The central role of chloride in the metabolic acid-base changes in canine parvoviral enteritis

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Abstract

The acid-base disturbances in canine parvoviral (CPV) enteritis are not well described. In addition, the mechanisms causing these perturbations have not been fully elucidated. The purpose of the present study was to assess acid-base changes in puppies suffering from CPV enteritis, using a modified strong ion model (SIM). The hypothesis of the study was that severe acid-base disturbances would be present and that the SIM would provide insights into pathological mechanisms, which have not been fully appreciated by the Henderson-Hasselbalch model.

The study analysed retrospective data, obtained from 42 puppies with confirmed CPV enteritis and 10 healthy control dogs. The CPV-enteritis group had been allocated a clinical score, to allow classification of the data according to clinical severity. The effects of changes in free water, chloride, L-lactate, albumin and phosphate were calculated, using a modification of the base excess algorithm. When the data were summated for each patient, and correlated to each individual component, the most important contributor to the metabolic acid-base changes, according to the SIM, was chloride ($P < 0.001$). Severely-affected animals

tended to demonstrate hypochloraemic alkalosis, whereas mildly-affected puppies had a hyperchloraemic acidosis (P = 0.007). In conclusion, the acid-base disturbances in CPV enteritis are multifactorial and complex, with the SIM providing information in terms of the origin of these changes.

Keywords: Canine parvovirus; Strong ion model; Henderson-Hasselbalch method

Introduction

Assessment of acid-base status is frequently used in veterinary critical care cases, because it can be used to detect early physiological derangements, alerting clinicians to the possibility of decompensation, as well as providing treatment directives (Hopper, 2012). Traditionally, the Henderson-Hasselbalch (HH) technique has been used, when assessing plasma acid-base disturbances, which involves measuring two variables, namely carbon dioxide tension (pCO_2) and bicarbonate (HCO_3^-) concentration (Constable, 2000). A change in either of these will invoke a compensatory response in the other, to maintain a constant plasma pH (Constable, 2000). The reciprocity of this relationship may obfuscate interpretation of a mixed or non-compensated disorder, where it is unclear to what extent pCO_2 and HCO_3^- have changed due to the primary disorder, or due to compensatory mechanisms (Constable, 2000; Sirker et al., 2002). Calculations based on the standard base excess (titratable acidity or alkalinity) and the anion gap have been used in conjunction with the HH model, in an attempt to abrogate this problem (Siggard-Andersen et al., 1960; Siggard-Andersen and Fogh-Andersen, 1995).

The strong ion model (SIM), also known as Stewart's strong ion model, is an alternative method, used in assessment of acid-base disturbances (Fencl and Leith, 1993;

Gilfix et al., 1993; Whitehair et al., 1995; Constable, 2002; Wooten, 2004; Greenbaum and Nirmalan, 2005; Story and Kellum, 2005; de Morais and Constable, 2006; Morgan, 2009). The fundamental premise of the SIM is that the strong ion difference (SID) of plasma (difference between the sum of all strong cations and strong anions) is the most important determinant of the hydrogen ion activity in a system. In addition to pCO_2 and SID the SIM considers a third variable, namely the sum of weak non-volatile organic acids, such as albumin and phosphate (denoted A_{tot}) (Fencl and Leith, 1993; Kellum, 2007). The SIM therefore provides rational explanations for acid-base disturbances that are not well understood in terms of the HH model, such as the effects of free water and plasma proteins (Kellum, 2008).

Notwithstanding the apparent advantage of the SIM, its application in medicine has met with opposition from some quarters, as it violates the traditional dogma of the Arrhenius principle of acid-base chemistry (Kurtz et al., 2008). In spite of such criticism, the SIM has gained momentum in critical care medicine, mainly because it provides more information in terms of disturbances within the metabolic compartment (Constable, 2000; Sirker et al., 2002; Kellum, 2007).

