

Metabolic Acidosis in Neonatal Calf Diarrhea—Clinical Findings and Theoretical Assessment of a Simple Treatment Protocol

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Background: Clinical assessment of metabolic acidosis in calves with neonatal diarrhea can be difficult because increased blood concentrations of D-lactate and not acidemia per se are responsible for most of the clinical signs exhibited by these animals.

Objectives: To describe the correlation between clinical and laboratory findings and D-lactate concentrations. Furthermore, the theoretical outcome of a simplified treatment protocol based on posture/ability to stand and degree of dehydration was evaluated.

Animals: A total of 121 calves with diagnosis of neonatal diarrhea admitted to a veterinary teaching hospital during an 8-month study period.

Methods: Prospective blinded cohort study. Physical examinations were carried out following a standardized protocol. Theoretical outcome of treatment was calculated.

Results: Type and degree of metabolic acidosis were age dependent. The clinical parameters posture, behavior, and palpebral reflex were closely correlated to base excess ($r = 0.74, 0.78, 0.68$; $P < .001$) and D-lactate concentrations ($r = 0.59, 0.59, 0.71$; $P < .001$), respectively. Thus, determining the degree of loss of the palpebral reflex was identified as the best clinical tool for diagnosing increase in serum D-lactate concentrations. Theoretical outcome of treatment revealed that the tested dosages of sodium bicarbonate are more likely to overdose than to underdose calves with diarrhea and metabolic acidosis.

Conclusions and Clinical Importance: The degree of metabolic acidosis in diarrheic calves can be predicted based on clinical findings. The assessed protocol provides a useful tool to determine bicarbonate requirements, but a revision is necessary for calves with ability to stand and marked metabolic acidosis.

Key words: Base excess; Dehydration; D-lactate; Sodium bicarbonate.

In calves with neonatal diarrhea, metabolic acidosis is a common occurrence requiring specific treatment. Because laboratory equipment is not routinely available in ambulatory practice, the degree of metabolic acidosis is usually assessed on the basis of clinical signs.^{1–9} Whereas the accuracy of the assessment of metabolic acidosis varied markedly among studies, most authors came to the conclusion that base excess and therefore bicarbonate concentration can be estimated to some degree on the basis of changes in posture and behavior. In addition, the age of the calf can be used to predict the severity of metabolic acidosis, because diarrheic calves during their first week of life are less acidemic than older calves with similar clinical signs.⁴ Furthermore, the suckling reflex is closely correlated with base excess values.⁶ A recent experimental study questioned the relationship between metabolic acidosis and clinical signs, because administration of hydrochloric acid induced severe hyperchloremic metabolic acidosis but no abnormal clinical signs or depression of appetite.¹⁰

By contrast, D-lactatemia frequently occurs in calves with neonatal diarrhea^{11–14} and most clinical signs of metabolic acidosis are attributable to this biochemical change.^{8,15} However, it is still possible to roughly estimate the degree of metabolic acidosis in calves with naturally acquired diarrhea¹⁶ because a significant correlation exists between D-lactate concentrations and base excess values.¹⁴

The aim of the present prospective study was to investigate whether simple guidelines for the dosage of sodium bicarbonate based on posture/ability to stand and degree of dehydration as sole criteria¹⁷ could be used to determine the treatment of metabolic acidosis without expensive laboratory equipment. Furthermore, the correlation between clinical signs and degree of acidosis was to be evaluated to improve the prediction of metabolic acidosis.

Material and Methods

Between September 2009 and April 2010, a prospective study was conducted involving 150 calves that were either admitted to the Clinic for Ruminants (Ludwig-Maximilians-University Munich) because of neonatal diarrhea or developed diarrhea while hospitalized. A total of 26 calves were excluded because of need for surgical intervention ($n = 2$), euthanasia or death during the first 24 hours of hospitalization ($n = 16$), marked hyponatremia (>170 mmol/L; $n = 4$), failure to receive the entire determined infusion volume ($n = 3$), or ruminal acidosis because of force feeding before admission ($n = 1$).

The data sets of 3 additional calves that were euthanized at a later point in time were excluded retrospectively because of findings at necropsy including peritonitis, BVDV-infection, and cecocolic intussusception. Thus, data for 121 calves remained in the study. Because of regional breed preferences by producers, most of the calves (92%) belonged to the Simmental breed.

