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FRACTIONAL EXCRETION OF ELECTROLYTES DURING PRE- AND POSTPARTUM PERIODS IN COWS

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In this study, fractional excretions (Fe) of sodium (Na), potassium (K), chloride (Cl), calcium (Ca), magnesium (Mg) and phosphorus (PO_4) were examined with the aim to demonstrate interactions between fractional excretions of these electrolytes within each period and relate them to electrolyte metabolism in clinically normal cows at different stages of lactation and dry period. The material of this study consisted of 20 clinically healthy Holstein-Friesian cows of the same age and milk yield. Blood and urine samples were collected on 190–200th, 240–250th and 270–280th days of pregnancy and on days 1–7th, 35–45th and 75–85th after calving, altogether 6 times. An increase was observed in Fe_{Ca} and Fe_{Mg} during the transition from the lactation to the dry period ($p < 0.05$), and a decrease in Fe_{Ca} ($p < 0.05$), Fe_{Mg} ($p < 0.01$) in the 2nd month of the dry period. Fe_{PO4} and Fe_{Mg}, respectively, increased on levels of $p < 0.01$ and $p < 0.05$, while Fe_{Ca} decreased on a level of $p < 0.05$ after gestation compared to the level before gestation. Fe_{Na} and Fe_K showed a decrease of $p < 0.001$ and $p < 0.01$, respectively, between the 1st and 2nd months of the dry period, while after gestation this value showed an increase in Fe_{Na} ($p < 0.05$) and Fe_K ($p < 0.01$). Fe_{Cl} increased significantly ($p < 0.05$) only from postpartum to the 1st month of lactation. There was a strong positive correlation between Fe_{Na} and Fe_{Cl} in all of the periods. It was concluded that there were significant changes in the Fe of Na, K, Cl, Ca, PO_4 and Mg before parturition and during lactation; these changes could have an important role in assessing renal function and electrolyte balance.

Key words: Cow, fractional excretion, electrolytes, lactation, dry period

Metabolic diseases associated with electrolyte disturbances in cattle, such as parturient paresis (hypocalcaemia), grass tetany (hypomagnesaemia), and displaced abomasum (alkalosis, hypochloraemia and hypokalaemia), develop predominantly before calving or in early lactation and have significant economic impact (Fleming et al., 1991; Fleming et al., 1992; Stevenson et al., 1999). Clinical

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signs develop late in the pathophysiological course of these diseases, and plasma concentrations of the electrolytes tend to remain within normal limits until the onset of clinical signs, making early detection and prevention difficult (Fleming et al., 1991). Moreover, potassium and magnesium are predominantly intracellular cations, which creates additional complications in interpreting changes in their plasma concentrations.

Urinary excretion of electrolytes is a complex process involving filtration, reabsorption and secretion in various areas of the nephron. Each of these processes may be influenced by numerous factors including dietary intake, plasma concentrations, level of activity of various hormones and concentrations and movements of other ions (Russo et al., 1986; Garry et al., 1990; Adams et al., 1991). Fractional excretion (Fe) expresses the proportion of substance that is excreted in the urine, compared with that filtered through the glomerulus by relating it to creatinine which is excreted purely via glomerular filtration. Fractional excretion of electrolytes could potentially be useful for evaluation of dietary adequacy, response to treatment of metabolic disease, and investigation of impaired renal function.

The purpose of the study reported here was to demonstrate the interactions between fractional excretions of these electrolytes within each period and compare them to electrolyte metabolism in clinically normal cows at different stages of lactation and dry period.

