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1 Canine parvovirus type 2 vaccine protects against virulent challenge with  
2 type 2c virus.

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26 **Abstract**

27 The ability of dogs vaccinated with a live attenuated CPV type 2 vaccine to resist  
28 challenge with a current CPV 2c isolate was investigated. Six SPF beagle dogs were  
29 given the minimum recommended course of vaccination, comprising a single  
30 inoculation of leptospirosis vaccine (Nobivac Lepto) at ten weeks of age followed  
31 two weeks later with a parvovirus vaccine in combination with distemper, adenovirus  
32 and parainfluenza virus (Nobivac DHPPi) and a repeat leptospirosis vaccine. Six  
33 control dogs were kept unvaccinated. All animals were challenged orally with a type  
34 2c isolate of CPV and monitored for clinical signs, virus shedding, white blood cell  
35 fluctuations and serological responses. All vaccinated dogs were fully protected;  
36 showing no clinical signs nor shedding challenge virus in the faeces, in contrast to  
37 control animals which displayed all the typical signs of infection with pathogenic  
38 CPV and shed challenge virus in the faeces.

39

40 **Keywords:** Canine parvovirus, vaccine, protection

41

## 42 Introduction

43

44 Canine parvovirus (CPV2) is a single stranded DNA virus which is responsible for an  
45 acute and sometimes fatal enteritis in dogs (Kelly, 1978; Appel et al., 1979). The  
46 virus, which first appeared in 1977 /1978, probably arose from a very closely related  
47 virus in cats, feline panleukopaenia virus (FPL) through a small number of mutations  
48 in the single capsid protein; a species jump which may have involved intermediate  
49 passage in other carnivores such as mink or raccoons (Truyen et al., 1996). As early  
50 as 1979 the first variants of CPV 2 appeared, termed CPV2a, and they were quickly  
51 followed by the appearance of CPV2b in 1984.(Parrish et al 1985, 1991). The original  
52 type 2 virus has now virtually disappeared from the field having been replaced by the  
53 2a and 2b variants; although the relative proportions of these two types varies from  
54 country to country (Truyen et al., 1996; Chinchkar et al., 2006; Pereira et al., 2006).

55

56 The amino acid changes in the capsid protein (VP2) which characterise the shift from  
57 2 to 2a and to 2b are very limited. Substitutions at positions 87 (Met to Leu), 300 (Gly  
58 to Ala), 305 (Tyr to Asp) and 555 (Val to Ile) occurred in the evolution of 2 to 2a and  
59 426 (Asn to Asp) and 555 (Ile to Val) in the emergence of 2b from 2a (Parrish et al.,  
60 1991; Truyen et al., 1995). However as recent 2a strains lacking the Val to Ile  
61 substitution at position 555 have been reported (Wang et al., 2005; Martella et al.,  
62 2006), then a single amino acid change can differentiate the CPV2a and CPV2b VP2  
63 sequences. More recently strains have emerged in Italy in which the amino acid at  
64 position 426 (Asn in 2a and Asp in 2b) has become a glutamic acid (Glu) residue  
65 (Buonavoglia et al., 2001; Martella et al., 2004). The fact that these Glu 426 variants,

66 termed CPV2c viruses, are circulating and co-existing with other CPV types in Italy  
67 and other European countries (Decaro et al., 2006b; C. Buonavoglia personal  
68 communication) and have also been isolated in countries as geographically diverse as  
69 Vietnam and Scotland (Nakamura et al., 2004; C. Buonavoglia personal  
70 communication) suggests that they have an advantage in at least a proportion of the  
71 dog population. The relatively rapid evolution of canine parvovirus has resulted in the  
72 loss and then re-gaining of the feline host range (Truyen et al., 1996), and this  
73 regained ability to replicate in cats may well account for the replacement of the  
74 original type 2 virus with the 2a, 2b and 2c variants.

75

76 In the late 1970's and early 1980's both live and inactivated FPL vaccines were used  
77 to protect dogs against CPV disease due to the shared antigens which stimulated  
78 cross protection, however the levels of protection they afforded was poor and duration  
79 of immunity was short. These vaccines were replaced by live attenuated CPV  
80 vaccines which provided excellent protection and longer duration of immunity.