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All physical examinations were carried out following a standardized protocol by the same person who was blinded to all laboratory values (Table 1). Examination of the posture/ability to stand included lifting of the animal if it was not able or willing to stand up. Attempts to lift the calves to their feet were carried out by 2 persons. Lateral recumbency was only diagnosed in calves that were not able to retain a sternal position. Skin tent duration was measured in seconds at the lateral portion of the thorax over the 6th to 9th ribs. For this purpose, skin was tented and twisted by 90° for 1 second. Skin tenting was monitored for 10 seconds, and the maximum assigned value was 10 seconds.^{18,19} The extent of enophthalmos was additionally quantified by measuring the distance (in mm) between the medial canthus and the eyeball.¹⁹

Grouping of calves was performed using simple guidelines for the dosage of sodium bicarbonate relying on posture/ability to stand and degree of dehydration as described in a retrospective analysis¹⁷:

- Group I (n = 30): Calf standing steadily, no enophthalmos; oral rehydration
- Group II (n = 37): Calf standing steadily, enophthalmos; infusion containing 250 mmol sodium bicarbonate
- Group III (n = 43): Calf standing unsteadily; infusion containing 500 mmol sodium bicarbonate
- Group IV (n = 11): Calf unable to stand; infusion containing 750 mmol sodium bicarbonate

Enophthalmos was defined as a visible gap between the eyeball and caruncula lacrimalis. Individual body masses of calves were disregarded.

Blood samples were taken from the jugular vein from all calves within 30 minutes of arrival. Venous blood pH and base

excess as well as concentrations of sodium, potassium, chloride, and actual bicarbonate were determined using a blood gas analyzer.^a After measuring the hemoglobin concentration (Hb) photometrically, blood base excess (in vitro base excess) was calculated by the unit using the following equation:

$$\text{Base excess (mmol/L)} = (1 - 0.014 \times \text{Hb}) \times [(\text{HCO}_3^- - 24.8) + (1.43 \times \text{Hb} + 7.7) \times (\text{pH} - 7.40)] \quad (1)$$

The anion gap (AG) was calculated as follows:

$$\text{AG (mEq/L)} = (\text{Na}^+ + \text{K}^+) - (\text{Cl}^- + \text{HCO}_3^-) \quad (2)$$

Serum concentrations of urea, creatinine, L-lactate, and D-lactate were determined using an automatic analyzing system.^b Determination of D-lactate concentration was carried out as described by Lorenz et al.²⁰

The theoretical outcome of treatment was calculated. For this purpose it was assumed that calves under group I receive 3 L of an oral rehydration solution with an effective strong ion difference of 60 mmol/L, thus providing an equivalent of 180 mmol sodium bicarbonate. The amount of sodium bicarbonate needed theoretically to correct metabolic acidosis was calculated for every calf using the following formula:

$$\text{HCO}_3^- (\text{mmol}) = \text{body mass (kg)} \times \text{base deficit (mmol/L)} \times 0.7(1/\text{kg}) \quad (3)$$

Negative values (caused by a negative base deficit) in calves with metabolic alkalosis were allowed. The recommended amount was then subtracted from the calculated amount.¹⁷

SPSS for Windows 18.0^c was used for statistical analysis of the results. A level of significance of .05 was chosen. Normal distribution was assessed visually using box-and-whisker plots and QQ plots. Because most of the data were not distributed normally, nonparametric tests were employed. Mann-Whitney *U*-tests were used for comparisons of continuous parameters between 2 groups. Differences between the 4 treatment groups were assessed using a Kruskal-Wallis test. For subsequent pairwise comparisons the Mann-Whitney *U*-test was used as well. In this case, the level of significance was adjusted using the Bonferroni method ($P \leq .008$). Spearman's coefficient of correlation was calculated in order to determine associations between parameters. Differences between 2 correlation coefficients were assessed using Fisher *t*-transformation.²¹

Results

The medians (and 25-/75-quartiles) for age (days) and body mass (kg) of the calves were 9.0 (6.0/12.5) and 43.0 (39.0/48.6), respectively. Blood base excess and serum D-lactate concentrations of calves are depicted in Figure 1.

Medians, minimal and maximal base excess, and D-lactate concentrations determined for the various clinical categories of calves are listed in Table 2. Figure 2 shows individual base excess values and serum concentrations of D-lactate in different clinical categories of posture/ability to stand, behavior, and the palpebral reflex. Only 11 out of 121 calves were categorized as recumbent (unable to stand). Attempts to lift the calves to their feet were carried out in 10 of these 11 calves. All 4 calves in lateral recumbency had increased D-lactate concentrations, whereas in 5 out of 6 calves in sternal recumbency, D-lactate

Table 1. Categorization of clinical signs.