Materials and methods

Twenty clinically healthy, pregnant adult Holstein-Friesian cows (five years old) with similar milk production (5500 kg/lactation period) and weighing between 400 and 500 kg were used for this study. Samples of urine and serum were obtained simultaneously six times before and after parturition. These periods were late lactation (190 to 200 days, period l), first month of dry period (240 to 250 days, period 2), second month of dry period and before parturition (270 to 280 days, period 3), after parturition (1 to 7 days, period 4), early lactation (35 to 45 days, period 5) and peak lactation (75 to 85 days, period 6). The cows were maintained in a free-stall barn or in stanchions, and in the dry period (periods 2 and 3) the diet comprised alfalfa hay and a concentrate containing 0.49% Ca, 0.24% PO_4, 0.18% Mg, 0.54% Cl, 1.43% K, and 0.25% Na (on dry matter basis). The electrolytes of the diet were within the recommended ranges. During lactation periods (periods 1, 4, 5 and 6) corn silage was also added to the diet given above.

All samples were obtained in the afternoon before the cows were milked. Urination was induced by perineal stimulation and midstream urine was collected into plastic scintillation vials. Blood was collected by tail puncture; samples were allowed to clot, centrifuged, and serum obtained. Following sample collection, serum and urine samples were stored at –20 °C until analysed for creatinine (Cr), Na, K, Cl, Ca, PO_4 and Mg.

Urine samples were centrifuged and the supernatant was used for biochemical analysis. Dilution was required for analysis of urinary electrolyte concentrations. Serum and urine concentrations of Cr, Ca, PO_4, Mg were analysed, using a chemistry analyser (MERCK Microlab 200, Germany). Serum and urine concentrations of Na and K were determined, using a flame photometer (CIBA Corning 480, USA) and Cl concentration was measured using a chloridometer (CIBA Corning 925, USA).

Fractional clearance of Na, K, Cl, Ca, PO_4 and Mg was calculated for 6 periods by the following formula (Coffmann, 1980; Itoh, 1989; Fleming et al., 1991; Fleming et al., 1992; Won et al., 1996; Hartmann et al., 2001):

$$Fe_x = (U_x/S_x) \times (S_{Cr}/U_{Cr}) \times 100,$$

where Fe_x = Fractional excretion of × (%), U_x = Urine concentration of × (mg/dl or mEq/L), S_x = Serum concentration of × (mg/dl or mEq/L), S_{Cr} = Serum concentration Cr (mg/dl), and U_{Cr} = urine concentration of Cr (mg/dl).

Data were analysed by one-way analysis of variance (ANOVA) for repeated measures and correlation among Fe within periods were determined using Spearman's rank correlation test.

Results

Mean (± se) and $x_{min} - x_{max}$ values for Fe of Na, K, Cl, PO_4, Ca and Mg during the six periods are given in Table 1 and illustrated in Fig. 1. Plasma levels of Ca, PO_4, and Mg during the six periods are illustrated in Fig. 2. The correlation values of these electrolytes in these periods are given in Table 2.

An increase ($P < 0.05$) in Fe_{Ca} and Fe_{Mg} was observed on the passing from late lactation (0.86 ± 0.13 and 10.21 ± 1.57) into the dry period (1.39 ± 0.18 and 18.55 ± 2.71), and a decrease in Fe_{Ca} ($P < 0.05$), Fe_{Mg} ($P < 0.01$) in the second month of the dry period (0.83 ± 0.10 and 8.50 ± 1.19). Fe_{PO4} and Fe_{Mg} increased significantly ($p < 0.01$ and $p < 0.05$) after parturition (0.61 ± 0.08 and 13.55 ± 1.78) compared to the level before parturition (0.33 ± 0.05 and 8.50 ± 1.19, respectively), while Fe_{Ca} decreased ($p < 0.05$) after parturition (0.38 ± 0.08) compared to the level before parturition (0.83 ± 0.10).

Fe_{Na} and Fe_K showed a decrease ($p < 0.001$ and $p < 0.01$) between the first (0.89 ± 0.09 and 86.3 ± 9.25) and second month (0.34 ± 0.12 and 52.7 ± 6.8) of the dry period, respectively, then these values showed an increase in Fe_{Na} (to 0.78 ± 0.13) and Fe_K (to 80.4 ± 6.75) after gestation. Fe_{Cl} increased statistically significantly ($p < 0.05$) only between the postpartum period (0.96 ± 0.19) and the first month of lactation (1.71 ± 0.20).