81 Currently the live attenuated vaccines are derived from either CPV2b isolates or the  
82 original type 2 virus. Since the type 2 virus has been entirely replaced in the field by  
83 2a, 2b and now 2c viruses there has been concern over the level of protection afforded  
84 by attenuated type 2 vaccines (Pratelli et al., 2001). However, based on studies with  
85 available monoclonal antibodies each new antigenic variant has lost at least one  
86 neutralising epitope compared with the former variant (Strassheim et al., 1994, Pereira  
87 et al., 2006). Previously it has been demonstrated that the live attenuated CPV 2  
88 vaccine is able to protect dogs against 2a and 2b field challenges (Greenwood et al.,  
89 1995) even though cross neutralisation studies conducted *in vitro* using sera raised  
90 against the various antigenic types do show marked differences (Pratelli et al., 2001).

91 The aim of this study was to investigate the ability of a live attenuated type 2 vaccine  
92 (Nobivac- Intervet) to protect dogs from challenge with one of the most recent CPV  
93 variants, CPV2c.

94

95

96

## 97 **Materials and Methods**

### 98 **Viruses & cell culture**

99

100 Nobivac DHPPi vaccine (Intervet) containing canine parvovirus (CPV2 – strain 154),  
101 canine adenovirus (type 2), distemper virus, and parainfluenza virus, Nobivac Lepto  
102 (inactivated leptospirosis vaccine - Intervet), and Nobivac Pi (live parainfluenza virus  
103 only) were used.

104 A CPV2c pathogenic strain (kindly provided by C. Buonavoglia, Department of  
105 Animal Health and Well-being, Faculty of Veterinary Medicine of Bari, Italy) was  
106 used as challenge virus.

107 CPV2c and CPV2-154 were propagated and titrated in Crandell Rees feline kidney  
108 cells (CrFK); isolation of virus from rectal swabs was also performed in CrFK cells  
109 which were cultured essentially as described by Mochizuki et al (1993) using M6B8  
110 medium (Intervet) supplemented with 5% foetal bovine serum containing penicillin  
111 and streptomycin.

112

### 113 **Serology & immunofluorescence**

114 Serum samples were assayed for antibodies to canine parvovirus using both  
115 haemagglutination inhibition (Churchill 1982) and serum neutralisation assays . The

116 CPV2 and CPV2c viruses were used in the HAI test at a constant 4 HA units. In the  
117 serum neutralisation assays viruses were used at a titre of  $10^{1.76}$  /well.  
118 Immunofluorescence was carried out as described previously (Vihinen-Ranta, 1998).  
119 Briefly, monolayers of CrFK cells were fixed ~72 hours post infection with methanol.  
120 The anti CPV monoclonal antibody A2F8 (Parrish et al., 1982) was used, followed by  
121 rabbit anti mouse FITC conjugate (SIGMA)

122

### 123 **Efficacy Study**

124 Twelve beagle dogs were obtained from unvaccinated unexposed bitches and  
125 therefore devoid of maternally derived antibodies against canine parvovirus. All the  
126 dogs were declared fit and healthy by veterinary inspection and shown to be sero  
127 negative with respect to CPV at the start of the experiment. The animals were divided  
128 into two groups, vaccinates and controls, with six animals in each group; each group  
129 was housed separately. The vaccinated group was given the minimum recommended  
130 course of vaccination which consisted of vaccination at 8 weeks of age with Nobivac  
131 Pi and Nobivac Lepto followed by a second vaccination at 10 weeks of age with  
132 Nobivac DHPPi and Lepto. The vaccinate group therefore only received a single  
133 vaccination with parvovirus vaccine. The control dogs received no vaccinations. Four  
134 weeks following vaccination both groups were challenged with the CPV2c  
135 parvovirus. Animals were deprived of food for 24 hours prior to, and for 12 hours  
136 following challenge; although water was available throughout. The challenge virus  
137 ( $10^{5.0}$  TCID<sub>50</sub>) was administered orally in a volume of 1.0ml. The dogs were bled pre-  
138 vaccination, pre-challenge and on selected days post challenge for measurement of  
139 serological responses and leucocyte/lymphocyte estimation. Animals were also  
140 swabbed at regular intervals for virus isolation and observed closely for clinical signs



141 of disease including malaise, reduced appetite, poor general condition and blood in  
142 faeces from 2 days before until 14 days after challenge.

