RENAL FUNCTION OF CATTLE UNDER VARIOUS WATER AND SALT LOADS

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THE countercurrent theory of kidney function as reviewed by Gottschalk (1960) has contributed to our knowledge of this organ. Ruminant urine is normally alkaline rather than acidic (Dukes, 1955). The normally herbaceous diet of a ruminant places a relatively high potassium load on its kidneys (Anderson and Pickering, 1962). Renal urea re-absorption is important to the ruminant, since blood urea nitrogen can be used in a protein regeneration cycle (Houpt, 1959). It is also possible that water absorption may differ between ruminant and non-ruminant stomachs.

Reported here are four studies of bovine kidney function involving water and saline loading and a 4-day total fast period. Renal excretion of sodium and urea-N, osmo-regulation and renal clearances were studied.

Experimental Procedures

Animals used were yearling Hereford heifers managed individually and adapted to the routine. Urine collections were made via indwelling inflation catheters. Unless otherwise noted, analytical techniques were the same in all experiments.

Experiment 1. Four heifers were used in a changeover design. Treatments were two levels of protein in feed (11.8 and 20.7%) and two water intake levels. Animals were fed at an estimated 150% of maintenance requirements (Garrett et al., 1959). Water treatments were tap water (containing less than 100 mg/liter total dissolved solids) ad libitum, and hydration to give a daily water intake equal to 150% of ad libitum intake with adjustment to metabolic size (W.\textsuperscript{75}). Hydration was by rumen drench at 4 p.m. daily. Each period of the changeover lasted 17 days with hydration and urine collection during the last 7 days. Fecal excretion was estimated by the chromic-oxide grab sample technique (Bolin et al., 1952). Urine analyses were on composite samples. Jugular blood was sampled on the last day of each changeover. Urine and plasma urea-N were determined by the diacetylmonoxime method (Friedman, 1953). The A.O.A.C. (1955) method was used for nitrogen, and urine energy was determined calorimetrically.

Experiment 2. Three heifers were used in a changeover design. Treatments were tap water ad libitum, 1% NaCl water ad libitum, and tap water ad libitum plus drench (as in Experiment 1) to equal the salt water intake of the day. The heifers were fed grass hay at 150% of maintenance requirements. The three treatment periods were 7 days each, with total urine collection at 2-hr. intervals on the last day. For clearance observations a jugular blood sample was taken via an indwelling catheter at the mid-point of each 2-hr. urine collection. Glomerular filtration rates (GFR) were estimated by the endogenous creatinine method of Hare (1950). Osmolalities were determined with a vapor pressure osmometer. The solvent for osmotic pressure measurements was water.

Experiment 3. Four heifers were observed during a 3-day tap water period, followed by 6 days during which the drinking water contained 1.5% NaCl, and then during a 3-day tap water rehydration period. They were fed grass hay ad libitum. Jugular blood was sampled every third day. Hematocrits were determined by capillary tube centrifugation, urine specific gravity by weight per volume, and sodium by flame photometry.

Experiment 4. Eight heifers were divided into two groups which were alternately totally fasted 4 days during autumn. The nonfasted group received alfalfa hay and tap water ad libitum. No shade was provided and maximum and minimum temperatures during fasts averaged 78 and 37°F, respectively. Relative humidity ranged between 50 and 67%. Total urine was collected. For clearance observations blood samples were taken immediately following a 2-hr. urine collection period. Twelve days for recovery were allowed between the changeover periods.

Data were tested by analysis of variance. Differences among treatment means were

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\textsuperscript{2} Journal Paper No. 20.
TABLE 1. HEIFER MEANS* DURING EUHYDRATION AND HYDRATION* ON TWO PROTEIN INTAKE LEVELS*

![Table 1](https://example.com/table1.png)

**Results**

**Experiment 1.** Hydration at 150% of *ad libitum* intake reduced voluntary drinking 35% and caused an 85% increase in urine volume (table 1). During hydration urine volume was 64% of water intake, compared to 49% during euhydration (*ad libitum* drinking). Since there were no differences among treatments in daytime urine volume, it is apparent that the water of hydration (average 10.1 liter per heifer daily) was quickly excreted. Water loading did not affect dry matter digestibility. Heifers absorbed a higher percent of feed nitrogen and were in greater nitrogen balance on the higher protein feed. Water loading and the resultant diuresis did not affect nitrogen balance.

