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

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Article info

Article history:
Accepted 24 January 2014

Keywords:
Canine parvovirus
Strong ion model
Henderson–Hasselbalch method

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 hyperchloremic 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.

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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 (Sigggaard-Andersen et al., 1960; Sigggaard-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 Nirmal, 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 $A_{an}$) (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 some degree of opposition, 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 information available regarding 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 alkalaeemic and one was acidotic. In contrast, in the study by Rai and Nauryal (1992) a significant acidemia was demonstrated in 21 cases of CPV enteritis. Furthermore, a decrease in actual and standard HCO₃⁻ and base excess was observed. In a later study, plasma pH was consistently increased in dogs affected with CPV enteritis, compared to the healthy dogs, but HCO₃⁻ was consistently decreased and the pH increase was deemed to be due to compensation, in the presence of decreased HCO₃⁻ 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 HCO₃⁻ and increased L-lactate production), but the blood pH was in fact higher than normal (i.e. alkalaeemia). Within this deviation of HCO₃⁻, 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, Anguillula spp. and Gardia 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 Herritage, 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 (V07/05, 20/12/2005).

The 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 and 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 °C 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 compared to each individual component by means of a Spearman’s rank correlation. Each of the variables used in the calculation 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 effects were summated to yield the Aₜot and the values 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, Aₜot acidosis (designated A); strong ion alkalosis, Aₜot alkalosis (designated B); strong ion alkalosis, Aₜot alkalosis (designated C) and strong ion alkalosis, Aₜot 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 Aₜot acidosis/alkalosis. The metabolic acid–base status of the dogs was displayed visually, using Venn diagrams as previously described by Vitu 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 Aₜot. 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 SID₄ was calculated from four major strong ions (Na + K + Cl + L-lactate) for both the CPV-affected and control groups. The Aₜot 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). SID₄ and the Aₜot derived from albumin and total protein (TP) in the CPV-affected and control groups were compared using the Student’s t-test.

Firstly, using the simplified model, a metabolic acid–base classification was assigned to each case, by comparing the CPV-affected group values for SID₄ and Aₜot (calculated from albumin and TP) to the experimentally-validated values for these variables (values taken from Constable and Stampfli, 2005). In addition, the SID₄ and Aₜot 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. Diagnosis was then assigned to the categories A–D as described previously, with the outcomes of this simplified method and the base excess algorithm compared using an inter-rater agreement plot.

Results

According to the SIM, 20 of 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 SID₄ acidosis and within this group, 19 had a concurrent Aₜot acidosis and one had a mild Aₜot acidosis, due to mild hyperphosphataemia (Fig. 1a). Of the individuals with metabolic alkalosis, 9/10 had a SID₄ alkalosis and 1/10 had a SID₄ alkalosis. All 10 patients had a concurrent Aₜot alkalosis (Fig. 1b). Within the neutralizing group, 8/12 had a SID₄ acidosis, with all eight of these having an Aₜot alkalosis. The remaining four dogs had a SID₄ alkalosis and, within this group, two had an Aₜot alkalosis, with the remaining two having an Aₜot acidosis (Fig. 1c).
From these data, it was concluded that the dominant metabolic acid–base change was an acidosis, characterised by a SID acidosis, which was partially offset by a concurrent Atot alkalosis, due to hypoalbuminaemia. The sum of all the components was not noticeably 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).

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 hyperchlo- raemic acidosis and severely-affected puppies had a hypochlo- raemic 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.

According to the SM, the SiD4 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 Stampfli (2005). The difference was significant for the CPV-affected group compared to the control group (P = 0.01). Atot 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 Stampfli, 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 Atot was calculated from total protein (Atot-Cp), 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 Atot-Cp instead of Atot-alb (compared to experimental values) and compared to the base excess algorithm, the diagnosis only changed in two cases (Atot 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 Atot 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 Atot. Conversely, a free water deficit would result in an increased SID alkalosis with a possible Atot acidosis, due to increased concentration of plasma proteins (Constable, 2003). In addition, an Atot 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 Atot was estimated from TP (according to the SM), the value was consistently higher; however, the value was still statistically lower than the Atot (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 Atot in dogs compared to humans (Constable and Stampfli, 2005). Therefore, the base excess algorithm using albumin, overestimated the contribution of Atot in CPV enteritis. Many of the control dogs had significant Atot alkalosis, according
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 i-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 i-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 hypona-trahaemic 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 hyperchlo-remic alkalosis, whereas mildly-affected individuals tended to have a hyperchloraeic 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 Atot 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 Atot changes. The base excess algorithm was

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### Table 1

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>CPV group (n = 42)</th>
<th>Control group (n = 10)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium (mMol/L)</td>
<td>137</td>
<td>143</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Potassium (mMol/L)</td>
<td>4.29</td>
<td>4.73</td>
<td>0.001</td>
</tr>
<tr>
<td>Chloride (mMol/L)</td>
<td>106</td>
<td>111</td>
<td>0.001</td>
</tr>
<tr>
<td>Corrected chloride (mMol/L)</td>
<td>113</td>
<td>112</td>
<td>0.58</td>
</tr>
<tr>
<td>Albumin (g/L)</td>
<td>21</td>
<td>25</td>
<td>0.01</td>
</tr>
<tr>
<td>i-Lactate (mMol/L)</td>
<td>2.43</td>
<td>2.7</td>
<td>0.17</td>
</tr>
<tr>
<td>Phosphate (mMol/L)</td>
<td>2.5</td>
<td>2.1</td>
<td>0.55</td>
</tr>
<tr>
<td>Sum of effects (mEq/L)</td>
<td>-2.44</td>
<td>-1.80</td>
<td>0.21</td>
</tr>
<tr>
<td>Free water effect (mEq/L)</td>
<td>-2.0</td>
<td>-0.51</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Chloride effect (mEq/L)</td>
<td>-2.51</td>
<td>-1.61</td>
<td>0.5</td>
</tr>
<tr>
<td>i-Lactate effect (mEq/L)</td>
<td>-2.5</td>
<td>-2.10</td>
<td>0.22</td>
</tr>
<tr>
<td>Albumin effect (mEq/L)</td>
<td>3.64</td>
<td>2.0</td>
<td>0.01</td>
</tr>
<tr>
<td>Phosphate effect (mEq/L)</td>
<td>0.07</td>
<td>-0.69</td>
<td>0.39</td>
</tr>
</tbody>
</table>

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**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).

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**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.
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 than TP might overestimate the magnitude of $A_{\text{tot}}$ 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.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.tvjl.2014.01.017.

References