Canine parvoviral (CPV) enteritis is characterised by severe vomiting and diarrhoea, often associated with a high mortality rate (Prittie, 2004; Goddard and Leisewitz, 2010; Schoeman et al., 2013). Medical therapy is implemented according to the severity of disease and includes fluid therapy, nutritional management and use of anti-emetic and/or antimicrobial drugs (Prittie, 2004). There is, however, a paucity of literature available on the acid-base disturbances in CPV enteritis on which to practise evidence-based medicine.

In one study, arterial blood gas and venous blood electrolyte data were collected for 17 puppies affected with CPV enteritis (Heald et al., 1986). Blood pH was within normal limits in 59% of cases and, of the remaining dogs, six were alkalaemic and one was acidaemic. In contrast, in the study by Rai and Nauriyal (1992) a significant acidaemia was demonstrated in 21 cases of CPV enteritis. Furthermore, a decrease in actual and standard HCO_3^- and base excess was observed. In a later study, plasma pH was consistently increased in dogs affected with CPV enteritis, compared to the controls, but HCO_3^- was consistently decreased and the pH increase was deemed to be due to compensation, in the presence of decreased HCO_3^- concentration (Nappert et al., 2002).

Of particular interest in the study by Nappert et al. (2002) is the fact that specific criteria were present that would allow a classification of metabolic acidosis (decreased HCO_3^- and increased L-lactate production), but the blood pH was in fact higher than normal (i.e. alkalaemia). Within this deviation of HCO_3^-, we predict that the SIM might unmask mixed acid-base disturbances, which would be obscured according to the HH model. Thus, the purpose of the present study was to utilize the SIM to dissect metabolic homeostasis in dogs affected with CPV enteritis, to provide further insights into the pathogenesis of the acid-base disturbances present.

Materials and methods

Sample population

Clinical and laboratory data, collected from 42 unvaccinated puppies affected with CPV enteritis and 10 age-matched control dogs were analysed using a modified strong ion approach, based on the base excess algorithm (Fencl and Leith, 1993; Hopper and Haskins, 2008). CPV had been confirmed in the clinical cases by electron microscopy, and

confounding infection with rotavirus, coronavirus, *Ancylostoma* spp. and *Giardia* spp. had been excluded.

Affected dogs were recruited as part of a project to assess the utility of biomarkers in assessment of severity and survival in CPV enteritis (Schoeman et al., 2007; 2013; Schoeman and Herrtage, 2008). All data were collected on the day of admission, before any therapy had been initiated. Diagnostic testing was undertaken by the Department of Clinical Pathology, Faculty of Veterinary Science, University of Pretoria reference laboratory. The control population consisted of healthy vaccinated dogs under 6 months of age, which were presented for routine clinical examination. The study was approved by the Animal Care and Ethics committee (VO76/05, 20/12/2005).

A clinical score was assigned to each CPV-affected dog on admission, which stratified the population according to the severity of clinical signs (mild, moderate or severe). The clinical score was based on appetite, habitus, vomiting, diarrhoea and mucous membrane colour (see Appendix A: Supplementary Table 1). This clinical scoring system was designed for a PhD thesis (Schoeman, 2008) and, although not formally validated, has been used extensively in the Onderstepoort Veterinary Academic Hospital. All clinical scoring was performed by a single observer (JPS). Patients with scores <9 were classified as severely affected, scores between 9 to 16 were considered moderately affected and scores >16 were classified as mildly affected.

Data analysis

Comprehensive records were obtained for each animal, containing a complete serum biochemistry profile, with the exception of chloride and serum inorganic phosphate. Serum

stored at –70 ºC was analysed for these latter electrolytes, using a Cobas Integra 400 Plus (Roche) analyser. Since no blood gas measurements had been taken, it was not possible to assess pH, base excess or bicarbonate. The calculation of the contribution of each of the components to the base excess (according to the SIM) is shown in Appendix A: Supplementary Table 2. The data for each category were compared to the control group using a commercial statistics package (Medcalc, version 12.7.2). D'Agostino-Pearson test for normality was performed for all data sets. The Mann-Whitney *U* test was used to compare medians, and Spearman's rank correlation was used to assess the relationship between different variables.