Plasma and urine urea-N concentrations were elevated on the higher protein feed. Water diuresis did not alter plasma osmolality during any of the 2-hr. observation periods. By contrast urine osmolality varied greatly. Coefficients of variation were 29.6, 18.3 and 48.4% for the control, salt water and drench observations, respectively. Salt water raised and drenching lowered the osmolar U/P ratio. With drenching urine osmolality was minimal during peak urine flow and significantly higher from 20

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**Experiment 2.** Pertinent data are summarized in table 2. Water intake was increased by 1% NaCl, and drenching depressed voluntary drinking. Urine volumes were increased 65.4 and 79.2% with salt and drenching, respectively. However, these changes were not significantly different from the urine volume when the heifers were on *ad libitum* tap water intake. When heifers were drenched, peak urine flows occurred during the 2 to 4 hr. postdrench observation. Diuresis was also noted from 0 to 2 hr. and 4 to 6 hr. post-drenching.

Plasma osmolality was very stable, and the coefficient of variation was 1.8% during control observations. There were no treatment differences, and drenching did not alter plasma osmolality during any of the 2-hr. observation periods. By contrast urine osmolality varied greatly. Coefficients of variation were 29.6, 18.3 and 48.4% for the control, salt water and drench observations, respectively. Salt water raised and drenching lowered the osmolar U/P ratio. With drenching urine osmolality was minimal during peak urine flow and significantly higher from 20
to 24 hr. postdrenching. Drenching lowered plasma urea-N concentration. Total urine urea-N excretion was increased 37.1% (P<.05) by 1% salt water, but drenching did not affect total urine urea-N excretion. Total nitrogen excreted in urine was increased 23.8% by the salt water treatment.

GFR, as estimated from creatinine clearance, was 4.29 liters/hr, per 100 lb. body weight when heifers were receiving tap water ad libitum. The differences among treatments were not significant. Water drenching did not affect GFR at any of the clearance periods, even though urine flow averaged 2.2 liters/hr. at maximum diuresis.

Osmolal clearance was increased by the

<table>
<thead>
<tr>
<th>Table 3. Means a for Heifers Drinking Tap Water Followed by Two Periods on 1.5% NaCl Water and Tap Water Recovery Period</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Item</strong></td>
</tr>
<tr>
<td>--------------------</td>
</tr>
<tr>
<td>Body weight, lb.</td>
</tr>
<tr>
<td>Feed consumption, lb./day</td>
</tr>
<tr>
<td>Water consumption, liters/day</td>
</tr>
<tr>
<td>Urine, liters/day</td>
</tr>
<tr>
<td>Urine of water weight, %</td>
</tr>
<tr>
<td>Urine specific gravity</td>
</tr>
<tr>
<td>Urine Na, mEq./day</td>
</tr>
<tr>
<td>Plasma Na, mEq./liter</td>
</tr>
<tr>
<td>Hematocrit, %</td>
</tr>
<tr>
<td>Plasma osmolality, mOsm./kg.</td>
</tr>
<tr>
<td>Urine osmolality, mOsm./kg.</td>
</tr>
</tbody>
</table>

a Experiment 3.

b Treatment periods follow consecutively from left to right, each of 3 days duration.

c, d, e Means on lines 1, 2, 5, 8, 9 and 10 bearing different superscripts are significantly (P<.05) different.  
d, e, f Means on lines 1, 2, 5, 8, 9 and 10 bearing different superscripts are significantly (P<.01) different; means on lines 3, 4, 7 and 11 are significantly (P<.05) different.

drench and salt water treatments, but maximum clearance occurred on salt water. The percent of filtered osmolality reabsorbed was significantly lower with salt water. This is consistent with the increased excretion of urea-N in heifers on salt water. Saline water did not significantly increase the percent of filtered urea-N excreted. However, the trend (47% on saline vs. 39% for ad libitum tap water) does support the observed increased excretion of urea due to salt water.