143

#### 144 **Statistical analyses.**

145 A one way analysis of variance test was carried out using the Mini Tab™ statistics  
146 software package.

147

## 148 **RESULTS**

### 149 **Clinical Observation**

150 The clinical observations are set out in **TABLE 1**. The control animals started to show  
151 clinical signs from 4 days post challenge and by day 6 post challenge three of the  
152 control dogs showed severe clinical signs and were euthanased on welfare grounds.

153 The remaining control animals exhibited less severe signs although oral electrolytes  
154 were needed to aid recovery. Nevertheless reduced appetite resulted in a marked  
155 check in their growth rate (results not shown). All the control animals exhibited a  
156 severe mucoid diarrhoea which was also haemorrhagic in the three dogs which  
157 required euthanasia, whereas the vaccinated group did not display any clinical signs of  
158 disease at any stage during the experiment. Rectal swabs taken post challenge were  
159 assayed for virus content by culture on CrFK cells (**TABLE 2**). Virus could be  
160 detected in swabs taken from all the control animals from day 3 to day 7 post  
161 challenge, whereas no evidence of viral excretion could be detected in any of the  
162 vaccinated dogs.

163 The mean white blood cell counts (mwcc) are shown in **TABLE 3**. Values were  
164 similar in both the vaccinates and control dogs prior to challenge, and in the  
165 vaccinated group the mwcc did not show a significant change after challenge ( $p=$

166 0.12). In the control group however there was a significant drop ( $p= 0.003$ ) in the  
167 mwcc post challenge to almost half the pre-challenge value.

168

### 169 **Serological responses**

170 In keeping with their SPF status and their derivation from unvaccinated mothers none  
171 of the animals had any detectable antibodies to canine parvovirus prior to vaccination  
172 (data not shown). At the time of challenge after the single parvovirus vaccination all  
173 the vaccinated dogs had developed HAI antibody titres ranging from 1600 to 6400  
174 (TABLE 4). There was no observable difference in HAI titre when the assay was  
175 conducted with 2c or vaccine parvovirus antigens. The serological responses were  
176 also measured in virus neutralisation assays against the challenge and vaccine viruses  
177 (TABLE 4) and in these assays the vaccinates demonstrated a markedly higher  
178 response to the type 2 strain compared to the 2c strain.

179 Following challenge the vaccinated animals did not show an anamnestic response to  
180 CPV, in HAI or VN assays when either the CPV 2c antigen or the vaccine antigen  
181 was used. The control animals remained seronegative up until the time of challenge,  
182 however after challenge the control animals did mount an antibody response which  
183 was noticeably higher in the recovered animals compared with the animals which  
184 were subsequently euthanased.

185

186

### 187 **Discussion**

188

189 Canine parvovirus continues to be an important pathogen of dogs and is responsible  
190 for serious occurrences of morbidity and mortality, despite the availability of safe and

191 effective vaccines (Decaro et al., 2006a, 2006b). Since the replacement of the original  
192 type 2 virus by the 2a , 2b variant and more recently the type 2c viruses (Parrish et al  
193 1991, Martella et al 2004) there have been concerns expressed over the efficacy of  
194 canine parvovirus vaccines which are based on the original type 2 strain (Martella et  
195 al., 2005; Truyen, 2006).

196 Although it has previously been demonstrated that a type 2 vaccine is able to provide  
197 protection against 2a and 2b field isolates (Greenwood et al 1995), the emergence of  
198 the 2c variant naturally raises the question of whether the type 2 vaccines can provide  
199 protection against this new variant also. We clearly demonstrate here that dogs  
200 vaccinated with a single dose of one particular type 2 parvovirus vaccine are protected  
201 from challenge with one of the type 2c field isolates; furthermore this isolate was able  
202 to cause a severe enteritis in unvaccinated dogs. Analysis of the rectal swabs (**TABLE**  
203 **2**) reveals that the vaccinated dogs were not only protected from clinical disease but  
204 also that vaccination prevented shedding of challenge virus. This finding is in line  
205 with the ability of this type 2 vaccine to prevent shedding of type 2a and type 2b virus  
206 following challenge (Greenwood et al., 1995). In addition the duration of virus  
207 shedding in the control animals was similar to that observed with other CPV strains  
208 (Greenwood et al., unpublished observations). Leucopenia is often a consequence of  
209 CPV infection (Chalmers et al., 1999) and is therefore another criterion by which  
210 infection and protection can be determined. The white cell counts (**TABLE 3**)  
211 demonstrate that the type 2c virus causes a leucopenia in the unvaccinated control  
212 animals, whereas the vaccinated group remained normal. Interestingly a differential  
213 white cell count did not show a specific drop in the lymphocytes normally associated  
214 with CPV infection .