To assess the relative contribution of each component to the overall metabolic acid-base changes, each of the components was summated and the sum obtained was compared to each individual component by means of a Spearman's rank correlation. Each of the variables used in the quantification of the metabolic acid-base compartment were compared, according to clinical disease severity. Using the principle of the base excess algorithm, the free water, chloride and L-lactate effect were summated and, if a negative value was obtained (within a -2.0 to 2.0 mEq/L tolerance range), a strong ion acidosis was diagnosed; whereas a strong ion alkalosis was diagnosed if the value was positive.

The albumin and phosphate effect were summated to yield the A_{tot} and the values were interpreted as for the strong ion compartment. This calculation was performed for each CPV-affected dog and a diagnosis for the metabolic compartment was assigned as follows: strong ion acidosis, A_{tot} acidosis (designated A); strong ion acidosis, A_{tot} alkalosis (designated B); strong ion alkalosis, A_{tot} acidosis (designated C) and strong ion alkalosis, A_{tot} alkalosis (designated D). The sum of all the effects was taken to represent the base excess, and

significantly negative values interpreted as a metabolic acidosis and positive values as a metabolic alkalosis. When the value of the sum was within the tolerance range, but significant changes were present in the constituents, a mixed neutralising disorder was diagnosed. A final classification for the metabolic compartment could then be assigned as follows: metabolic acidosis/alkalosis (or neutralising), characterised by strong ion acidosis/alkalosis, and A_{tot} acidosis/alkalosis. The metabolic acid-base status of the dogs was displayed visually, using Venn diagrams as previously described by Viu et al. (2010).

The base excess algorithm suggested by Hopper and Haskins (2008), based on the original work of Fencl and Leith (1993), has not been validated in dogs, and is based on the assumption that albumin is the most important contributor to A_{tot}. A simplified technique (referred to subsequently as the simplified model, SM), using experimentally-determined values, validated for dogs was used (Constable and Stampfli, 2005) and compared to the traditional base excess algorithm. Briefly, the SID_4[1] was calculated from four major strong ions (Na + K – Cl + L-lactate) for both the CPV-affected and control groups. The A_{tot} was estimated from albumin, based on the determination of a net protein charge of 0.42 mEq/g of albumin in dogs, yielding a value of 15.8 mEq/L for normal dogs (Constable and Stampfli, 2005). The net protein charge was also determined using total protein (0.25 mEq/g of total protein). This was determined for both groups and compared to the experimentally-determined normal value of 15.8 mEq/L (Constable and Stampfli, 2005). SID_4 and the A_{tot} derived from albumin and total protein (TP) in the CPV-affected and control groups were compared using the Student's *t* test.

[1] SID_4 denotes the SID as estimated from the difference between four major strong ions.

Finally, using the simplified model, a metabolic acid-base classification was assigned to each case, by comparing the CPV-affected group values for SID_4 and A_{tot} (calculated from albumin and TP) to the experimentally-validated values for these variables (values taken from Constable and Stampfli, 2005). In addition, the SID_4 and A_{tot} obtained from the SM were compared to those obtained for the control dog samples. This enabled assessment of the validity of comparing samples from CPV-affected dogs to experimentally-determined values. Diagnoses were then assigned to the categories A-D as described previously and the outcomes of this simplified method and the base excess algorithm compared using an inter-rater agreement plot.

Results

According to the SIM, 20/42 patients in the CPV-affected group were considered to have a metabolic acidosis, 10/42 had a metabolic alkalosis and in 12/42 patients the overall effect was neutralizing. Of the 20 patients affected with metabolic acidosis, all had a SID acidosis and within this group, 19 had a concurrent A_{tot} alkalosis and one had a mild A_{tot} acidosis, due to mild hyperphosphataemia (Fig. 1a). Of the individuals with metabolic alkalosis, 9/10 had a SID alkalosis and 1/10 had a SID acidosis. All 10 patients had a concurrent A_{tot} alkalosis (Fig. 1b). Within the neutralizing group, 8/12 had a SID acidosis, with all eight of these having an A_{tot} alkalosis. The remaining four dogs had a SID alkalosis and, within this group, two had an A_{tot} alkalosis, with the remaining two having an A_{tot} acidosis (Fig. 1c).

