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MOVEMENT OF URINE IN THE LOWER COLON AND CLOACA OF OSTRICHES[1]

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Abstract. Retrograde movement of urine from the coprodeum to the colon and ceca in birds can be important in the recovery of water and NaCl. Water can be gained both from hypotonic luminal fluid and from hypertonic fluid as long as the rate of Na^+-linked water absorption exceeds the rate of osmotic water loss. If the luminal fluid is sufficiently hypertonic, however, there may be a net water loss. As a consequence, post-renal modification of ureteral urine is particularly important in birds with poor renal concentrating ability. In examining the lower colon and cloaca of the Ostrich (*Struthio camelus*), two opposing possibilities were envisioned: (1) substantial retrograde movement because post-renal modification of urine is vital in the water balance of the Emu and this bird is also a large, flightless ratite; and (2) negligible retrograde movement because Ostriches are able to concentrate their ureteral urine to a much greater extent than emus and, in a previous report, no traces of uric acid were found in the terminal portion of the colon. The cloaca was divided into a coprodeum and proctodeum, but no urodeum was evident. Urine was stored mainly in the proctodeum which acted as a "bladder" and which changed dramatically in size. In eight-week-old chicks, it was 6–8 cm in diameter prior to urination when normally hydrated and 1–2 cm in diameter following urination. Mean cloacal urine osmolality was 395 ± 167 mOsm/kg. Considerable uric acid was observed in the coprodeum of all specimens but only traces were found on or within feces in the terminal 5 cm of the colon. Most of a barium sulfate suspension administered into the coprodeum of an adult Ostrich moved aborad into the proctodeum within 20 min; no orad movement was observed radiographically. A contrast medium injected intravenously into Ostrich chicks was cleared by the kidneys into the coprodeum, then moved immediately into the proctodeum, and was held there until excreted. Urine and feces were excreted separately (urine first) and the birds were coprophagic. We conclude that Ostriches rely mainly on kidney function for final composition of voided fluid.

Key words: Struthio camelus; *retrograde urine movement; post-renal modification; image intensification radiology; coprodeum; proctodeum.*

INTRODUCTION

Retrograde movement of urine from the urodeum into the lower colon and cecae of birds via colonic antiperistalsis (Lai and Duke 1978) is well known (Akester et al. 1967, Ohmart et al. 1970, Duke 1989) and has been described for eight avian orders (Duke 1989). In this way, significant amounts of water and NaCl may be recovered from the urine before it is voided. This post-renal mechanism of conserving water would be particularly useful in birds with colonic luminal fluid hypotonic to plasma. Net water absorption also occurs in the lower colon if the rate of Na^+-linked water absorption exceeds the rate of osmotic water loss (Skadhauge 1981). However, if the ureteral fluid is sufficiently hyperosmotic, retrograde movement would not be beneficial for water conservation since there would be a net loss of water.

Consequently, retrograde movement in the lower colon and post-renal modifications would be most important in birds with a poor renal concentrating ability. Such was found to be the case with the Emu, a large, flightless ratite that inhabits Australian deserts but that can concentrate ureteral urine only up to 1.5 times that of plasma (Dawson et al. 1985, Dawson et al. 1991).