215

216 There was no anamnestic response following challenge in the vaccinated dogs  
217 indicating that they had sterilising immunity to CPV. Moreover the HAI responses in  
218 the vaccinated group did not show a marked difference in titre whether the test was  
219 performed with the 2c antigen or the type 2 vaccine antigen. However the responses  
220 of the 3 control dogs which survived the challenge did show a difference in HAI when  
221 measured against the 2c antigen compared with the vaccine antigen. All the control  
222 animals were able to mount an immune response and it may be that differences in the  
223 serological responses observed in the control group may have been due in part to the  
224 different sampling intervals, in that the recovered dogs were sampled 7 days post  
225 challenge whereas the other control dogs were sampled at the point of euthanasia on  
226 day 6 post challenge.

227

228 These data indicate that whilst there may be antigenic differences between the type 2c  
229 virus and the precursor type 2 virus used in the vaccine these differences do not have  
230 a material significance in terms of protection from disease, i.e there is effective cross  
231 reactivity of the type 2 vaccine against the 2c virus.

232

233 Whilst the haemagglutination inhibition assay has been routinely used to assess  
234 protective serological responses in CPV studies, it may be argued that serum  
235 neutralisation would give a more accurate view of the protection afforded by a  
236 vaccine against any variant field strains. Not surprisingly in all the vaccinated dogs  
237 the neutralisation titres are higher when measured against the vaccine strain compared  
238 with the 2c challenge virus. However after challenge the neutralisation titres against  
239 2c or the vaccine did not increase indicating that as shown with the HAI responses the  
240 animals had sterilising immunity. Therefore it is interesting to note that antibody titres

241 in these dogs were as high as in the recovered control dogs. These and other data  
242 support the view that despite the minor differences between the original type 2 virus  
243 and the 2a, 2b and now 2c variants, dogs vaccinated with this type 2 vaccine will  
244 mount a robust immune response to CPV and are fully protected against challenge  
245 from any of the current CPV types.

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TABLE 1 Clinical observations of dogs challenged with CPV Glu-426

Animal Number	Group	Clinical Observation (days post challenge)														
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
5256	Vaccinate	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
5260		N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
9815		N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
9819		N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
9823		N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
9829		N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
5254		N	N	N	N	M, RA, BF	M, RA, BF	E	-----	-----	-----	-----	-----	-----	-----	-----
5258		N	N	N	N	M, RA, BF	M, RA, BF	E	-----	-----	-----	-----	-----	-----	-----	-----
9813	Control	N	N	N	N	M, RA, BF	M, RA, BF	M, RA, BF	PC, RA	RA	N	N	N	N	N	N
9817		N	N	N	N	M, RA, BF	M, RA, BF	E	-----	-----	-----	-----	-----	-----	-----	-----
9821		N	N	N	N	M, RA, BF	M, RA, BF	M, RA, BF	PC, RA	PC, RA	RA	N	N	N	N	N
9827		N	N	N	N	M, RA, BF	M, RA, BF	M, RA, BF	PC, RA	PC, RA	N	N	N	N	N	N

N= Normal, M= Malaise, RA= Reduced appetite, BF= Blood in faeces, PC= Poor condition

TABLE 2 Post challenge viral excretion

Group/ Animal Number	CPV titre (Days post challenge)						
	0	3	4	5	6	7	
Control	5254	0	3.30	6.70	6.30	5.45 (euthanased)	-
	5258	0	4.45	6.20	7.45	7.10 (euthanased)	-
	9813	0	3.45	5.54	7.20	6.20	5.01
	9817	0	4.30	7.10	6.45	3.30 (euthanased)	-
	9821	0	3.95	5.70	5.85	5.85	6.30
Vaccinate	9827	0	<1.45	4.20	7.95	6.30	6.70
	5256	0	0	0	0	0	0
	5260	0	0	0	0	0	0
	9815	0	0	0	0	0	0
	9819	0	0	0	0	0	0
	9823	0	0	0	0	0	0
	9829	0	0	0	0	0	0