Posture/ability to stand	1	Calf standing up by itself
	2	Calf standing up after encouragement
	3	Standing steadily after lifting
	4	Standing unsteadily, but is able to correct position if forced
	5	Standing unsteadily, unable to correct position if forced
	6	Unable to stand, sternal recumbency
	7	Unable to stand, lateral recumbency
Behavior	1	Adequate reaction to acoustic and optical stimuli, very bright and alert
	2	Adequate reaction to acoustic and optical stimuli
	3	Delayed reaction to acoustic and optical stimuli
	4	Calf reacts only to painful stimuli (eg, venipuncture)
Degree of enophthalmos	5	No reaction to painful stimuli
	1	None
	2	Slightly sunken (visible gap between globe and caruncula lacrimalis)
	3	Moderately sunken
Suckling reflex	4	Severely sunken
	1	Strong
	2	Weak
Palpebral reflex	3	Absent or chewing movements
	1	Eyelids are closed immediately and fully
	2	Eyelids are closed immediately but not fully
	3	Eyelids are closed with delay and not fully
	4	Eyelids are not closed at all

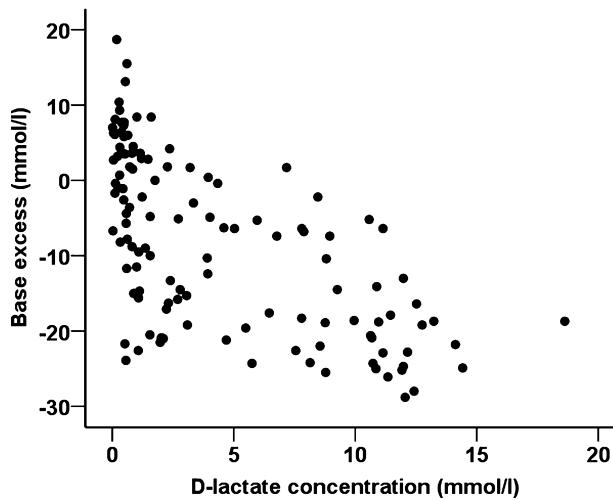


Fig 1. D-Lactate concentrations and base excess values in 121 calves with neonatal diarrhea.

Table 2. Base excess and D-lactate concentrations in 121 calves with neonatal diarrhea in relation to clinical categories (listed in Table 1).

	Category (n)	Base Excess (mmol/L)	D-Lactate (mmol/L)
		Median (min/max)	Median (min/max)
Posture/ ability to stand	1 (7)	-2.2 (-11.7/7.7)	0.5 (0.3/2.7)
	2 (53)	0.0 (-20.5/18.7)	1.1 (0.0/11.1)
	3 (7)	2.8 (-21.7/9.3)	0.8 (0.3/9.0)
	4 (14)	-11.7 (-22.6/-2.6)	7.3 (0.5/12.0)
	5 (29)	-20.6 (-28.0/-4.8)	9.3 (0.9/18.6)
	6 (7)	-20.9 (-23.9/-6.3)	2.4 (0.6/14.1)
	7 (4)	-25.4 (-28.8/-24.2)	11.7 (8.1/12.1)
Behavior	1 (18)	2.5 (-10.3/18.7)	0.5 (0.1/8.5)
	2 (37)	1.8 (-15.8/15.5)	0.8 (0.0/11.1)
	3 (42)	-14.6 (-24.3/13.1)	3.2 (0.4/12.8)
	4 (20)	-21.0 (-28.0/-13.3)	10.3 (0.6/18.6)
	5 (4)	-25.4 (-28.8/-24.2)	11.7 (8.1/12.1)
Degree of enoph.	1 (41)	-0.4 (-24.9/18.7)	1.6 (0.0/14.4)
	2 (32)	-6.6 (-28.8/7.3)	3.1 (0.0/12.2)
	3 (29)	-18.8 (-28.0/15.5)	2.3 (0.5/18.6)
	4 (19)	-14.5 (-24.7/2.8)	2.0 (0.6/12.0)
Suckling reflex	1 (33)	-2.2 (-24.9/18.7)	1.6 (0.0/14.4)
	2 (42)	-5.4 (-26.1/8.4)	1.6 (0.1/13.2)
	3 (46)	-17.4 (-28.8/9.3)	2.4 (0.0/18.6)
Palpebral reflex	1 (55)	0.7 (-22.6/18.7)	0.8 (0.0/7.2)
	2 (34)	-7.6 (-21.0/7.7)	2.3 (0.0/11.1)
	3 (24)	-19.9 (-28.0/-5.2)	10.7 (5.8/18.6)
	4 (8)	-24.3 (-28.8/-18.7)	12.0 (0.6/14.1)

concentrations were not notably increased. A total of 18 calves were able to stand despite base excess concentrations below -20 mmol/L.