We examined whether retrograde movement

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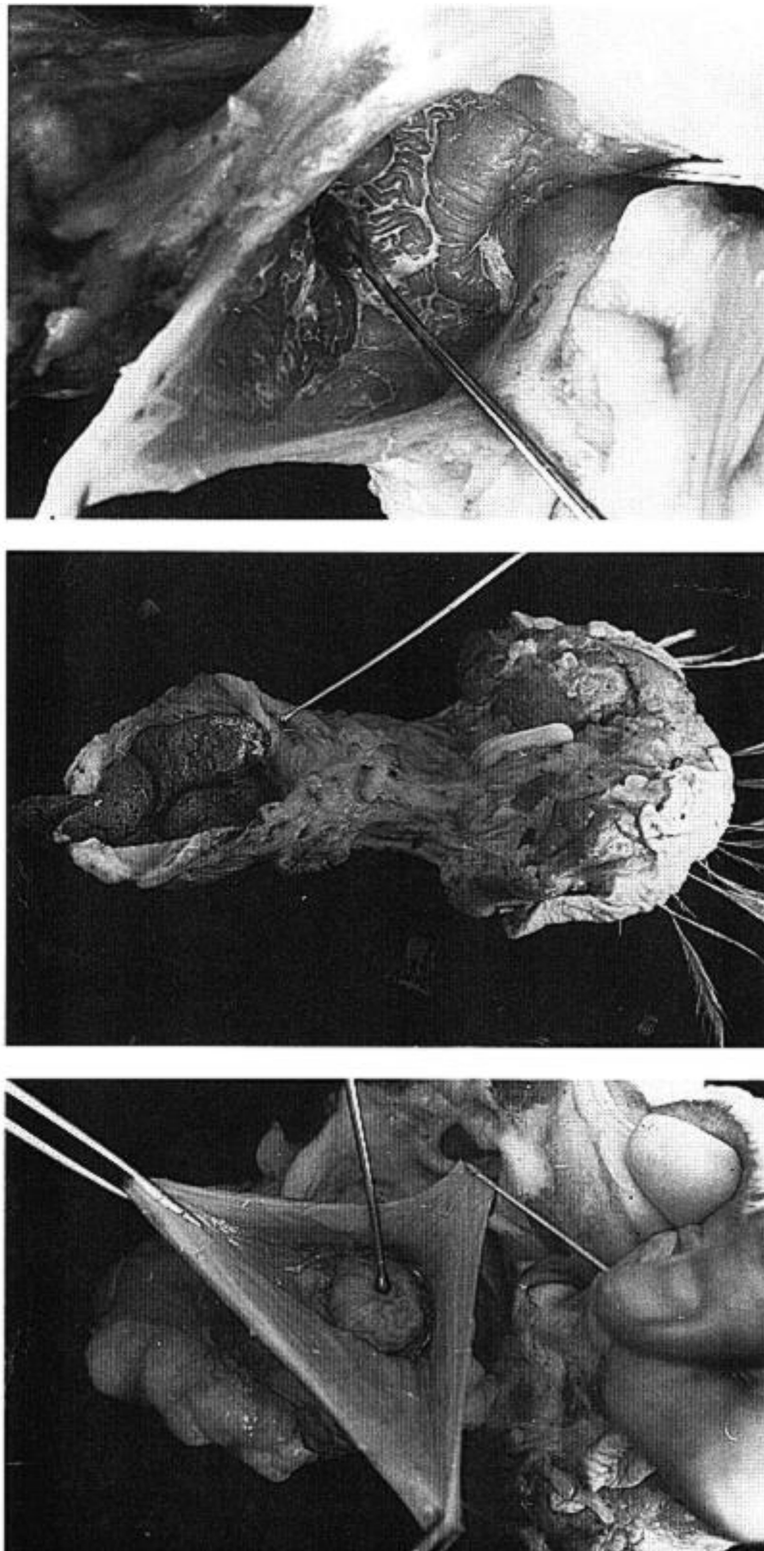

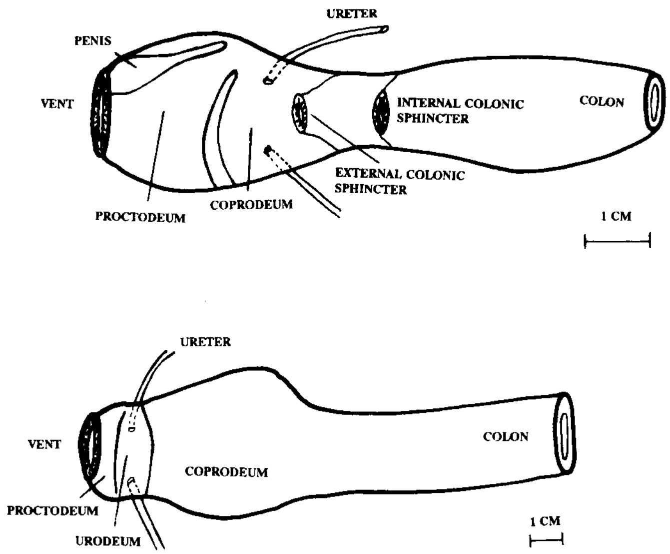

FIGURE 2. Diagrammatic representation of cross-sections of the cloaca and colon of an Ostrich (above) and broiler hen (below) drawn from dissections. Scale in Ostrich was drawn approximately 1:4 and in hen 1:1.

of urine occurs in the lower colon of the Ostrich, also a large flightless ratite that inhabits deserts, but a species which can concentrate its ureteral urine to about 2.7 times that of plasma (Louw et al. 1969). Two opposing possibilities were envisioned. In the first possibility, we expected substantial retrograde movement since post-renal modification of urine is vital in the water balance of the Emu (Skadhauge et al. 1991). In the second possibility, we expected negligible retrograde movement since Ostriches are able to concentrate their ureteral urine to a much greater extent than emus making retrograde movement less necessary in the conservation of body water. Furthermore, no uric acid was observed in the terminal portion of the colon of four adult Ostriches studied by Skadhauge et al. (1984).

