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Expanded abstract

Seasonal effects of diet on serum and urinary nitrogen in muskoxen

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Urea and creatinine concentrations in serum are commonly measured as indicators of renal function in clinical settings and as indices of nutritional status in wild ruminant populations. Creatinine is produced during muscle catabolism and blood levels are generally proportional to an animal's muscle mass, while urea is the end product of nitrogen metabolism and more closely reflects protein intake (Saltz and White 1991). Urinary creatinine can be used as an index of concentration when comparing urine samples because it is freely filtered at the glomerulus and excretion is relatively constant. Serum levels of urea and creatinine in captive muksoxen appear to be higher than those reported for domestic ruminants (International Species Inventory System), suggesting that muskoxen may have an unusal capacity to recycle and/or store nitrogen.

This study was undertaken to investigate these metabolites further in relation to renal function and diet in muskoxen. Seasonal serum and urinary levels of urea and creatinine were measured in 9 captive muskoxen (mature females and castrated males) on a relatively constant diet during 1990-91 and in wild muskoxen (males and females, 2+ years of age) from Victoria Island, Canada, during 1989-91. Nitrogen levels in dried rumen contents were used as an index of seasonal protein intake in wild muskoxen. Glomerular filtration rate (GFR) was also measured in 2 captive muskoxen in June 1991.

Captive muskoxen housed outdoors near Saskatoon were fed a standard brome grass hay of approximately 11 % protein and a pelleted supplement throughout sampling periods (Adamczewski *et al.* 1991). Animals were weighed every 2 weeks and subjected to health examinations monthly. Data from 3 animals were excluded from this study due to illness. Blood samples were drawn through jugular catheters and free-catch urine samples were collected opportunistically the same day. Two mature females were given single intravenous injections of inulin (25 mg/kg) and para-amino hippuric acid (PAH) (12 mg/kg) after which blood samples were taken over 5 hours. Calculated clearance rates of inulin and PAH represented GFR and effective renal plasma flow (ERPF), respectively (Brewer *et al.* 1988).

Wild muskoxen were bled immediately after being shot and urine was collected several hours later cystocentesis. Carcass and kidney (parenchymal) weights were obtained. Grab-samples of rumen contents were freeze-dried and analysed for nitrogen (dry matter basis) by the Kjeldahl procedure.

All samples were kept chilled or frozen until assayed. Standard analyses for urea and creatinine were performed at the clinical pathology laboratory, Western College of Veterinary Medicine, Saskatoon, and urine specific gravity was measured using a refractometer.

In wild muskoxen serum and urinary urea concentrations changed seasonally paralleling changes in rumen nitrogen levels, carcass weights and kidney weights. Rumen nitrogen levels peaked in July, at 5.5 %, and were approximately half that throughout winter. Carcass weights peaked in August and September (95 ± 7.6 kg) and were lowest in April (65 ± 3 kg; Adamczewski *et al.* 1991). Kidney weights increased from April (240 ± 8 g), to a peak in July (510 ± 20 g). Serum urea concentrations peaked in July at 12 mmol/l and were <5 mmol/l during most of the winter (Fig. 1).

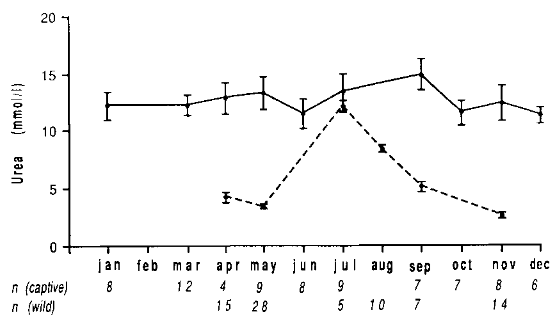

Fig. 1. Seasonal serum urea concentrations in a group of captive adult muskoxen given a standard diet (—) and wild muskoxen from Victoria Island, Canada (---). Vertical bars represent standard errors and sample sizes (captive/wild) are given below graph.