Experiment 3. The heifers lost 9.5% of their body weight during the first 3 days on hypertonic saline, even though consumption of feed and water was not significantly changed (table 3). After 6 days body weights had decreased 13.7%, and feed and water consumption was reduced. When offered tap water, the animals immediately drank water equivalent to 14.3% of their dehydrated body weight. When the heifers were drinking tap water, urine weight was 30% of water consumed, but with hypertonic saline urine weight was 80% of water consumed. Urine specific gravity was not increased by dehydration. Urine sodium excretion increased markedly during saline dehydration. However, sodium excreted in urine was only 52% of that consumed in water. Hypernatremia was apparent during dehydration. There were no significant changes in plasma or urine urea-N during the experiment.

Hematocrit values were not increased during dehydration. In fact, values were lower after 6 days dehydration than previously. After 3 days rehydration hematocrits were still 19.9% below the initial levels. Erythrocyte concentration at this time averaged 7,560,000/mm³. However, 59% of the erythrocytes were crenated.

Plasma osmolality was significantly increased after 3 and 6 days dehydration. This hyperosmolarity was not reflected in the urine. Maximum urine osmotic pressure attained in a daily collection during salt water dehydration was only 1130 mOsm/kg. Urine osmotic pressure was decreased 37.4% after rehydration.

Experiment 4. The heifers lost 16.1% of their body weight during the 4-day fast. This weight was recovered by 2 days postfasting, although animals were allowed water ad libitum only during the last half day. Urine volume decreased (P<.01) to 37.2% of nonfasting volume after a 1-day fast. The rate of decline was then slower (figure 1), and after 4 days urine volume was about one-tenth of the prefasting level. Urine specific gravity did not increase significantly until the fourth day of fast, at which time it averaged 1.0323.
Hematocrits (table 4) were increased significantly after 4 days fasting (41.4 vs. 34.2%). Erythrocyte concentrations were significantly elevated on day 4 of fast. There was no evidence of crenation.

GFR was $5.51 \pm 0.87$ liters/hr. per 100 lb.

Figure 1. Changes in volume, osmolality and sodium content of urine of heifers during a 4-day fast. Day 0 is a prefast observation. Each point is the mean of eight observations.
### Table 4. Mean responses of heifers to 4 days total fasting followed by 2 days recovery (Experiment 4)

<table>
<thead>
<tr>
<th>Item</th>
<th>Control*</th>
<th>Fast</th>
<th>Control</th>
<th>Fast</th>
<th>Control</th>
<th>Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hematocrit, %</td>
<td>34.7</td>
<td>39.5**</td>
<td>34.2</td>
<td>41.4**</td>
<td>33.1</td>
<td>34.3</td>
</tr>
<tr>
<td>Erythrocytes, mm³ x 10⁵</td>
<td>744</td>
<td>803</td>
<td>706</td>
<td>910**</td>
<td>668</td>
<td>764</td>
</tr>
<tr>
<td>Creatinine clearance, liters/hr.</td>
<td>32.02</td>
<td>24.41**</td>
<td>32.98</td>
<td>22.67**</td>
<td>32.45</td>
<td>16.70**</td>
</tr>
<tr>
<td>Urea-N/U'P ratio</td>
<td>46</td>
<td>144**</td>
<td>45</td>
<td>125**</td>
<td>48</td>
<td>54</td>
</tr>
<tr>
<td>Urea-N/Creatinine clearance</td>
<td>0.78</td>
<td>0.53**</td>
<td>0.70</td>
<td>0.41**</td>
<td>0.63</td>
<td>0.98**</td>
</tr>
<tr>
<td>Plasma Na, mEq./liter</td>
<td>147</td>
<td>151</td>
<td>145</td>
<td>158**</td>
<td>145</td>
<td>144</td>
</tr>
<tr>
<td>Filtered Na reabsorbed, %</td>
<td>99.88</td>
<td>99.93</td>
<td>99.91</td>
<td>97.75*</td>
<td>99.93</td>
<td>98.86*</td>
</tr>
<tr>
<td>Plasma mOsm./kg</td>
<td>285</td>
<td>291</td>
<td>281</td>
<td>306**</td>
<td>282</td>
<td>274*</td>
</tr>
<tr>
<td>Urine mOsm./kg</td>
<td>839</td>
<td>1202**</td>
<td>804</td>
<td>1289**</td>
<td>831</td>
<td>849</td>
</tr>
<tr>
<td>Osmolal clearance, liters/hr.</td>
<td>1.50</td>
<td>0.37**</td>
<td>1.55</td>
<td>0.31**</td>
<td>1.38</td>
<td>0.90**</td>
</tr>
<tr>
<td>Filtered mOsm. reabsorbed, %</td>
<td>95.28</td>
<td>98.46**</td>
<td>95.17</td>
<td>98.59**</td>
<td>95.65</td>
<td>94.41</td>
</tr>
</tbody>
</table>