METHODS

ANIMALS

Ostriches, 10 months of age and 90–110 kg, were slaughtered in mid-July and used for anatomical examination. They were raised on range in the Negev Desert and, in addition to the natural vegetation, were provided with commercial feed (2 kg/bird daily) and fresh alfalfa. Water was available *ad libitum*. Environmental conditions in the area ranged from 6–8°C in January to 32–34°C in August, with an average rainfall of about 200 mm annually, all during the winter.

Nine young (eight-week-old) Ostriches (10–12 kg), one adult male Ostrich (153 kg) and one adult chicken (broiler hen, 2.5 kg) were used for radiographic studies. Seven of the young Ostriches, the adult Ostrich and the broiler hen were hatched, raised and maintained at the Isan Center, Ben-Gurion University and offered only concentrate feed (Degen et al. 1991). Two other eight-week-old Ostriches on loan from "The Bird House," Prior Lake, Minnesota, were used for image intensification radiology (IIR) at the University of Minnesota, College of Veterinary Medicine. They were also fed only concentrate feed.

GROSS ANATOMY

The lower colon and cloaca were collected from 16 Ostriches at the time of slaughter. Four initial samples were used to visually differentiate and determine the spatial relationships of the coprodeum and proctodeum. These four and 12 sub-

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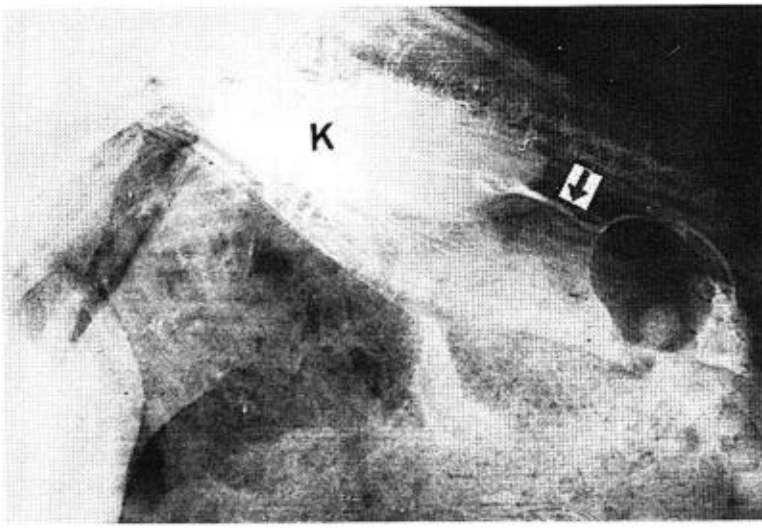
FIGURE 1. Photographs from an adult Ostrich during post-mortem examination showing (upper) uric acid in the coprodeum, (middle) uric acid on feces in the terminal bulbous portion of the colon and (lower) the external colonic sphincter which protrudes aborad into the coprodeum (held open with forceps).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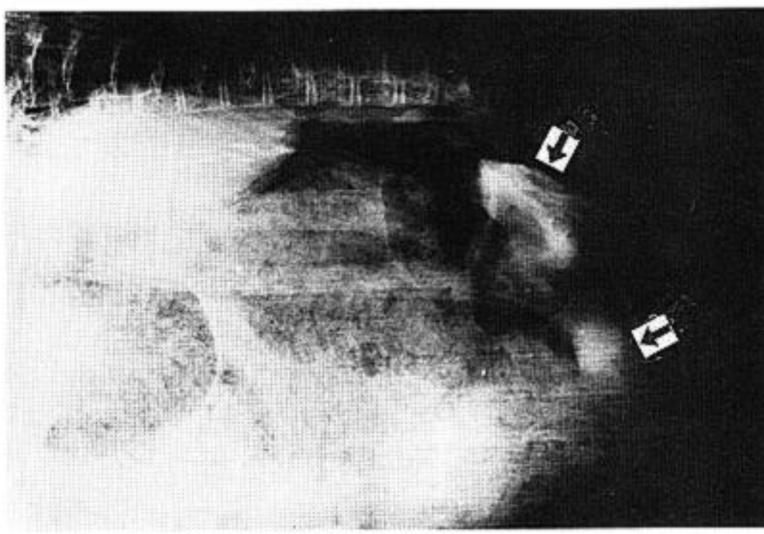

