A review of the renal system and diurnal variations of renal activity in livestock

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Kidneys are the main organs regulating water-electrolyte homeostasis in the body. They are responsible for maintaining the total volume of water and its distribution in particular water spaces, for electrolyte composition of systemic fluids and also for maintaining acid-base balance. These functions are performed by the plasma filtration process in renal glomeruli and the processes of active absorption and secretion in renal tubules, all adjusted to an 'activity-rest' rhythm. These diurnal changes are influenced by a 24-hour cycle of activity of hormones engaged in the regulation of renal activity. Studies on spontaneous rhythms of renal activity have been carried out mainly on humans and laboratory animals, but few studies have been carried out on livestock animals. Moreover, those results cover only some aspects of renal physiology. This review gives an overview of current knowledge concerning renal function and diurnal variations of some renal activity parameters in livestock, providing greater understanding of general chronobiological processes in mammals. Detailed knowledge of these rhythms is useful for clinical, practical and pharmacological purposes, as well as studies on their physical performance.

Key words: Key words: diurnal variations, renal activity, effective renal blood/plasma flow, glomerular filtration rate, tubular resorption/secretion, electrolyte/water excretion

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Glossary:

ADH – antidiuretic hormone
AVP – arginine-vasopressin, vasopressin
bw – body weight
Ccr – changes in glomerular filtration rate (GFR) based on endogenic creatinine clearance
Cin – changes in glomerular filtration rate (GFR) based on inulin clearance
ERPF – Effective renal plasma flow (ml/min/m²)
EPBF – Effective renal blood flow (ml/min/m²)
FF – Filtration fraction (%)
GFR – Glomerular filtration rate (ml/min/m²)
Posm – Plasma osmolality (mmol/kg H_2O)
Uosm – Urine osmolality (mmol/kg H_2O)
P – plasma level (mmol/l)
C – clearance (ml/min/m² or *ml/min/kg bw)
F – filtered load (mmol/min/m²)
TR – tubular resorption (%)
U*V – excretion in urine (μmol/min/m² or *μmol/min/kg bw)

Introduction

Living matter and evolving organisms are influenced by the Earth's rotation and revolution around the sun with its periodicity of day/light and night/darkness, with periodic changes in the length of the daily light and dark span and with seasons and climatic changes. Therefore, a variety of biological variables oscillate within an organism including: behaviour, physiological functions; and, biochemical factors. If any event within a biological system recurs at approximately regular intervals, it is generally referred to as a biological rhythm. Biological rhythms affect a variety of activities, such as the sleep-wake cycle, migration behaviour (birds, fish), seasonal fattening, reproductive cycles etc. The predominant rhythms in nature are daily rhythms e.g., rest-activity, body temperature, synthesis and/or secretion of many hormones, heart and respiratory rate, blood pressure, glomerular filtration rate, renal plasma flow, electrolyte concentrations in urine etc. Studies on chronobiological aspects of physiological functions have been carried out mainly on humans and laboratory animals (Koopman *et al.*, 1989; Refinetti and Menaker, 1992; Windle *et al.*, 1992).

Few studies have been carried out on livestock (Piccione *et al*., 2002, 2003a, 2003b, 2004, 2005).

Biological rhythms and circadian clock

Daily biological rhythms are endogenously controlled by self-contained circadian clocks, which are not merely passive responses to the daily alternation of light and darkness, as they persist even in a non-periodic environment (e.g., constant light). The word ‘circadian’ implies that under constant external conditions the rhythms free-run with a period of approximately, but not precisely, twenty-four hours. Recent evidence indicates that the length of the period is controlled by an endogenous circadian oscillator (clock, zeitgeber, pacemaker) (Aschoff, 1981; Edmunds, 1994; Ikonomov *et al*., 1998).