Table 1

Pre- and postpartal fractional excretions of electrolytes in dairy cows

Fractional excretion (%)	Period 1 (a)	Period 2 (b)	Period 3 (c)	Period 4 (d)	Period 5 (e)	Period 6 (f)	Statistics
Ca							
$x \pm Se$	0.86 ± 0.13	1.39 ± 0.18	0.83 ± 0.10	0.38 ± 0.08	0.57 ± 0.10	0.69 ± 0.12	
$x_{min} - x_{max}$	0.09 – 2.13	0.33 – 3.14	0.28 – 1.92	0.05 – 1.65	0.08 – 1.92	0.08 – 2.01	$a < b^{*} > c^{*} > d^{**}$
PO_4							
$x \pm Se$	0.35 ± 0.05	0.39 ± 0.07	0.33 ± 0.05	0.61 ± 0.08	0.61 ± 0.06	0.64 ± 0.11	
$x_{min} - x_{max}$	0.09 – 1.09	0.06 – 1.61	0.09 – 1.12	0.08 – 1.61	0.2 – 1.3	0.07 – 2.0	$c < d^{**}$
Mg							
$x \pm Se$	10.21 ± 1.57	18.55 ± 2.71	8.50 ± 1.19	13.55 ± 1.78	12.97 ± 1.6	13.77 ± 1.63	
$x_{min} - x_{max}$	2.12 – 25	2.8 – 50.0	1.76 – 25.0	2.12 – 33.9	2.1 – 30.0	1.72 – 30.0	$a < b^{*} > c^{**} < d^{*}$
Na							
$x \pm Se$	0.96 ± 0.09	0.89 ± 0.09	0.34 ± 0.12	0.78 ± 0.13	1.22 ± 0.17	1.23 ± 0.17	
$x_{min} - x_{max}$	0.36 – 1.96	0.34 – 2.19	0.04 – 2.33	0.18 – 2.32	0.19 – 3.3	0.07 – 2.82	$b > c^{***} < d^{*}$
K							
$x \pm Se$	97.7 ± 5.02	86.6 ± 9.25	52.7 ± 6.8	80.4 ± 6.75	97.4 ± 8.78	106.1 ± 12.4	
$x_{min} - x_{max}$	65.4 – 168.3	13.2 – 177.5	15.2 – 126.0	24.5 – 152.1	39 – 217.5	26 – 239.8	$b > c^{**} < d^{**}$
Cl							
$x \pm Se$	0.88 ± 0.12	0.85 ± 0.1	0.68 ± 0.14	0.96 ± 0.19	1.71 ± 0.2	2.19 ± 0.23	
$x_{min} - x_{max}$	0.16 – 2.48	0.1 – 1.93	0.11 – 2.18	0.05 – 3.96	0.41 – 3.62	0.75 – 3.75	$d < e^{*}$