Titres are given in TCID<sub>50</sub>/ml

TABLE 3 White Blood Cell Counts

Dog ID/Group	Days Prior to Challenge								Days post challenge														
	5		3		0		mean		1	2		3		4		5		7		9			
	twc	ly	twc	ly	twc	ly	twc	ly	twc	ly	tec	ly	twc	ly	twc	ly	twc	ly	twc	ly	twc	ly	
<b>Control</b>																							
5254	15.30	7.04	15.60	8.27	11.70	4.91	<b>14.20</b>	6.74	13.60	5.98	13.10	4.19	18.00	2.52	8.93	2.59	8.25	1.73	Euthanased				
9813							<b>14.53</b>	6.99	15.00	6.15	13.90	4.73	14.60	2.48	10.20	4.69	12.70	2.67	9.87	4.84	8.77	6.67	
9817	14.90	8.2	16.90	8.28	11.80	4.48	<b>13.77</b>	7.54	12.40	5.83	11.30	3.96	10.20	1.94	8.84	1.86	1.56	0.66	Euthanased				
9821	13.00	7.15	16.30	9.94	12.00	5.52	<b>11.21</b>	5.11	10.30	5.05	16.00	6.24	11.70	1.17	8.68	2.86	8.03	1.98	3.18	3.02	6.33	2.66	
5258	12.20	5.73	12.30	5.66	9.14	3.93	<b>13.27</b>	5.93	15.90	7.47	13.60	6.26	17.10	2.22	7.55	1.06	7.79	3.82	Euthanased				
9827	12.50	5.75	14.30	6.44	13.00	5.59	<b>13.80</b>	6.88	16.30	6.68	14.10	6.63	13.60	5.71	13.10	2.1	7.55	1.06	9.87	2.86	8.63	6.3	
<b>mean</b>	<b>13.85</b>	<b>6.81</b>	<b>15.08</b>	<b>7.77</b>	<b>11.46</b>	<b>5.0</b>	<b>13.46</b>	<b>6.53</b>	<b>13.92</b>	<b>6.19</b>	<b>13.67</b>	<b>5.34</b>	<b>14.20</b>	<b>2.67</b>	<b>9.55</b>	<b>2.53</b>	<b>7.65</b>	<b>1.99</b>	<b>7.64</b>	<b>3.57</b>	<b>7.91</b>	<b>5.18</b>	
<b>Vaccinate</b>																							
9815	11.10	5	12.00	6.24	8.85	3.19	<b>10.65</b>	4.81	13.30	6.25	12.90	5.29	13.80	7.59	13.90	5.14	13.70	4.8	9.86	4.63	9.56	4.4	
9819	18.00	7.74	14.10	4.79	9.59	2.78	<b>13.90</b>	5.10	15.90	4.61	13.20	6.2	12.50	5.63	12.00	4.8	11.70	4.68	11.10	5.11	11.00	4.84	
9823	15.30	6.89	14.60	7.74	10.70	3.32	<b>13.53</b>	5.98	13.80	5.66	12.30	4.55	15.20	6.84	13.40	7.91	15.10	5.74	13.90	6.81	12.90	7.35	
5256	14.10	4.65	13.00	4.94	10.60	3.82	<b>12.57</b>	4.47	16.40	6.56	13.90	4.87	13.80	5.11	12.20	5.37	14.60	4.23	12.00	5.64	11.70	4.1	
5260	17.50	5.95	14.40	3.02	10.20	3.88	<b>14.03</b>	4.28	11.90	4.17	11.60	4.99	12.40	5.33	8.92	3.75	12.10	4.24	11.90	3.81	10.90	4.58	
9829	15.00	5.4	14.40	4.9	10.40	2.5	<b>13.27</b>	4.27	13.90	3.38	12.80	5.12	10.80	3.89	13.80	6.35	13.70	3.7	11.10	2.44	13.20	4.22	
<b>mean</b>	<b>15.17</b>	<b>5.94</b>	<b>13.75</b>	<b>5.27</b>	<b>10.06</b>	<b>3.25</b>	<b>12.99</b>	<b>4.82</b>	<b>14.20</b>	<b>5.11</b>	<b>12.78</b>	<b>5.17</b>	<b>13.08</b>	<b>5.73</b>	<b>12.37</b>	<b>5.55</b>	<b>13.48</b>	<b>4.57</b>	<b>11.64</b>	<b>4.74</b>	<b>11.54</b>	<b>4.92</b>	

twc= total white cell count; ly= lymphocyte count  
 Counts are given in  $10^9$  cells/litre