Analysis of the theoretical outcome of the treatment regime revealed that the suggested dosages of sodium bicarbonate are more likely to overdose than to underdose calves with diarrhea and metabolic acidosis. Ten calves would have been underdosed and 40 calves

would have been overdosed by quantities of more than 250 mmol of sodium bicarbonate, and 5 of 40 calves would theoretically have been overdosed by dosages between 500 and 750 mmol of sodium bicarbonate. Base excess and D-lactate concentrations for calves in different treatment groups are listed in Table 3. No significant difference in base excess and D-lactate concentrations could be determined between calves that stood unsteadily and those that were recumbent (unable to stand); 8 of the 10 calves that were theoretically underdosed by considerable amounts of sodium bicarbonate belonged to group III (standing unsteadily). Body masses were not significantly different between groups.

Type and degree of metabolic acidosis were age dependent. Figures 3 and 4 show base excess and D-lactate concentrations in relation to the age of the calves. Calves that suffered from diarrhea within their first 6 days of life had significantly higher base excess ($P < .001$) and significantly lower D-lactate concentrations ($P < .001$) than older calves. Simultaneously, L-lactate concentrations were significantly higher ($P = .047$) in younger calves (Table 4). These differences are more distinct ($P = .001$) if L-lactate concentrations in calves less than 8 days of age (median: 2.7 mmol/L) are compared with those calves that were 8 days or older (median: 1.3 mmol/L). However, measured degrees of enophthalmos were not significantly different between these age groups. In addition, there was no clear influence of age on the accuracy of the estimation of degree of metabolic acidosis based on alterations in posture (Table 5).

Good correlations between base excess and D-lactate concentrations, on the one hand, and the clinical parameters posture, behavior, and palpebral reflex, on the other hand, were observed (Table 6). Despite this fact, a wide range of base excess concentrations could be detected in calves exhibiting similar clinical signs (Table 2). Coefficients of correlation between posture and base excess were significantly higher ($P = .003$) in calves with D-lactate concentrations above 5 mmol/L ($r = -0.80$) than in calves with D-lactate concentrations ≤ 5 mmol/L ($r = -0.47$).

The suckling reflex and levels of dehydration correlated only moderately with base excess values, and no correlation existed with D-lactate concentrations in blood (Table 6). However, in calves with D-lactate concentrations ≤ 3 mmol/L the correlation between the degree of enophthalmos and base excess was significantly ($P = .046$) higher ($r = -0.67$) than in calves with D-lactate concentrations > 3 mmol/L ($r = -0.41$). Ten calves showed signs of moderate to severe metabolic acidosis (standing unsteadily or unable to stand) without obvious signs of dehydration (normal position of the eyeball). All had increased serum D-lactate concentrations ranging from 6.8 to 14.4 mmol/L.

Discussion

In this study, good correlations of base excess values and concentrations of D-lactate with the clinical