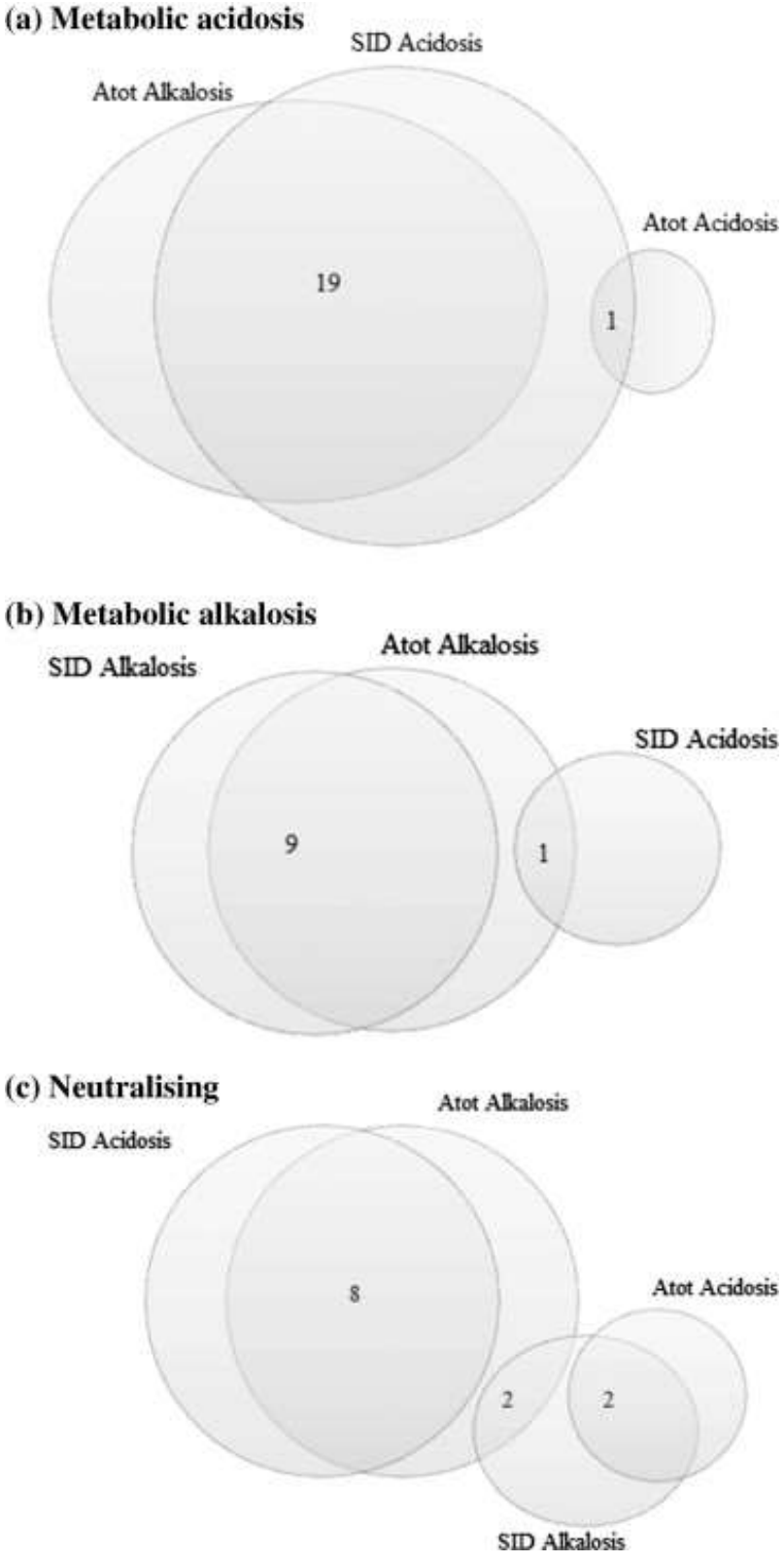

Fig. 1. Venn diagrams characterising the CPV-affected dogs with (a) metabolic acidosis, (b) metabolic alkalosis or (c) neutralising effects within the acid-base compartment. The circles indicate the metabolic changes (SID or A_{tot}) and the numbers indicate the number of animals within each group.