Creatinine levels in serum and urine of wild muskoxen fluctuated seasonally, showing a pattern opposite to that of urea (Fig. 2). Creatinine concentrations rose from July to September when muscle mass, as indexed by gastrocnemius weights, also increased (Adamczeski *et al.* 1991). Creatinine levels peaked in April, however, when muscle mass was lowest, suggesting that muscle catabolism increased as dietary protein diminished. The decrease in kidney size over winter may also have been associated with a compensatory decrease in GFR, thereby decreasing creatinine excretion, and elevating serum levels.

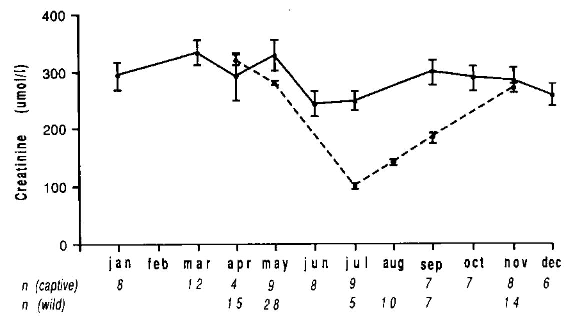

Fig. 2. Seasonal serum creatinine concentrations in a group of captive adult muskoxen given a standard diet (—) and wild muskoxen from Victoria Island, Canada (---). Vertical bars represent standard errors and sample sizes (captive/wild) are given below graph.

Seasonal changes were minimal in the captive muskoxen. Stable serum and urinary urea concentrations (Fig. 1) probably reflected their relatively constant diet. Small changes in creatinine levels (Fig. 2) mirrored changes in body weights which were slightly but consistently lower in June and July (256 ± 15 kg) than in winter (272 ± 13 kg). The lower weights in summer may simply reflect changes in rumen fill, however the association between patterns of weight gain and serum creatinine concentrations indicates that seasonal changes in muscle catabolism of GFR may occur in animals on a relatively constant diet. Bahnak *et al.* (1979) considered season an important factor to be considered when interpreting data on urea and creatinine concentrations.

Serum creatinine levels were higher in captive muskoxen than in wild muskoxen, probably reflecting the higher body weights in captivity. Urea levels were also highest in the captive animals, despite an apparently higher protein intake among wild muskoxen during summer. This may be related to the body condition of wild muskoxen prior to the increased energy demands of lactation during summer (Kirkpatrick *et al.* 1975). White-tailed deer fed on a low plane of nutrition showed a large decrease in urea levels during the last trimester of pregnancy and peak of lactation, but does on a higher quality diet showed no similar decline (Bahnak *et al.* 1979).

Large increases in serum and urinary urea concentrations can occur during starvation. In such situations, the usual correlation of urea with nitrogen intake is reversed, and urea concentrations of over 20 mmol/l (30 mg/dl) after 2-4 weeks of fasting have been recorded in white-tailed deer (DelGiudice and Seal 1988). No evidence of such high urea levels during the time of low dietary protein (when creatinine levels were elevated) was observed in wild muskoxen, suggesting that on Victoria Island, muskoxen do not currently experience periods of extreme malnutrition. This is supported by the finding that body condition of hunter-killed muskoxen on Victoria Island remained good throughout the year (Adamczewski *et al.* 1991).

Renal disease can also cause elevations in serum urea and creatinine concentrations which are typically with changes in urine specific gravity and GFR (Campbell and Watts 1970). Urine specific gravity was similar in both groups of muskoxen and highest when snow was their primary source of water. Urine density in the captive animals ranged from 1.017 g/ml in summer to 1.024 g/ml in winter, and in the wild muskoxen, from 1.024 g/ml to 1.028 g/ml. Although sodium excretion was not measured in this study, captive animals had access to salt licks all year, and likely consumed more sodium than did the wild muskoxen, which would promote water intake and excretion of a more dilute urine. However, the regular seasonal pattern and clinical assessment of the captive animals make disease an unlikely cause of the relatively high blood levels of urea and creatinine in these muskoxen.