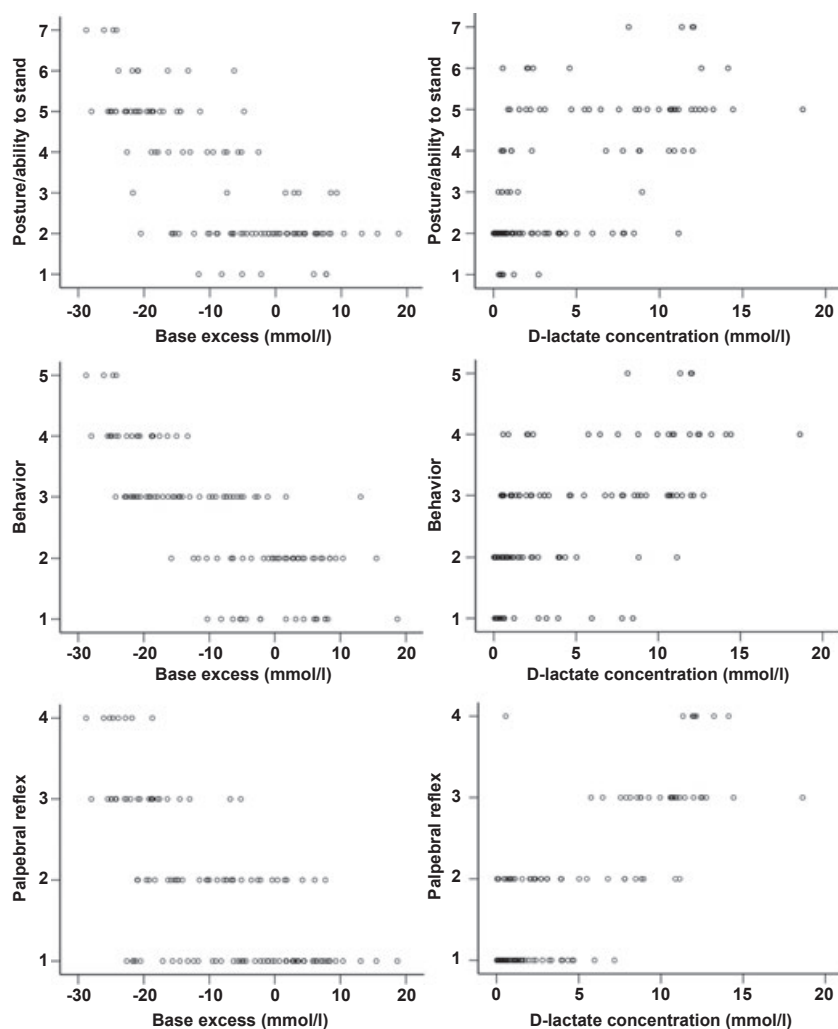


Fig 2. Base excess and D-lactate concentrations of 121 calves with neonatal diarrhea in different clinical categories of posture/ability to stand, behavior, and palpebral reflex.

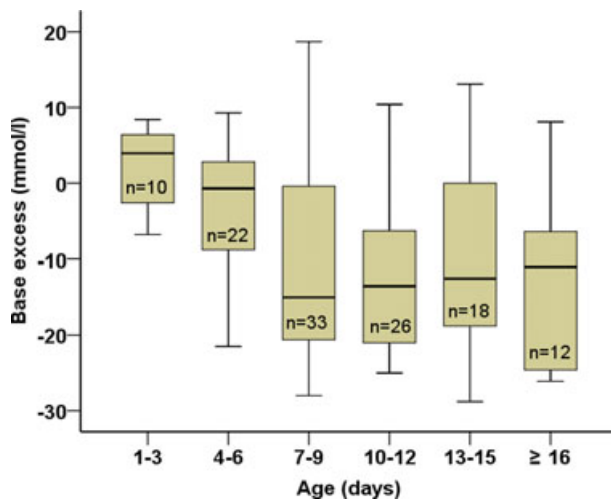
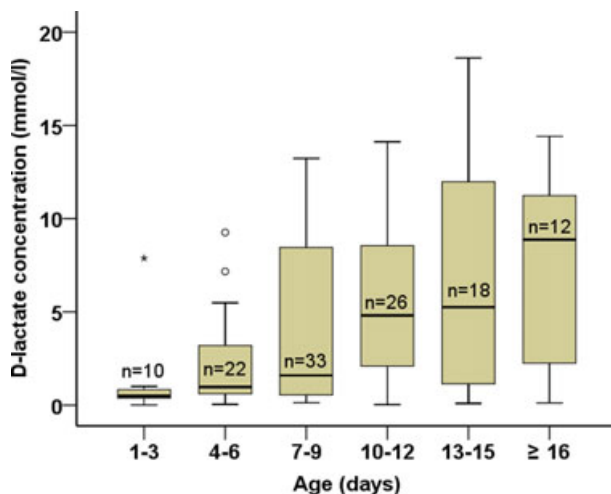
parameters posture, behavior, and palpebral reflex were observed leading to the conclusion that the degree of acidosis could be predicted based on these clinical signs. This conclusion is supported by the median base excess values in the treatment groups based on basic clinical signs. Despite this relationship, data of this study show that base excess values can vary markedly in calves showing a similar clinical picture (Table 2). This was especially true for calves having serum D-lactate concentrations below 5 mmol/L. A pronounced variability of clinical signs has previously been reported in a comparable investigation as well,⁷ but the authors did not mention presence or absence of D-lactic acidosis as a possible explanation for this phenomenon. However, analyzing data from a large group of calves ($n = 103$), these authors also found good correlations between base excess, on the one hand, and alterations in behavior ($r = -0.72$) and posture ($r = -0.63$), on the other hand.⁷ Another study showed that D-lactate values were distributed over the entire range of detected values from 0 to 17.8 mmol/L

in calves with acute diarrhea and base excess of -10 to -25 mmol/L.¹⁴ Especially in this subset of diarrheic calves with moderate to severe metabolic acidosis, variations in behavior and in posture could be better explained by increases in serum D-lactate concentrations than by decreases in base excess.⁸ In accordance with this finding, 2 recent studies clearly demonstrated that most of the clinical signs previously attributed to metabolic acidosis can be reproduced by infusion of hypertonic sodium-D-lactate or isotonic D-L-lactic acid.^{15,22} Calves that had received D-lactate showed impairment of the palpebral reflex, somnolence and a staggering gait.¹⁵ In this context the lowest serum D-lactate concentrations associated with clinical signs in an experimental study were reported to be 6 mmol/L.²³ Remarkably, in healthy calves, neither an experimentally induced severe dehydration¹⁸ nor an experimentally induced severe hyperchloremic acidemia and metabolic acidosis over a period of 80 minutes with base excess values as low as -33 mmol/L¹⁰ was accompanied by a deterioration of the general

Table 3. Base excess and D-lactate concentrations and number of calves that were theoretically underdosed by more than 250 mmol sodium bicarbonate in different treatment groups.