Animals appear to have central clocks that reside in discrete pacemaker tissues in the central nervous system, whose signals direct circadian output responses in peripheral tissue areas (Takahashi, 1995). Pacemakers are primary oscillators, genetically determined self-sustained oscillators without external time cues, which provide timing signals that synchronise a multitude of rhythms in the same frequency range. The suprachiasmatic nuclei (SCN), localised to a region of the hypothalamus, is an example of an anatomical locus of the mammalian circadian clock. This circadian oscillator can impose daily patterns on a wide array of physiological functions via retino-hypothalamic projection (Gillette and Reppert, 1987; Cassone and Stephan, 2002). Most physiological rhythms have both endogenous and exogenous influences (e.g., the renal system).

Diurnal rhythmicity of renal activity in animals, maintained under a synchronised light-dark cycle, is characterised by three parameters: (1) the mean value around which parameters oscillate, the ‘phase’ of the oscillation in relation to the light-dark cycle; (2) the peak, being referred to as the ‘acrophase’; and, (3) the minimum value, referred to as the ‘batyphase’.

Diurnal variability of renal system

Kidneys are the main organs regulating water-electrolyte homeostasis in the body. They are responsible for maintaining the total volume of water and its distribution in particular water spaces, for electrolyte composition of bodily fluids and also for maintaining acid-base balance. These functions are performed by plasma filtration in renal glomeruli and absorption and secretion in renal tubules (Belsano, 1991; Kokot, 1992).

Spontaneous rhythms of renal activity have been reported for many years (Branderberger *et al*., 1998; Koopman *et*

Table 1: Mean values (or range of values) of effective renal plasma flow (ERPF), effective renal blood flow (ERBF), glomerular filtration rate (GFR), filtration fraction (FF), diuresis, urine osmolality (Uosm) in some species of livestock. GFR - (ml/min/m^2) or *(ml/min/kg body weight).

	ERPF (ml/min/m^2)	ERBF (ml/min/m^2)	GFR (ml/min/m^2) or *(ml/min/kg bw)	FF (%)	Uosm (mmol/kg H_2O)	Numbers of animals	Age of animals	References
goats	490	650	55	10	1100	12		Vogel (1962)
		650	51	10	1100	12		Ketz (1960)
goat kids			1.69-3.08*			8	8-30 days old	Drzezdzon *et al.* (2001)
sheep	490		58			12		Vogel (1962)
			1.1-2.3*			89 female 19 male		Bickhardt and Dungelhoef (1994)
cattle	472		73		>1100	12		Ketz (1960)
			70					Boehnecke and Tiews (1972)
calves			1.75-3.32*			10	1-14 days old	Skrzypczak (2001)
	230-289	359-455	36.5-47.8	14-19		10 female	1-7 days old	Skrzypczak (1991)
				20				Dalton (1968)
				14-24		12		Ketz (1960)
	326						2-3 days old	Hartmann *et al.* (1987)
	379						4-20 days old	Hartmann *et al.* (1987)
	351		2.31*			23	1-6 weeks old	Wanner *et al.* (1981)
pigs					<1100			Vogel (1962)

al., 1989). The diurnal changes in the renal blood flow intensity, glomerular filtration and excretion with urine, are still a subject of intense study. These diurnal changes are influenced by a 24-hour cycle of activity of hormones engaged in the regulation of renal activity e.g., AVP (arginine-vasopressin), vasoactive peptides, the renin-angiotensin-aldosterone complex and melatonin. The cycle involves synthesis, excretion and concentration of hormones in blood plasma, but most importantly the activity of effector target sites (George *et al*., 1975; Van Acker *et al*., 1993; Boemke *et al*., 1995; Skotnicka and Hlynczak, 2001; Skotnicka, 2003, 2004, 2005).