Among the captive muskoxen, urinary creatinine concentrations correlated closely with urine specific gravity, as expected, but this relationship was not as strong in the wild muskoxen. Between May and July, urinary creatinine concentrations decreased from 14,000 μmol/l, to 2,000 μmol/l, whereas changes in urine specific gravity were minimal. After death, autolysis may have increased the apparent density of urine, an effect which would likely be most pronounced during the hot summer months when autolysis occured most rapidly. This may explain the relatively high urine density found in association with extremely low creatinine levels in wild muskoxen during July.

In 2 clinically healthy muskoxen GFRs were 0.75 and 0.93 ml/kg/min and ERPFs were 5.4

Table 1. Glomerular filtration rate (GFR) and effective renal plasma flow (ERPF) in muskoxen and domestic ruminants.

	GFR (ml/kg/min)	ERPF (ml/kg/min)
Muskoxen	0.75–0.93	5.4– 6.9
Cattle[a]	1.7 -2.4	11.6–18.6
Sheep[b]	2.1 -2.9	13.9–20.6
Goats[c]	1.9 -2.7	7.5–16.3

[a] Mangelson *et al.*, 1968
[b] Kaufman & Bergman, 1978
[c] Brown *et al.*, 1990

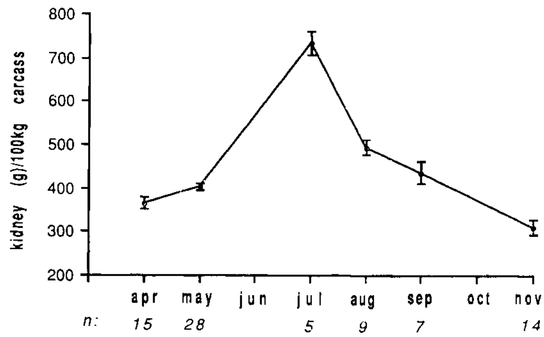

Fig. 3. Seasonal kidney weight (g)/100 kg carcass weight in wild muskoxen from Victoria Island, Canada. Vertical bars represent standard errors and sample sizes are given below graph.

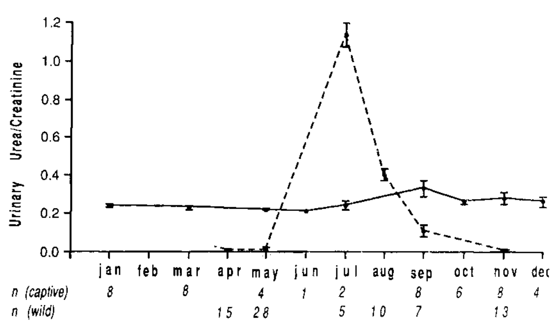

Fig. 4. Urinary urea/creatinine ratios in a group of captive adult muskoxen given a standard diet (—) and wild muskoxen from Victoria Island, Canada (---). Vertical bars represent standard errors and samples sizes (captive/wild) are given below graph.

and 6.9 ml/kg/min (Table 1). These rates are lower than those reported for domestic ruminants (Kaufman and Bergman 1977 and Varma *et al.* 1981), and consistent with a finding of very slow water turnover rate in muskoxen (MacFarlane *et al.* 1971). Seasonal fluctuations in GFR might be associated with the dramatic changes in kidney weight of wild muskoxen, which, when expressed relative to carcass weight (Fig. 3), paralleled seasonal urinary urea/creatinine ratios (Fig. 4). High dietary protein has also been reported to increase GFR in sheep (Ergene and Pickering 1978). Seasonal changes in GFR may be an important adaptation allowing wild muskoxen to excrete large amounts of urea during summer, when dietary protein is plentiful, and to retain nitrogen in the form of urea and creatinine during winter, when protein intake is minimal.

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