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

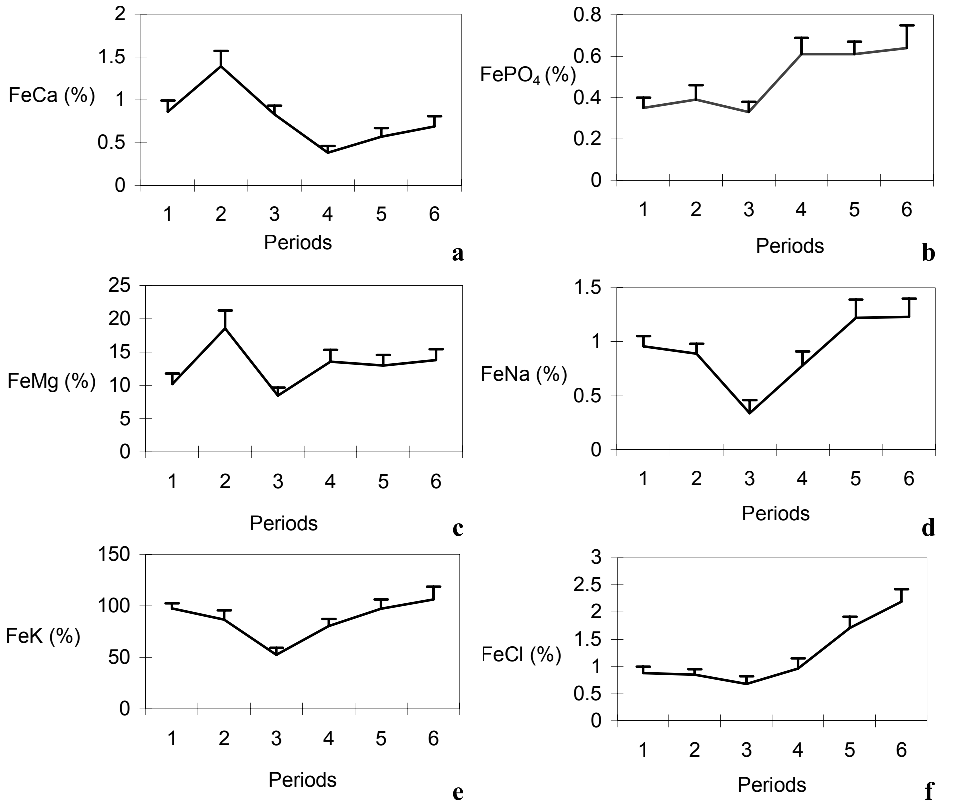

Fig. 1. Fractional excretion of electrolytes during pre- and postpartum periods in cows: (a) calcium; (b) phosphate; (c) magnesium; (d) sodium; (e) potassium; (f) chloride

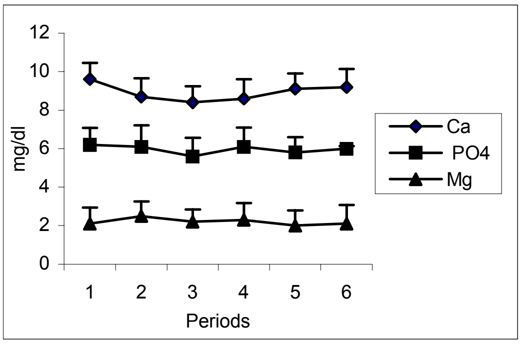

Fig. 2. Plasma levels of Ca, PO_4 and Mg during pre- and postpartum periods in cows

Table 2

Correlations of fractional excretions of electrolytes within periods

	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Ca-PO_4	–0.07	0.13	0.01	–0.07	–0.01	0.04
Ca-Mg	–0.22	0.36*	0.05	0.05	0.32	0.16
Ca-Na	0.52*	–0.03	–0.05	0.12	0.22	–0.20
Ca-Cl	0.27	0.26	0.33*	0.62***	0.53*	0.38*
Ca-K	0.07	0.06	0.01	–0.20	–0.02	0.25
PO_4-Mg	0.20	0.73***	–0.30	–0.18	–0.29	–0.05
PO_4-Na	0.01	–0.15	0.65**	0.05	–0.39*	0.24
PO_4-Cl	0.23	–0.20	0.11	0.10	–0.13	–0.16
PO_4-K	0.22	–0.15	0.43*	–0.18	–0.18	–0.26
Mg-Na	–0.25	0.12	–0.22	–0.05	0.05	–0.06
Mg-Cl	–0.04	–0.03	–0.16	0.06	0.45**	0.29
Mg-K	0.13	–0.016	–0.33*	0.07	0.22	0.12
Na-Cl	0.48*	0.43*	0.44*	0.65***	0.47**	0.36*
Na-K	0.03	–0.08	0.50*	–0.27	0.26	0.02
Cl-K	–0.01	0.30	0.15	0.32	0.64**	0.73***

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

There was a strong positive correlation between Fe_{Na} and Fe_{Cl} in all of the periods and between Fe_{Ca} and Fe_{Cl} within periods 3, 4, 5 and 6. Values for Ca and Na were positively correlated in period 1; Ca and Mg, PO_4 and Mg were positively correlated in period 2; PO_4 and Na, PO_4 and K, Na and K were positively correlated but Mg and K were negatively correlated in period 3; Mg and Cl, Cl and K were positively correlated but PO_4 and Na were negatively correlated in period 5; Cl and K were positive correlated in period 6.