* Control means are for ad libitum fed and watered heifers observed on same day as fasting or recovering heifers.
** Significantly (P<.05) different from control observation on same day.
§ Significantly (P<.01) different from control observation on same day.

body weight for 32 control observations. This was decreased 23.8% after a 2-day fast and 31.3% after 4 days. At 2 days postfasting it was 48.5% below control rates. This decrease in GFR was caused mainly by a decreased urine creatinine concentration without an appreciable rise in urine volume.

The urea-N U/P ratio was elevated by fasting, because of the increased concentration of urea-N in the urine. The ratio of urea-N clearance to creatinine clearance decreased (P<.01) with fasting. This ratio then exceeded (P<.01) control values after 2 days of realimentation. This suggests that the percent of filtered urea which was reabsorbed was increased by fasting and decreased during recovery.

Plasma sodium was elevated only on the fourth day of fasting. Urine sodium concentrations were significantly (P<.05) higher by the second day of fasting, but total urinary excretion was lower (P<.01) throughout fasting. An average of 99.88±.06% of the filtered sodium was reabsorbed during prefasting. Percent reabsorbed was slightly (P<.05) reduced on the fourth day of fast and after 2 days of realimentation.

Plasma osmolality was significantly increased after a 4-day fast and then lowered (P<.05) at 2 days postfasting. Urine osmotic pressure was increased 43.3 and 60.3% after 2 and 4 days fasting, respectively (figure 1). Osmolal clearance was reduced (P<.01) during fasting and had not returned to control levels after 2 days recovery. The percent of filtered osmolality reabsorbed increased (P<.01) during fasting. There was a gross correlation of 0.80 between osmolar U/P ratio and percent of filtered osmolality reabsorbed. A supporting correlation (0.61) was found between urea-N U/P ratio and percent of filtered urea-N reabsorbed.

**Discussion**

The impetus for these studies was created by the observation (Weeth and Haverland, 1961) that blood urea concentration was reduced 24%, in heifers drinking 1% NaCl water, even though feed consumption was unaffected. Since saline water consumption exceeded tap water, it was believed that there was increased washing out of filtrate urea in cattle consuming the salt water, resulting in lowered blood urea. However, it was shown in the present studies that water diuresis did not increase total urinary excretion of urea or nitrogen. There was no washing out of urea such as Sellers and Roepke (1951) observed with calcium, sodium, chloride and phosphate during water diuresis. These investigators made their observations during peak diuresis following drenching. In the present study water loading increased urea excretion during the first 4 hr., but thereafter excretion decreased so that over a 24-hr. period urea losses were no greater than with ad libitum drinking.