Melatonin, the neurohormone of the pineal gland, plays a role in the regulation of the function of many body systems and, likewise, circadian rhythms. Recent studies suggest a possible role of melatonin in the regulation of water and electrolyte metabolism and renal function, by influencing the RAA system activity (Kawashima *et al*., 1987; Song *et al*., 1993; Song *et al*., 1995), through synthesis and/or secretion of AVP (Richardson *et al*., 1992; Forsling *et al*., 1993; Juszczak *et al*., 1995; Forsling, 2000) and through direct influence on melatonin receptors in kidneys (Song *et al*., 1993; Viswaythan *et al*., 1993; Song *et al*. 1995; Song *et al*., 1997).

The vegetative nervous system, which shows a diurnal variation as well, also seems to play a certain role here. Many investigators have reported that renal activity indices, like sympathetic activity, increase significantly during the day and decrease during the night; parasympathetic activity does the opposite (Lapinski *et al*., 1993; Branderberger *et al*., 1994; Dabrowska and Lapinski, 1996). Studies on renal activity diurnal variation have been carried out mainly on humans (Bultasova *et al*., 1986; Aslanian *et al*., 1989; Koopman *et al*., 1989; Ballauf *et al*., 1991; Cugini *et al*., 1992) and laboratory animals (Luke *et al*., 1991; Aizman *et al*., 1994; Schnecko *et al*., 1995). Few studies have been carried out on livestock. Moreover, their results cover only some aspects of renal physiology (Skrzypczak *et al*., 1992a, 1992b; Muszczynski, 1995).

Effective renal blood and plasma flow and glomerular filtration rate

Values of the effective renal blood and plasma flow (ERBF, ERPF) and glomerular filtration rate (GFR) are indicators of glomerular activity. The values of both ERBF and ERPF are very different in livestock species and increase with kidney development. GFR value depends directly on the effective filtration pressure and the area and permeability of the active filtration membrane. (Ketz, 1960; Vogel, 1962; Boehncke and Tiews, 1972; Skrzypczak, 1991; Drzezdzon *et al*., 2001).

ERPF through kidneys in goats is about 490 ml/min/m^2 (Vogel, 1962). Similar values were observed in sheep by Vogel (1962) and in cattle (472 ml/min/m^2) by Ketz (1960). ERPF in calves in the postnatal period of life was 230-289 ml/min/m^2 (Skrzypczak 1991). Effective renal blood flow (ERBF) in goats, according to Ketz (1960) and Vogel (1962), is about 650 ml/min/m^2 and the filtration fraction (FF) volume is about 10%. ERBF in calves in the postnatal period of life is 359-455 ml/min/m^2 and FF about 14-19% (Skrzypczak, 1991). According to Ketz (1960), the volume of GFR in goats (measured both by the volume of insulin clearance and endogenic creatinine) is 51 ml/min/m^2. Similar results were reported in sheep (58 ml/min/m^2) by Vogel (1962). GFR in adult cows is higher – about 70 ml/min/m^2 (Boehncke and Tiews, 1972). GFR in goat kids on the first month after birth is low and ranges from 1.69 to 3.08 ml/min/kg body weight (Drzezdzon *et al*., 2001). GFR in newborn calves is similar and ranges from 1.75 to 3.32 ml/min/kg body weight (Skrzypczak and Drzezdzon, 2001). Some ERPF, ERBF and GFR values in livestock are shown in **Table 1**. ERBF, ERPF and GFR show the greatest variation during a 24-hour period. GFR value in livestock, measured by the volume of inulin clearance (Cin) as well as based on endogenic creatinine clearance (Ccr), shows the highest volume (acrophase) during the day and the lowest volume (batyphase) at night. GFR also increases with an animal's age and development (Vogel, 1962; Skrzypczak *et al*., 1992a; Muszczynski, 1995).