	Group I: Oral Rehydration n = 30	Group II: Infusion Containing 250 mmol HCO ₃ ⁻ n = 37	Group III: Infusion Containing 500 mmol HCO ₃ ⁻ n = 43	Group IV: Infusion Containing 750 mmol HCO ₃ ⁻ n = 11
Base excess (mmol/L)	3.6 ^a (-2.4/7.2)	-1.7 ^b (-10.2/1.8)	-18.7 ^c (-22.6/-14.1)	-21.8 ^c (-24.7/-16.4)
D-lactate (mmol/L)	0.6 ^a (0.3/3.2)	0.9 ^a (0.5/2.5)	8.8 ^b (2.3/11.0)	8.1 ^b (2.1/12.1)
Body mass (kg)	45.5 ^a (40.8/49.6)	40.6 ^a (37.0/46.0)	45.2 ^a (40.0/50.5)	41.6 ^a (36.0/46.0)
Underdosed calves (>250 mmol HCO ₃ ⁻)	n = 0	n = 2	n = 8	n = 0

Values are given as medians and 25-/75-quartiles. Different letters indicate significant differences between the groups ($P \leq .008$).

**Fig 3.** Base excess concentrations in relation to age in 121 calves with neonatal diarrhea.**Fig 4.** D-Lactate concentrations in relation to age in 121 calves with neonatal diarrhea (*indicates mild outliers; *indicates extreme outliers).

condition. In another study the infusion of hydrochloric acid over 6 hours also had no significant effect on ability to stand and the menace, tactile, and palpebral

Table 4. Base excess and D-lactate and L-lactate concentrations in relation to age in 121 calves with neonatal diarrhea.

	<7 Days of Age (n = 32)	≥ 7 Days of Age (n = 89)	P Value
Base excess (mmol/L)	1.6 (-6.5/4.2)	-14.1 (-20.9/-2.2)	<.001
D-lactate (mmol/L)	0.8 (0.5/2.3)	3.9 (1.0/10.6)	<.001
L-lactate (mmol/L)	2.6 (1.5/4.3)	1.6 (0.7/4.0)	.046

Values are given as medians and 25-/75-quartiles.

reflexes, but resulted in a depression of the suckling reflex.²² These studies led to the conclusion that metabolic acidosis without appreciable increase in D-lactate concentrations has only minor influence on posture and behavior. Nevertheless this was only partly true for the calves of our study. The fact that impairment of ability to stand was observed in many of these calves without remarkable increases in D-lactate concentrations requires explanation. In this respect concurrent disturbances or diseases in some calves such as pneumonia, navel ill, or cachexia might have had some importance, even though calves with obviously incurable diseases were excluded from this study. It was also speculated that posture and especially behavior are additionally influenced to some degree by factors like stress of transportation, because these clinical parameters had normalized after correction of metabolic acidosis at 4 hours after admission in a number of calves, despite persistent increase in D-lactate concentrations.²⁴ Obviously, D-lactate is not the only factor responsible for clinical alterations observed in calves with naturally acquired diarrhea and metabolic acidosis. This offers interesting approaches for future investigations.

The calculated theoretical outcome of treatment in the calves of this study was similar to the results of a retrospective analysis.¹⁷ Ten calves (8%) would theoretically have been underdosed whereas 40 calves (33%) would theoretically have been overdosed by considerable amounts (250 mmol) of sodium bicarbonate. The latter finding may be partly explained by the preselection of calves that are admitted to a university

Table 5. Base excess concentrations in young (age < 7 days) and older (age ≥ 7 days) calves in relation to clinical categories of posture/ability to stand.

Posture	<7 Days of Age Base Excess ^a (mmol/L)	≥ 7 Days of Age Base Excess ^a (mmol/L)	P Value
Steadily	2.8 (−0.9/5.5) (n = 24)	−2.2 (−9.0/6.0) (n = 43)	.047
Unsteadily, able to correct position if forced	−6.8 (−9.1/−3.4) (n = 4)	−15.2 (−18.5/9.7) (n = 10)	.036
Unsteadily, not able to correct position if forced	−19.6 (−21.5/−14.5) (n = 3)	−20.8 (−24.3/−18.4) (n = 26)	.52
Unable to stand	−13.3 (n = 1)	−22.9 (−25.1/−19.8) (n = 10)	–

^aValues are given as medians and 25-/75-quartiles.

Table 6. Coefficients of correlation between selected clinical and laboratory parameters.