Results were different when the drinking water contained NaCl, providing the concentration was not high enough to cause anorexia. With increased osmolar clearance, the fraction of the osmotic load which was reabsorbed was decreased. When heifers were either drenched with tap water or drank 1% NaCl water, there was a gross correlation of 0.81
between osmolar clearance and urine urea-N excretion. If urea reabsorption in the proximal tubules is by passive back diffusion as theorized by Wesson (1954), it could be expected that an increased osmotic load would increase tubular flow and decrease urea reabsorption. The studies of Shannon (1938) with dogs and Lassiter et al. (1964) with rats demonstrated increased urea excretion during osmotic diuresis. These observations are at variance with the observations of Schmidt-Nielsen et al. (1958) on sheep in osmotic diuresis. They concluded that solute load had little or no effect upon urea excretion.

When heifers were offered 1.5% NaCl water, there was no increased urea excretion, probably because of the anorexia. It was established that dietary protein influences urine urea excretion. It is interesting that plasma sodium and osmolality were no higher after 6 days than after 3 days of saline dehydration. Also, from a comparison of the data in tables 3 and 4, it appears that these indices of plasma tonicity increased more with salt loading than with fasting.

Responses of heifers to a 4-day fast were similar to those noted by Macfarlane et al. (1961) in sheep. However, there are some differences which suggest that the kidneys of cattle are not as efficient as those of sheep during dehydration and solute loading. Fasted sheep increased urine osmolarity to a maximum of 3200 mOsm./liters. In this respect sheep are similar to camels (Schmidt-Nielsen et al., 1956). Maximum urine osmolality in the fasted heifers averaged only 1256 mOsm./kg. The maximum attained in a day's urine collection was only 1566 mOsm./kg. Urine specific gravity in the fasted sheep of Macfarlane et al. (1961) was 1.069. With fasted heifers it reached only 1.0323. Potter (1963) noted that sheep drinking rainwater ad libitum had a urine specific gravity of 1.043 and osmolality of 1610 mOsm./liter; both values are higher than those for fasted heifers.

An animal's ability to maintain osmotic equilibrium depends partly on its ability to reabsorb filtrate water and excrete a high osmolar urine. The bovine kidney responds to water deprivation by reducing urine volume and to a limited extent by increasing urine osmolality. Although direct comparisons have not been made, it appears that Hereford cattle rank below camels, rats and sheep in their ability to tolerate high solute loads (Heller, 1933; Schmidt-Nielsen et al., 1956; Peirce, 1957; Macfarlane et al., 1961; Peters, 1963; Potter, 1963).

Summary and Conclusions

Effects of water loading, sodium chloride loading and 4 days total fasting on kidney function were studied in growing Hereford heifers. Water diuresis did not affect the urine excretion of urea-N or total nitrogen. Peak urine flow occurred between 2 and 4 hr. following drenching. Water drenching did not affect glomerular filtration rate. When the drinking water contained 1.0% NaCl, the urinary excretion of urea-N was increased 37.1% over that of heifers drinking tap water ad libitum, even though feed intake was unchanged. This may be an osmotic effect, since a correlation of 0.81 was observed between osmolar clearance and total urine urea-N excretion.

Hypertonic NaCl (1.5%) drinking water increased the ratio of urine excretion to water intake from 0.31 during euhydration to 0.82 during salt loading. Plasma osmolality increased from control values of 291 to 332 mOsm./kg. during salt loading, and there was marked hypernatremia. Urine sodium excretion increased approximately ten-fold; however, there was no increase in urine osmolality.

Urine volume decreased from a prefast daily level of 2.47 liters to 0.25 liters per 100 lb. prefast body weight after 4 days fasting. Creatinine, urea-N, and osmolal clearances were significantly reduced after 2 and 4 days fasting and were still reduced after 2 days rehydration. Since urine osmolality averaged only 1256 mOsm./kg. after 4 days total fasting, it is suggested that these heifers had a limited ability to conserve water by excreting a high osmolar urine.

Literature Cited

Friedman, H. S. 1953. Modification of the determina-