From these data, it was concluded that the dominant metabolic acid-base change was an acidosis, characterized by a SID acidosis, which was partially offset by a concurrent A_{tot} alkalosis, due to hypoalbuminaemia. The sum of all the components was not noticeably

Table 1. Median and interquartile range (IQR) of serum electrolytes and the effects of free water, chloride, L-lactate, albumin and phosphate in puppies with CPV enteritis compared to healthy controls.

	CPV group (*n* = 42)		Control group (*n* = 10)		*P*-value
Parameter	Median	IQR	Median	IQR	
Sodium (mMol/L)	137	134 – 139	143	142 – 146	<0.001
Potassium (mMol/L)	4.29	3.95 – 4.7	4.73	4.54 – 4.95	0.001
Chloride (mMol/L)	106	98.6 – 116	111	109 – 115	0.001
Corrected chloride (mMol/L)	113	105 – 116	112	110 – 114	0.58
Albumin (g/L)	21	19 – 24	25	21 – 28	0.01
Phosphate (mMol/L)	2.43	2.06 – 2.70	2.7	1.42 – 3.1	0.17
L-Lactate (mMol/L)	2.5	1.85 – 3.25	2.1	1.7 – 2.65	0.55
Sum of effects (mEq/L)	–2.44	–5.98 – 2.55	–1.80	–2.62 – 2.55	0.21
Free water effect (mEq/L)	–2.0	–2.62 – –1.55	–0.51	–0.75 – 0.41	<0.0001
Chloride effect (mEq/L)	–2.51	–6.10 – 4.13	–1.61	–2.32 – 1.28	0.5
L-Lactate effect (mEq/L)	–2.5	–3.20 – –1.75	–2.10	–2.65 – –1.70	0.22
Albumin effect (mEq/L)	3.64	2.22 – 4.26	2.0	0.80 – 3.60	0.01
Phosphate effect (mEq/L)	0.07	–0.52 – 0.64	–0.69	–1.40 – 1.75	0.39

different from the control group, due to a wide range of possible outcomes in the CPV-affected group and similar medians (Table 1). Sodium, chloride (not corrected) and albumin were significantly lower in the CPV-affected group (Table 1). When chloride was corrected for changes in free water, the value was not significantly different from the control population and neither was the chloride effect. When each of the variables used in the quantitative assessment were correlated with the sum of all the effects, the strongest correlation was seen with the chloride effect (Fig. 2).