Muszczynski (1995) demonstrated the existence of GFR diurnal rhythms in goats, on the basis of insulin clearance. The filtration varied from 41.2 to 62.3 ml/min/m^2, with an acrophase at 13:40. The same author also examined changes in glomerular filtration using endogenic creatinine (Ccr) and proved that, despite the observed differences in the volume of both clearances, the courses of particular rhythm phases were similar. Similarly, Vogel (1962), observed four-week-old goats to have 'day-night' differences in glomerular filtration (Ccr at 08:00hr was 46.4 ml/min/m^2; Ccr at 20:00hr was 24.6 ml/min/m^2). Also Skrzypczak *et al*. (1992a) observed significant 'day-night' differences in GFR volume in four-week-old calves (Cin at 10:00hr was 60.39 ml/min/m^2, Cin at 22:00hr was 49.99 ml/min/m^2). Diurnal variations of GFR for some livestock animals have been shown in **Table 2**.

The GFR increases during the light phase of the photoperiod with an increase in blood pressure and a simultaneous increase in filtration pressure in renal glomeruli (ERBF/ERPF are in phase with the GFR rhythm) (Koopman, 1989). The circadian rhythm of GFR in livestock is most likely affected by autonomic nervous system activity and also by circadian fluctuations of the following systems: the hypothalamus-hypophysis axis; vasoactive peptides; and, the renin-angiotensin-aldosterone complex, as studies on humans suggest (Koopman, 1989; Van Acker *et al*., 1993). Feeding time and diet (particularly the protein content in food) can modify renal activity, which results in hyperperfusion and then plasma hyperfiltration in renal glomeruli (Stoynev and Ikonomov, 1983; Luke *et al*., 1991; Skrzypczak *et al*., 1996). However, Muszczynski (1995), in his studies on goats, did not observe an influence of feeding time on GFR diurnal variation.

Tubular resorption and secretion and electrolyte excretion with urine

Kidneys of adult livestock can be very economical in sodium and chloride excretion. Tubular sodium resorption (TR_{Na}) and chloride resorption (TR_{Cl}) in goats, sheep and cattle renal duct tubules are above 93-100% of the filtered load (Ketz, 1960; Vogel, 1962). Tubular sodium and chloride resorption in calves and goat kids in the postnatal period are stable and similar to the levels in adult animals (Skrzypczak, 1991; Drzezdzon *et al.*, 2001). Potassium resorption is significantly lower than sodium and chloride resorption and is between 24% and 54 % of the filtered load in calves (Skrzypczak, 1991), 70.5% in goats and 90% in sheep (Vogel, 1962). Values of tubular resorption (TR) and filtered load (F) of sodium, potasssium and chloride ions in livestock are presented in **Table 3**.

The changes in electrolyte excretion with urine (U*V) are due to the filtration in renal glomeruli and resorption in tubules. The volume of electrolyte excretion is different for various species of livestock and depends on their age and development. Electrolyte excretion varies greatly in the first week of the animal's life (Skrzypczak, 1991; Drzezdzon *et al.*, 2001). Values of electrolyte excretion in urine ($U{*}V_{Na}$, $U{*}V_{K}$, $U{*}V_{Cl}$) have been shown in **Table 3**.

The diurnal rhythm of sodium, potassium and chloride filtered load (F) in goats (Muszczynski, 1995) have acrophases during the day, the changes in F_{Na} and F_K being parallel to those in GFR. Tubular resorption of sodium (TR_{Na}) and potassium (TR_K) also show a diurnal rhythm with an acrophase at night, ranging from 94.44% to 99.83% for sodium and from 75.94% to 82.92% for potassium. However, tubular resorption of chloride is rather stable, ranging from 97.21% to 98.92% compared to the filtered load, with the lowest values (batyphase) in the morning. In goats, diurnal rhythms of sodium, potassium and

Table 2: Mean values (or range of values) of diurnal variations of selected indicators of renal activity in some species of livestock. Acrophase is the peak value. Batyphase is the minimum value. GFR - (ml/min/m^2); C_{Na}, C_K, C_{Cl}, CH_2O (ml/min/m^2); TR_{Na}, TR_K, TR_{Cl} (%); diuresis (ml/min/m^2); and, Uosm (mmol/kg H_2O).

