial blood smear and molecular results from Case 3 (days from initial diagnosis)

552

Parameter	Day 1	Day 60
<i>Hepatozoon</i> spp PCR	Pos.	Pos.
<i>Hepatozoon</i> gamonts on blood smear ⁺	~40%	Neg.

553

554 Abnormal findings are denoted by bold font.

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556 +: % of neutrophils containing *H. canis* gamonts on the monolayer

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558 Abbreviations: *Pos.* positive; *Neg.* negative

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