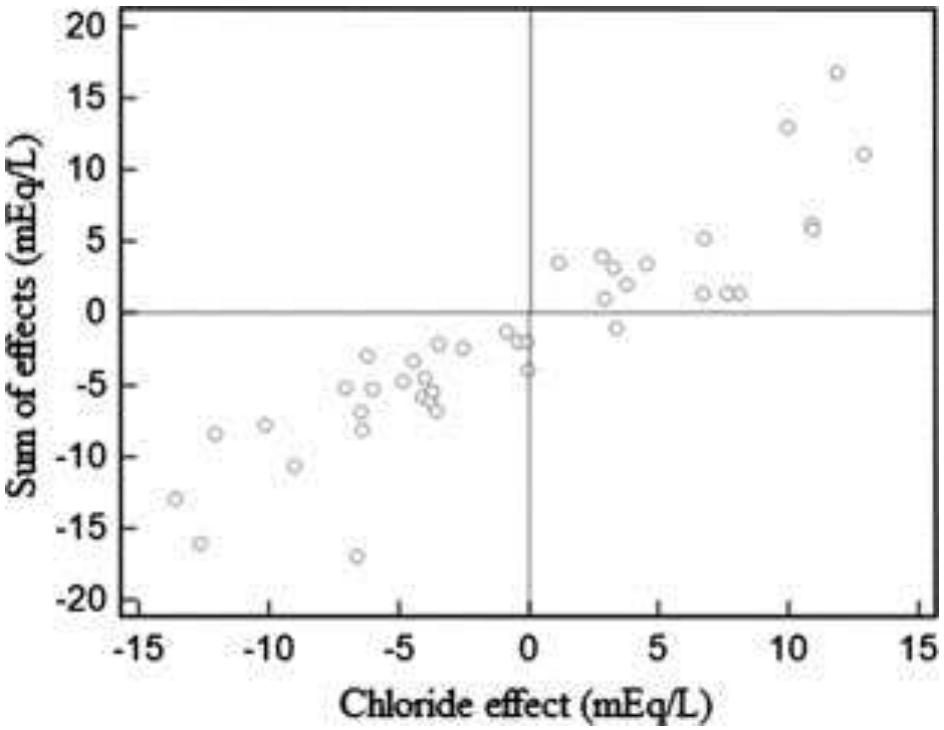

Fig. 2. Spearman's rank correlation of the sum of effects and the chloride effect. The horizontal line on the graph indicates the neutral point of the sum, and the vertical line represents a neutral chloride effect. The change in the chloride effect is strongly correlated with the change of the sum, both of which consistently change in the same direction, either positive or negative ($P < 0.001$).

None of the other variables correlated significantly with the sum of all the effects. Furthermore, when each of the SIM variables were statistically compared, according to clinical disease severity, a significant difference was noted within the chloride effect (Fig. 3), where mildly-affected puppies tended to have a hyperchloraemic acidosis and severely-affected puppies had a hypochloraemic alkalosis. According to these findings, and those of the Spearman's rank correlation, knowledge of the chloride effect most consistently predicted the outcome of the metabolic compartment in CPV-affected dogs according to the SIM.

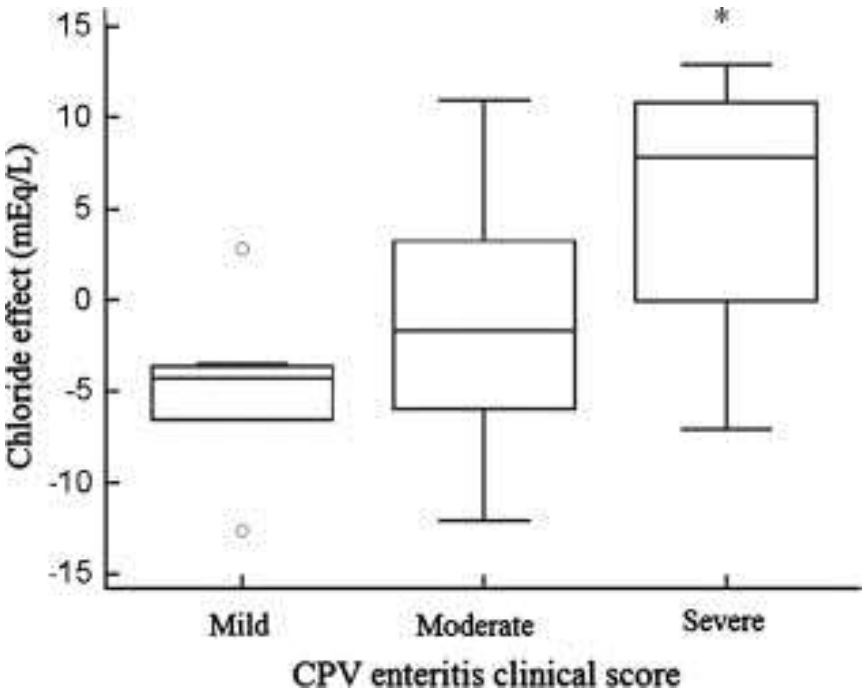

Fig. 3. Box plot comparing the chloride effect in mildly-affected (*n* = 10), moderately-affected (*n* = 21) and severely-affected (*n* = 11) dogs with CPV enteritis. Boxes indicate interquartile range (IQR), the solid horizontal lines represent the median, the whiskers 1.5 ± IQR and the open circles outliers. **P* = 0.007 comparing severely-affected and mildly-affected dogs.