Discussion

The Fe values of electrolytes in healthy cows vary due to metabolic demands during lactation and the diet (Fleming et al., 1991). This variability is more pronounced especially in minerals which are present in the structure of skeletal system during lactation and the dry period (Braithwaite, 1976). In this study, it was also observed that the Fe values of Ca, PO_4 and Mg changed significantly during the prepartal and postpartal periods based on the metabolic requirements of lactation and the dry period.

The increase in Fe_{Ca} on the passage from late lactation to the dry period could be explained by the reduced Ca requirement of cows following lactation. At the beginning of the lactation period the sudden increase in Ca requirement, which increases parathormone activity (Reinhardt et al., 1988), causes a reduction in Ca excretion and an increase in PO_4 and Mg excretion (Fleming et al., 1992). In this study, the level of Fe_{Ca} was found to be significantly higher before parturition than after parturition ($P < 0.01$), whereas Fe_{PO4} and Fe_{Mg} values increased significantly ($P < 0.01$) in the same period. Comparing the peak lactation to the early lactation, Fleming et al. (1992) reported that Fe_{Ca} was stabilised as Ca requirements peaked and Fe_{PO4} and Fe_{Mg} were higher at peak lactation, indicating increased parathormone activity. In our study, it was also found that there was no significant difference in the Fe_{Ca}, Fe_{Mg} and Fe_{PO4} values between the beginning and the peak of lactation.

Fleming et al. (1992) reported that there was no significant change in Fe_{Na}, Fe_K and Fe_{Cl} during the lactation period. However, in the present study significant differences were found between values before and after parturition. This situation could be explained by the data of Itoh (1989), who reported that the fractional excretions of electrolytes varied with changing season. Itoh (1989) also found that the Fe of Na, K and Cl values was lowest in spring and highest in summer. In the present study, the transition from dry period to lactation was between spring and summer.

The Na and Cl ions of the body are controlled by similar mechanisms. Cl is absorbed with Na from the proximal tubules (Michell et al., 1989); this explains the positive correlation between Fe_{Na} and Fe_{Cl} during all periods. The Fe values of Ca and Cl were correlated within periods 3, 4, 5 and 6. This is an important finding, given the success of ammonium chloride supplementation of prepartum diets in reducing the prevalence of hypocalcaemia (Block, 1984). The Fe values for other electrolytes were correlated within various periods. These correlations did not follow a recognisable pattern and are probably a result of day-to-day variations in the amount of feed consumed by cows.

The dietary cation-anion balance and dietary Ca and PO_4 contents during the dry period may play an important role in the incidence of hypocalcaemia. Feeding low Ca–low PO_4 or anionic diets during the dry period tends to reduce hypocalcaemia, while high Ca–high PO_4 or cationic diets tend to induce it (Kichura et al., 1982; Gaynor et al., 1989; Goff et al., 1991). However, the effects of Ca and PO_4 contents in the anionic diet on mineral metabolism are not fully understood. An anionic diet is thought to induce metabolic acidosis which increases Ca resorption from the bones and urinary Ca excretion (Gaynor et al., 1989; Goff et al., 1991; Wang and Beede, 1996). In this study, although there were changes in plasma Ca and PO_4 values in cows fed a diet containing low Ca–low PO_4 in the peripartal phase, statistically significant difference could not be seen. However, statistically significant differences were found in the Fe of these electrolytes. It was seen that monitoring the changes in the Fe of electrolytes could be used in the prevention of potential bone damage associated with dietary Ca and PO_4.

It was concluded that there were significant changes in the Fe of Na, K, Cl, Ca, PO_4 and Mg before parturition and during lactation of dairy cows. These changes could have an important role in assessing renal function and electrolyte balance.

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