	Base Excess	D-Lactate	L-Lactate	Anion Gap	Urea	Creatinine
Behavior						
rho	−0.78	0.59	0.04	0.77	0.48	0.41
P value	<.001	<.001	.649	<.001	<.001	<.001
Posture						
rho	−0.74	0.59	0.0	0.76	0.44	0.40
P value	<.001	<.001	.999	<.001	<.001	<.001
Palpebral reflex						
rho	−0.68	0.71	−0.31	0.54	0.28	0.09
P value	<.001	<.001	<.001	<.001	.002	.331
Suckling reflex						
rho	−0.45	0.14	0.40	0.57	0.49	0.50
P value	<.001	.129	<.001	<.001	<.001	<.001
Estimated degree of enophthalmos						
rho	−0.43	0.06	0.53	0.65	0.71	0.67
P value	<.001	.533	<.001	<.001	<.001	<.001
Duration of skin tenting thorax						
rho	−0.39	0.0	0.52	0.55	0.69	0.68
P value	<.001	.970	<.001	<.001	<.001	<.001
Enophthalmos (mm)						
rho	−0.39	0.02	0.56	0.62	0.70	0.69
P value	<.001	.806	<.001	<.001	<.001	<.001

teaching hospital, because a metabolic alkalosis (base excess > 5 mmol/L) caused by pretreatment could be detected in 17 calves on admission (Fig 1). In some cases, calves had been pretreated with large amounts of sodium bicarbonate but not enough volume of infusion before referral; therefore they were still clinically dehydrated upon arrival and would have received infusions with additional sodium bicarbonate.

Requirements for sodium bicarbonate were calculated using a factor of 0.7 in Formula 3 as recently recommended.²⁴ Calves with clinical signs of a D-lactic acidosis need higher doses of sodium bicarbonate (when determining the treatment for a period of 24 hours)²⁴ than calculated with a factor of 0.5–0.6 in the formula as previously suggested.^{2,3,25} The size of the factor was traditionally interpreted as distribution space of bicarbonate^{1,3} but newer research indicates that it is also influenced by the dynamics of the bicarbonate pool most probably as a result of ongoing intestinal losses of bicarbonate ions or absorption of D-lactate from the gastrointestinal tract or both.^{24,26}

In this study no significant difference in base excess values could be detected between calves that stood

unsteadily (group III) and calves presented in sternal or lateral recumbency (group IV). Remarkably, ability to stand was maintained in 18 calves despite base excess values below −20 mmol/L, which demonstrates the risk of undercorrection of metabolic acidosis with the provided amounts of sodium bicarbonate. Thus, it comes as no surprise that 8 of the 10 calves that were theoretically under dosed with considerable amounts of sodium bicarbonate belonged to group III. In conclusion, furthermore investigations will be necessary to identify additional clinical findings the consideration of which could improve the success of the treatment regime.

Accurate assessment and categorization of clinical parameters, especially the results of attempts to lift the calves to their feet, may have contributed to the finding that maintenance of ability to stand was observed in many calves despite marked metabolic acidosis. Thus, the proportion of calves that were unable to stand was low in comparison to other reports.^{3–6,12,27} It can be speculated that in some investigations examination of posture was done without lifting of the calves. This might explain the wide variation of base

excess values that are given by different authors when estimating the degree of metabolic acidosis based on clinical signs. Actually, in one of the studies⁶ it was explicitly mentioned that inability to stand was assumed if encouragement of calves to stand up was unsuccessful, whereas other authors use the term "recumbent" without specific reference to the ability to rise or stand.^{4,5,12,25,27}

This study underlines again that the nature and degree of metabolic acidosis in calves with neonatal diarrhea are age dependent. Calves under 1 week of age showed a greater tendency for L-lactic acidosis than older calves. This is consistent with previous studies.^{26,28} The finding of numerous investigations^{4,5,28,29} that diarrheic calves older than 1 week of age usually exhibit a higher base deficit could be confirmed, as well. It was additionally reported that the influence of the severity of acidosis on "demeanor" was much stronger in diarrheic calves during their first week of life.⁴ Based on this observation a protocol was developed to predict the severity of metabolic acidosis and to determine bicarbonate requirements of calves suffering from diarrhea in different age groups.²⁵ However, in this investigation the data showed no clear influence of age on the accuracy of the estimation of the degree of metabolic acidosis based on alterations in posture. Remarkably, both base deficit and D-lactate concentrations increased simultaneously with age. In a recent investigation a possible explanation was offered, since calves infected with enterotoxigenic *Escherichia coli* were younger and less acidemic than calves suffering from neonatal diarrhea caused by viral or cryptosporidium infections.²⁹ This is compatible with the hypothesis that an increase in production of D-lactate in diarrheic calves results from villous atrophy in the small intestine with maldigestion and malabsorption and subsequent microbial fermentation of substrates in the large intestine.^{12,30} Another author²⁸ also suggested that the acid-base findings and tendency for severe dehydration in calves under 8 days of age are attributable to enterotoxigenic *E. coli* infections, which are more common in this age group. The enterotoxins of this pathogen cause rapid dehydration, and severe tissue hypoperfusion would favor formation of L-lactate during anaerobic glycolysis.