TABLE 4 Serum neutralisation and HAI responses

Group	Animal ID	Post Vaccination				Post challenge*			
		HAI		VN		HAI		VN	
		2c	Vaccine	2c	Vaccine	2c	Vaccine	2c	Vaccine
Control	5254	<10	<10	<3	<3	†1280	†320	†2896	†2656
	9813	<10	<10	<3	<3	10240	2560	38968	16384
	9817	<10	<10	<3	<3	†5120	†640	†2896	†2656
	9821	<10	<10	<3	<3	10240	2560	13141	11585
	5258	<10	<10	<3	<3	†5120	†640	†2299	†4598
	9827	<10	<10	<3	<3	10240	2560	55109	46341
Vaccine	9815	1600	3200	18390	>370328	2560	2560	7298	105130
	9819	1600	6400	36781	>370328	2560	2560	23170	339959
	9823	3200	1600	12634	339959	2560	2560	14218	~210261
	5256	1600	3200	10624	147123	2560	2560	9195	65536
	5260	3200	1600	32768	339959	2560	2560	46341	~262144
	9829	1600	3200	18390	202141	2560	2560	36781	65536
+ve control		800	1600	2896	13141	1280	2560	2896	13141

\* Samples taken 7 days post challenge

† Samples taken at time of euthanasia

## REFERENCES

- Appel, M.J.G., Scott, W.F., Carmichael, L.E., 1979. Isolation and immunization studies of canine parvo-like virus from dogs with haemorrhagic enteritis. *Vet. Rec.* **105**, 156-159.
- Buonavoglia, C., Martella, V., Pratelli, A., Tempesta, M., Cavalli, A., Buonavoglia, D., Bozzo, G., Elia, G., Decaro, N., Carmichael, L.E., 2001. Evidence for evolution of canine parvovirus type-2 in Italy. *J. Gen. Virol.* **82**, 3021-3025.
- Chalmers, W.S.K., Truyen, U., Greenwood, N.M., Baxendale, W., 1999. Efficacy of feline panleukopenia vaccine to prevent infection with an isolate of CPV2b obtained from a cat. *Vet. Microbiol.* **69**, 41-45.
- Chinchkar, S.R., Mohana Subramanian, B., Hanumantha Rao, N., Rangarajan, P.N., Thiagarajan, D., Srinivasan, V.A., 2006. Analysis of VP2 gene sequences of canine parvovirus isolates in India. *Arch. Virol.* **151**, 1881-1887.
- Churchill, A.E., 1982. A potency test for inactivated small animal parvovirus vaccines using chicks. *J. Biol. Stand.* **10**, 1-8.
- Decaro, N., Desario, C., Elia, G., Campolo, M., Lorusso, E., Mari, V., Martella, V., Buonavoglia, C., 2006a. Occurrence of severe gastroenteritis in pups after canine parvovirus vaccine administration : A clinical and laboratory diagnostic dilemma. *Vaccine* **25**, 1161-1166.