	Species	Acrophase		Batyphase		References [n - numbers of animals]
		clock time (hr) or midnight period	Mean value	clock time (hr) or midnight period	Mean value	
GFR	goats	13:40 hr	61.9-62.3	at night	41.2-51.6	Muszczynski (1995); [n=12]
	goat kids	10:00 hr	46.4	at night	24.6	Vogel (1962); [n=12]
	calves	In the day	60.39	at night	49.99	Skrzypczak *et al.* (1992a); [n=6]
P_{Na}, P_K, P_{Cl}	goats	constant				Muszczynski (1995)
P_{Na}	calves	20:00 hr				Skotnicka *et al*. (1997); [n=10]
P_K		08:30 hr				
P_{Cl}		constant				
TR_{Na}	goats	22.00 hr	99.8	12.00 hr	94.44	Muszczynski (1995)
TR_K		03.00 hr	82.92	12.00 hr	75.94	
TR_{Cl}		constant	97.21-98.92			
TR_{Na}	calves	in the day		at night		Skrzypczak (1992b)
TR_K		at night		in the day		
TR_{Cl}		in the day		at night		
C_{Na}	goats	12:00 hr	0.08	03.00 hr	0.35	Muszczynski (1995)
C_K		14:00 hr	7.86		14.4	
C_{Cl}		17:00 hr	0.65		1.24	
CH_2O		12:00 hr				
C_{Na}	goat kids	in the day	0.17	in the evening	0.08	Vogel (1962)
C_K			15.0		11.0	
C_{Cl}			0.52		0.33	
F_{Na}, F_K, F_{Cl}	goats	14.00 hr				Muszczynski (1995)
$(U{*}V)_{Na}$	goats	13.00 hr		03.00 hr		Muszczynski (1995)
$(U{*}V)_K$		14.00 hr				
$(U{*}V)_{Cl}$		16.00 hr				
$(U{*}V)H_2O$		13.30 hr				
$(U{*}V)_K$	calves			at night		Skrzypczak (1992b)
Diuresis	goats	in the day	1.26	at night	0.39	Muszczynski (1995)
	goat kids	in the day	1.32	in the evening	0.62	Vogel (1962)
Uosm	goats	at night	1245.9	in the day	828.7	Muszczynski (1995)
	goat kids	at night	367	in the day	215	Vogel (1962)

chloride excretion in urine (U*V) have acrophases during the day. The lowest renal elimination for these electrolytes (batyphase) is at night. The data are presented in **Table 2**. Renal activity of two-week-old calves (Skrzypczak *et al*. 1992b) shows higher sodium and chloride resorption during the day and lower at night. Trends of changes in the filtered load and excretion of sodium and chloride are parallel. Changes in the tubular resorption of potassium are the opposite – resorption is higher at night, which results in decreased potassium excretion with urine. Tubular resorption and secretion and electrolyte excretion with urine reach a maximum during the day and a minimum at night in other species of mammals, including dogs (Boemke *et al*., 1995), rats (Stoynev and Ikonomov, 1983; Luke *et al*., 1991) and humans (Bultasova *et al*., 1986; Aslanin *et al*., 1989; Koopman *et al*., 1989; Ballauf *et al*., 1991). Koopman *et al*. (1989) observed a positive correlation between sodium excretion and GFR rhythm acrophases in humans. According to that report, maximum values of potassium excretion occur earlier than the maximum glomerular filtration and are correlated with the potassium rhythm acrophase in plasma. The amount of excreted potassium depends mainly on the resorption processes and the tubular secretion in kidneys and, to a lesser extent, on the plasma filtration in renal glomeruli. Potassium excretion rhythm in adults is also very 'regular'. That is, it maintains regularity with the 24 hour cycle. Taking into consideration similarities between diurnal rhythms of livestock and other mammalian species, it seems that a similar mechanism may take place in livestock.The value of the renal plasma clearance coefficient for sodium, potassium and chloride in goats, sheep, cattle and horses is presented in **Table 3**.