In the present study, all clinical parameters of dehydration correlated moderately with base excess values, but not with D-lactate concentrations in blood. Intestinal bicarbonate losses are inevitably accompanied by fluid losses. This may explain the significant correlation between levels of dehydration and base excess values. The facts that not every dehydrated calf with metabolic acidosis has increased concentrations of D-lactate, and that calves with D-lactic acidosis are not necessarily dehydrated, explain why the severity of dehydration is not correlated with D-lactate concentrations.

High AG acidosis as a result of hyper-D-lactatemia requires a higher dosage of sodium bicarbonate than a metabolic acidosis that is predominantly caused by intestinal bicarbonate losses.²⁴ Because most

laboratories have not readily access to D-lactate methodology it was of interest to know whether AG can be used as proxy for D-lactate concentration. The results of this study show that alterations in behavior, ability to stand, and palpebral reflex in calves with an increase in AG indicate D-lactic acidosis, whereas in calves with severe clinical dehydration a high AG is more likely to be attributable to L-lactic acidosis (Table 6). L-Lactic acidosis is associated with a more guarded prognosis than D-lactic acidosis.³¹

The degree of metabolic acidosis could not be predicted with sufficient certainty based on clinical signs of dehydration (Tables 2 and 6). This is consistent with previous studies^{4,5,7,8,28} that revealed mostly no significant or only a weak correlation between base excess and degree of dehydration. Therefore, dehydration and metabolic acidosis should be evaluated separately, especially in calves with distinct clinical signs attributable to D-lactic acidosis (impairment of the palpebral reflex). However, in calves that are still able to stand (which indicates low concentrations of D-lactate) an existing enophthalmos seems to be a helpful tool to determine bicarbonate requirements because calves of group II with an existing enophthalmos had significantly lower base excess concentrations compared to calves of group I without obvious signs of dehydration. This finding justifies the difference in the provided amounts of buffer substances between groups I and II.

As indicated by a high correlation coefficient, determining the degree of loss of the palpebral reflex was identified as the best clinical tool for diagnosing an increase in D-lactate concentrations. This is in agreement with clinical and experimental investigations that showed that disturbances of the palpebral reflex are associated with high serum concentrations of D-lactate.^{8,15} However, in the experience of the first author (F.M.T.), examination of the palpebral reflex can be difficult in severely dehydrated calves, because calves with deeply sunken eyeballs cannot close their eyelids fully. This explains the weak but significant correlation between serum urea concentrations as an indicator of hydration status and the palpebral reflex. In prerenal azotemia caused by dehydration, the rise of urea concentrations is relatively more pronounced than that of creatinine concentrations.³² Many newborn calves have distinctly increased concentrations of serum creatinine which decline in the course of several days.³³ These 2 facts might explain the lack of correlation between serum creatinine concentrations and the palpebral reflex.

In conclusion, analysis of correlation between clinical and laboratory parameters revealed that the degree of metabolic acidosis can be estimated on the basis of alterations in posture and behavior whereas the degree of loss of the palpebral reflex offers a reliable tool for the prediction of increased D-lactate concentrations. Inability to stand seems to be a rare complication of metabolic acidosis if attempts to lift the calves to their feet are included in the clinical assessment of posture. The theoretical outcome of treatment indicates that the suggested dosages of sodium bicarbonate can be

used as guidelines to treat metabolic acidosis successfully without laboratory diagnostics. More importantly, this outcome shows that the amounts of sodium bicarbonate required for correction of metabolic acidosis in diarrheic calves seem to be higher than those of previously published treatment protocols, which were based on retrospective studies.^{25,34} However, prospective studies are necessary to test the success of the regime in practice. In particular, revisions of the recommendations are deemed necessary for calves with maintained ability to stand in spite of marked metabolic acidosis. Because the provided amounts of sodium bicarbonate are more likely to overdose than to underdose acidemic diarrheic calves, the impact of iatrogenic alkalosis on the success of treatment also needs to be evaluated.

Footnotes

^a Rapidlab 865 blood gas analyzer, Bayer Vital GmbH, Fernwald, Germany

^b Automatic Analyzer Hitachi 911, Roche Diagnostics, Indianapolis, IN

^c SPSS Inc, Chicago, IL

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