- Decaro, N., Martella, V., Desario, C., Bellaciccio, A.L., Camero, M., Manna, L., d'Aloja, D., Buonavoglia, C., 2006b. First detection of canine parvovirus type 2c in pups with haemorrhagic enteritis in Spain. *J. Vet. Med. B. Infect. Dis. Vet. Public Health.* **53**, 468-472.
- Greenwood, N.M., Chalmers, W.S.K., Baxendale, W., Thompson, H., 1995. Comparison of isolates of canine parvovirus by restriction enzyme analysis and vaccine efficacy against field strains. *Vet. Record.* **136**, 63-67.
- Kelly, W.R., 1978. An enteric disease of dogs resembling feline panleukopenia. *Aust. Vet. J.* **54**, 593.
- Martella, V., Cavalli, A., Pratelli, A., Bozzo, G., Camaro, M., Buonavoglia, D., Narcisi, D., Tempesta, M., Buonavoglia, C., 2004. A canine parvovirus mutant is spreading in Italy. *J. Clin. Microbiol.* **42**, 1333-1336.
- Martella, V., Cavalli, A., Decaro, N., Elia, G., Desario, C., Campolo, M., Bozzo, G., Tarsitano, E., Buonavoglia, C., 2005. Immunogenicity of an intranasally administered modified live canine parvovirus type 2b vaccine in pups with maternally derived antibodies. *Clin. Diagn. Lab. Immunol.* **12**, 1243-1245.
- Martella, V., Decaro, N., Buonavoglia, C., 2006. Genetic and antigenic variation of CPV-2 and impicance in antigenic/genetic characterization. *Virus Genes* **33**, 11-13.

Mochizuki, M., Harasawa, R., Nakatani, H., 1993. Antigenic and genomic variabilities among recently prevalent parvoviruses of canine and feline origin in Japan. *Vet. Microbiol.* **38**, 1-10.

Nakamura, M., Tohya, Y., Miyazawa, T., Mochizuki, M., Phung, H.T.T., Nguyen, N.H., Huynh, L.M., Nguyen, L.T., Nguyen, P.N., Nguyen, P.V., Nguyen, N.P., Akashi, H., 2004. A novel antigenic variant of canine parvovirus from a Vietnamese dog. *Arch. Virol.* **149**, 2261-2269.

Parrish, C.R., Carmichael, L.E., Antczack, D.F., 1982. Antigenic relationships between canine parvovirus type 2, feline panleukopenia virus and mink enteritis virus using conventional antisera and monoclonal antibodies. *Arch. Virol.* **72**, 267-278.

Parrish, C.R., O'Connell, P.H., Evermann, J.F., Carmichael, L.E., 1985. Natural variation of canine parvovirus. *Science* **230**, 1046-1048.

Parish, C.R., Aquadro, C.F., Strassheim, M.L., Evermann, J.F., Sgro, J.Y., Mohammed, H.O., 1991. Rapid antigenic-type replacement and DNA sequence evolution of canine parvovirus. *J. Virol.* **65**, 6544-6552.

Pereira, C.A.D., Leal, E.S., Durigon, E.L., 2006. Selective regimen shift and demographic growth increase associated with the emergence of high fitness variants of canine parvovirus. *Infect. Genet. Evol.* *Article in press.*

Pratelli, A., Cavalli, A., Martella, V., Tempesta, M., Decaro, N., Carmichael, L.E., Buonavoglia, C., 2001. Canine parvovirus vaccination: Comparison of neutralising antibody responses in pups after inoculation with CPV2 or CPV2b modified live virus vaccines. *Clin. Diag. Lab. Immunol.* **8**, 612-615.

Strasheim, M.L., Gruenberg, A., Veijalainen, P., Sgro, J-Y., Parrish, C.R., 1994. Two dominant neutralising antigen determinants of canine parvovirus are found on the threshold of the three fold spike of the virus capsid. *Virology*, **198**, 175-184.

Truyen, U., Gruenberg, A., Chang, S.F., Obermaier, B., Veijalainen, P., Parrish, C.R., 1995. Evolution of the feline subgroup parvoviruses and the control of canine host range in vivo. *J. Virol.* **69**, 4702-4710.

Truyen, U., Evermann, J.F., Vieler, E., Parrish, C.R., 1996. Evolution of canine parvovirus involved loss and gain of feline host range. *Virology* **215**, 186-189.

Truyen, U., 1999. Emergence and recent evolution of canine parvovirus. *Vet. Microbiol.* **69**, 47-50.

Truyen, U., 2006. Evolution of canine parvovirus- a need for new vaccines. *Vet. Microbiol.* **117**, 9-13.

Vihinen-Ranta, M., Kalela, A., Makinen, P., Kakkola, L., Marjomaki, V., Vuento, V., 1998. Intracellular route of canine parvovirus entry. **72**, 802-806.

Wang, H.C., Chen, W.D., Lin, S.L., Chan, J.P.W., Wong, M.L., 2005. Phylogenetic analysis of canine parvovirus VP2 gene in Taiwan. *Virus Genes*. **31**, 171-174.

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