The value of renal plasma clearance coefficient for electrolytes change over a 24 hour period. In goats (Muszczynski, 1995), diurnal rhythms for sodium renal plasma clearance range between 0.08 and 0.35 ml/min/m^2; for potassium between 7.86 and 14.40 ml/min/m^2; and for chloride between 0.65 and 1.24 ml/min/m^2, with the acrophases in the day. The lowest values for the examined ions were observed at night. A similar trend was observed in goat kids: 'day-night' differences in renal plasma clearance of sodium, potassium and chloride ions were significantly lower in the evening than in the morning (Vogel, 1962) (**Table 2**). Many studies on various mammalian species (livestock, rats, humans) suggest that the circadian variation of plasma clearance of electrolytes is influenced by various factors. Apart from the duration of light and dark phases, the outer controller of the rhythm could be the time of meals during the day (Stoynev and Ikonomov, 1983), which modifies only the amplitudes of the circadian rhythms (Muratani *et al*., 1985). Undoubtedly all the aforementioned factors, especially sleep-activity phases, modify the rhythms of excretion of osmotically

Table 3: Mean values (or range of values) of tubular resorption and secretion and electrolyte (sodium, potassium and chloride) excretion in urine in some species of livestock. P – plasma level (mmol/l); C – clearance (ml/min/m^2); F – filtered load (mmol/min/m^2);TR – tubular resorption (%); and, U*V – excretion in urine (μmol/min/m^2).

	Sodium					
	P	C	F	TR	U*V	References [n - numbers of animals]
goats		0,1		99,9		Vogel (1962); [n=12]
	135-145					Muszczynski (1995); [n=12]
goat kids	143-149			97.3-99.5	1.19-5.68*	Drzezdzon *et al*. (2001); [n=8]
sheep		0.76		99.9		Vogel (1962)
cattle		0.1		99.9		Vogel (1962)
calves	120-135	0.02-0.51	4.7-6.0			Skrzypczak (1991); [n=10]
				98.5-99.5	0.22-4.3*	Skrzypczak *et al*. (2001); [n=10]
horses		0.1				Vogel (1962)
	Potassium					
	P	C	F	TR	U*V	
goats		25		70.5		Vogel (1962)
	4.5-5.4					Muszczynski (1995)
sheep				90		Vogel (1962)
cattle		80				Vogel (1962)
calves	3.4-4.9	5.31-28.83	0.15-0.21	24-54	26-134	Skrzypczak (1991)
	Chloride					
	P	C	F	TR	U*V	
goats		1.1		99.28		Vogel (1962)
	93-103					Muszczynski (1995)
sheep		1.77				Vogel (1962)
cattle		0.7				Vogel (1962)
calves	91-99	0.16-2.38	3.8-4.5	93-100	23-217	Skrzypczak (1991)
horses		0.38				Vogel (1962)

active electrolytes in urine. Motor activity influences the circadian rhythms of both synthesis and release of certain hormones (e.g., vasopressin, vasoactive peptides, renin-angiotensin-aldosterone and melatonin), which are direct cellular regulators of electrolyte absorption and secretion. It seems that the circadian rhythms of renal excretion of electrolytes are a consequence of diurnal changes in GFR and the volume of the filtered load. Resorption and secretion processes in the tubules may modify these changes, however not significantly (Koopman *et al*., 1989).

Renal water excretion

Electrolyte balance is closely connected with water balance, so any changes in electrolyte excretion are followed by changes in renal water economy. In mammals active during the day, the amount of excreted urine is lowest at night (in the rest phase) and the amplitude of changes lowers. During the day, diuresis increases (Muratani *et al*., 1985; Koopman *et al*., 1989; Skrzypczak *et al*., 1992a; Muszczynski, 1995).

In goats' excretion of water with urine, the osmotic clearance and free water clearance change diurnally, with an acrophase in the day and batyphase at night (Muszczynski 1995) (**Table 2**). In humans, the acrophase of water excretion with urine also takes place in the day (Muratani *et al*., 1985; Aslanin *et al*., 1989), with a certain similarity between circadian changes in diuresis and changes in electrolyte excretion.