According to the SM, the SID_4 of the CPV-affected group was 35 ± 3.0 mEq/L, compared to 39.2 ± 6 mEq/l for the control group and 39 mEq/L, experimentally determined by Constable and Stamplfi (2005). The difference was significant for the CPV-affected group compared to the control group (P = 0.01). A_{tot} of the CPV-affected group, using albumin alone, was 8.9 ± 2.9 mEq/L, compared to 10.5 ± 1.5 mEq/L for the control dogs and 15.8 mEq/L (Constable and Stamplfi, 2005). This difference between CPV-affected dogs and the controls was significant ($P < 0.005$).

When the diagnoses were categorised (A-D), using the simplified method (based on comparison to the experimental values), and the outcomes using this method compared to the diagnosis using the base excess algorithm, there was good agreement between the two models

(kappa = 0.72). When A_{tot} was calculated from total protein ($A_{tot\text{-}tp}$), the value was 12.58 ± 2.3 mEq/L and 14.6 ± 1.8 mEq/L for the CPV-affected and control dogs, respectively (*P*= 0.006). When the diagnostic outcomes were performed using the $A_{tot\text{-}tp}$ instead of $A_{tot\text{-}alb}$ (compared to experimental values) and compared to the base excess algorithm, the diagnosis only changed in two cases (A_{tot} normal), and there was still good agreement between the two models (kappa = 0.71).

Discussion

Both vomitus and diarrhoea are electrolyte-rich fluids and therefore the presence of plasma electrolyte disturbances was not surprising in dogs affected with CPV enteritis. Sodium was consistently low in the CPV group, indicating a relative free water excess. According to the SIM principles, a free water excess will invoke acidosis, partly due to a decrease in the strong ion difference (SID) (Kellum, 2007). In addition, an A_{tot} alkalosis may occur with a free water excess, due to decreased plasma protein concentration, which may offset the magnitude of SID acidosis, as is the case in dilutional acidosis (Constable, 2003). In the case of CPV enteritis, this mechanism could be even more complex, due to dehydration and concurrent protein loss through the gut, resulting in diverse outcomes in the plasma protein concentration and therefore the contribution of A_{tot}. Conversely, a free water deficit would result in an increased SID alkalosis with a possible A_{tot} acidosis, due to increased concentration of plasma proteins (Constable, 2003). In addition, an A_{tot} alkalosis was also common due to significant albumin losses.

The findings of the present study gave insight into the complexity of the acid-base changes in CPV enteritis and potentially explained why minor changes in bicarbonate concentrations have been observed in previous studies, in the face of significant metabolic

disturbances. When the A_{tot} was estimated from TP (according to the SM), the value was consistently higher; however, the value was still statistically lower than the A_{tot} (estimated from the TP) in the control group. This finding confirms the assertion that plasma globulin proteins play a more significant role in the determination of A_{tot} in dogs compared to humans (Constable and Stampfli, 2005). Therefore, the base excess algorithm using albumin, overestimated the contribution of A_{tot} in CPV enteritis. Many of the control dogs had significant A_{tot} alkalosis, according to the base excess algorithm, although when the A_{tot} was estimated using TP, the value was close to the normal value previously calculated (15.8 mEq/L) in the control dogs.

One limitation of this study was the absence of blood gas analysis, which precluded a direct comparison between the HH and the SIM model. Notwithstanding this constraint, valuable information can still be obtained from this study, regarding the pathophysiology of the acid-base disturbances present in dogs affected with CPV enteritis. A previous study showed a marked increase in L-lactate production, a significantly decreased base excess, with only a mild decrease in bicarbonate and significantly reduced carbon dioxide tension (Nappert et al., 2002). Bicarbonate values roughly approximated to those expected during compensation with a primary respiratory alkalosis, in the face of significantly increased L-lactate and β-hydroxybutyrate, which would be expected to result in a metabolic acidosis. These findings, compared with those of the present study, suggest the HH paradigm is too simplistic to explain the complex underlying metabolic acid-base changes in CPV enteritis.