Goat kidneys show a great ability in concentrating and diluting urine, the maximum urine osmolality being about 1100 mmol/kg H_2O. This value is lower than those observed in cattle and sheep, but significantly higher than those in pigs (Ketz, 1960; Vogel, 1962) (**Table 1**). In four-week-old goat kids, there are certain differences in 'day-night' diuresis (with minimum values in the day and minimum values at evening) and 'day-night' urine osmolality (with minimum values in the day and minimum values at night) (Vogel, 1962) (**Table 2**). In adult goats, there are some changes in urine osmolality, showing a negative correlation with the changes in diuresis (Muszczynski, 1995) (**Table 2**). In calves, the diuresis diurnal rhythm is usually consistent with changes in glomerular filtration (Skrzypczak *et al*., 1992a), which is in accordance with the earlier data found in humans (Koopman *et al*., 1989).

It seems that GFR is not the only reason for diuresis circadian rhythms. Water excretion with urine could also be influenced by the level of the intake of liquids, changes in body posture and endocrinic factors (George *et al*., 1975; Asplund and Aberg, 1991; Van Acker *et al*., 1993; Boemke *et al*., 1995; Branderberger *et al*., 1998; Skotnicka and Hlynczak, 2001; Skotnicka 2003, 2005). Undoubtedly, an increase in diuresis during the active phase (day) and a decrease during rest (night) are consequences of a change in the concentration of antidiuretic hormones that reach kidneys at night, mainly vasopressin (and/or melatonin).

Blood plasma electrolytes

One of the consequences of renal filtration, resorption and secretion is the electrolyte concentration in blood and plasma osmolality. The blood plasma electrolyte concentration in adult livestock is relatively stable (**Table 3**). However, two-week-old calves show certain diurnal variation and the acrophases of sodium and potassium concentration in blood plasma are very different. At about 20:00hr and 08:30hr, respectively, the chloride concentration in plasma is, however, relatively stable (Skotnicka *et al*., 1997). Diurnal rhythm in potassium concentration, both in livestock and humans, has been reported by other authors (Kanabrocki *et al*., 1973; Bernardi *et al*., 1985; Koopman *et al*., 1989; Solomon *et al*., 1991; Branderberger *et al*., 1994, Muszczynski, 1995; Skotnicka, 2003).

Muszczynski (1995) and Skotnicka (2005), in goats, and Skotnicka *et al*. (1997), in calves, did not observe diurnal changes in plasma osmolality. However Skotnicka (2005), in a study on pregnant goats, observed significant plasma osmolality differences between maximum (in the evening) and minimum (in the morning). Many published studies of diurnal blood plasma electrolyte concentrations and plasma osmolality show the influence of other factors such as age, sex, physiological state and feeding (time, type of food, water availability) on the rhythmic periodicity.

Conclusion

The values of renal activity parameters (e.g., ERBF, ERPF, GFR, F, TR, U*V) are very different among livestock species and increase with animal age and kidney development. Changes in renal activity in livestock are mostly diurnal rhythms, with distinct periods, acrophases and different amplitudes.

Most renal activity indices have maximum values during the day and minimum values at night. Diurnal changes in renal activity (values of ERBF, ERPF, GFR, F, TR, U*V), with the relatively stable composition of blood plasma, seem to confirm the adaptational character of the rhythms. Through changes in GFR, diurnal changes in resorption and tubular secretion intensity, as well as changes in ultimate urine composition, kidneys make it possible for an organism to adapt to changing environments (also diurnal changes).

Detailed knowledge of renal diurnal rhythms is useful for clinical, practical and, especially, pharmacological purposes and studies on physical performance. Chronobiological studies are extremely important for veterinary medicine, not only for the application of better therapy and for more reliable interpretation of experimental results, but also for controlled and economical development of livestock productivity.

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