When the sum (summated components of the base excess algorithm) was correlated with its constituents, the most significant relationship was with chloride (corrected). This was an interesting finding, since it would have been expected that a significant relationship would

have been observed between the sum and free water changes, although this was not the case. Interestingly, the two most consistently deranged variables, namely sodium and albumin, showed the least significant relationship with the sum. This finding appears to emphasise the significance of chloride disturbances in the pathogenesis of acid-base changes in CPV enteritis, which is not appreciated by the HH model. Therefore, regardless of a consistent hyponatraemic acidosis and hypoalbuminaemic alkalosis, the direction and magnitude of the changes in chloride will likely determine the outcome of the sum, in most cases. The importance of chloride changes was further highlighted, since it was the only variable in which differences were observed, according to clinical severity. The more severely-affected puppies, according to clinical score, tended to have a hypochloraemic alkalosis, whereas mildly-affected individuals tended to have a hyperchloraemic acidosis. These changes might reflect differences in the severity of vomiting or the period of illness that had elapsed, before sampling. Further studies are needed to determine if chloride changes correlate with outcome and whether therapeutic chloride correction is warranted.

Finally, this study was able to demonstrate the utility of a simplified SIM technique, making use of standard plasma electrolyte and albumin analysis. When SID and A_{tot} were calculated and compared to experimentally-established values, there was good agreement between the two models. This method, therefore, compared well with the base excess algorithm approach in reaching a diagnosis of strong ion and A_{tot} changes. The base excess algorithm was principally employed, due to its common use in determining acid-base status. Our results showed that the model was robust and that it compared well with data obtained using a model validated in dogs. Clinicians should recognise that in dogs the base excess algorithm using albumin rather that TP might overestimate the magnitude of A_{tot} changes.

Conclusions

Application of the SIM for clinical assessment of the acid-base status in puppies affected with CPV enteritis, indicated that significant electrolyte and albumin disturbances are present, but that chloride is the most important variable in the pathogenesis of the acid-base disturbances.

Conflict of interest statement

None of the authors has any financial or personal relationship that could inappropriately influence or bias the content of the paper.

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Appendix A

Supplementary Table 1. Clinical scoring system for patients with canine parvoviral enteritis

Parameter	Score	Criteria
Habitus	1	Collapsed / moribund
	2	Severe depression
	3	Mild-to-moderate depression
	4	Normal
Appetite	1	No interest in food
	2	Voluntarily eats small amounts of food offered
	3	Voluntarily eats moderate amounts of food offered (but not normal)
	4	Normal
Vomiting	1	Severe (≥ 6 times per 12h)
	2	Moderate (3-5 times per 12h)
	3	Mild (1-2 times per 12h)
	4	Absent
Faecal consistency	1	Watery diarrhoea, bloody
	2	Watery diarrhoea, not bloody
	3	Soft
	4	Well-formed
Mucous membranes	1	Congested
	2	Pale
	3	Normal
Capillary refill time	1	> 2 seconds
	2	< 1 second
	3	1-2 seconds

Supplementary Table 2. Calculation of the contribution of each of the SIM variables to the buffer base (Fencl and Leith, 1993; Hopper and Haskins, 2008)

Changes in base excess Caused By Changes in $[A_{tot}]$ in mEq/L

Albumin Contribution:

Δ Albumin = 4 $([alb]_{normal} - [alb]_{patient})$

Phosphate Contribution:

Δ Phosphate = 1.8 $[phosphate]_{patient}$

Changes in base excess Caused by Changes in SID in mEq/L

Contribution from free water:

Δ free water = 0.25 $([Na]_{patient} - [Na]_{normal})$

Contribution from Chloride:

Δ Chloride = $([Cl^-]_{normal} - [Cl^-]_{corrected})$

Sum of all the effects

Xa = (Δ albumin + Δ phosphate + Δ free water + Δ chloride)

Normal values used where: sodium (145 mmol/L), chloride (110mmol/L), albumin (3 g/dl) and phosphate (2.4mmol/L; 0.78mg/dL)

Corrected Chloride = $Cl^-_{patient} \times (145/Na_{patient})$