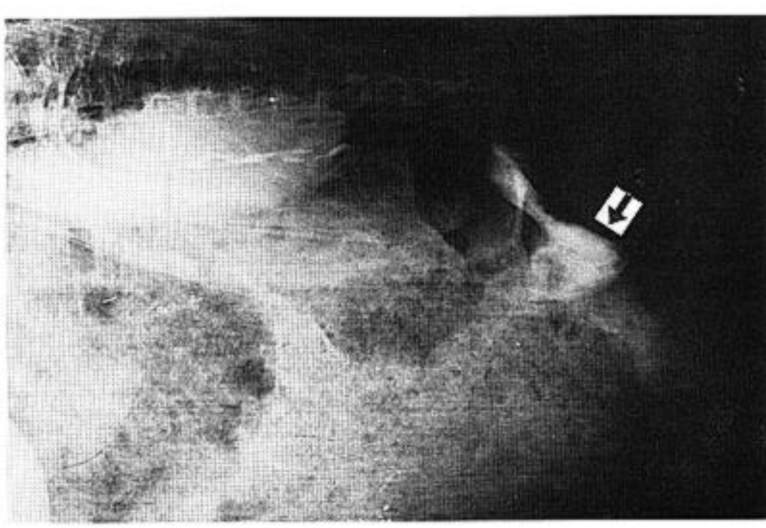

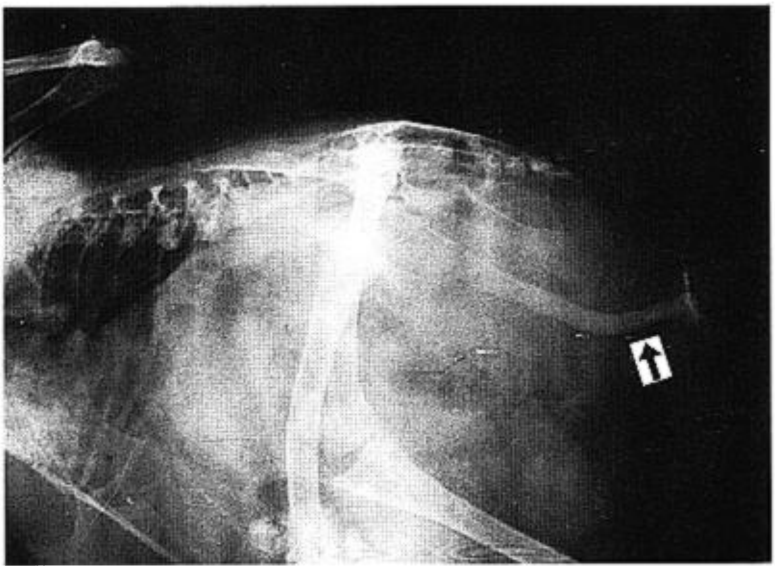

FIGURE 4. Radiograph from a broiler hen showing retrograde movement of contrast medium. The medium has passed from kidneys via ureters to cloaca and refluxed into the colon (arrow).

sequent samples also were used to determine (1) if urine passed into the terminal colon (detected via presence of uric acid) and (2) the distribution of urine between the coprodeum and proctodeum. Chambers were opened longitudinally and the presence of uric acid and urine were noted. In addition, urine samples were collected from 10 cloacae and centrifuged. Total osmolality of the supernatant was measured (Wescor 5100C, Wescor Inc., % Gibbco Scientific, Coon Rapids, MN 55433, U.S.A.).

RADIOLOGY

Serial radiographic observations were employed using a left lateral radiographic view (Philips Medical Systems, Inc., Model 1130, Shelton, Connecticut). A suspension of 25% (w/v) barium sulfate ($BaSO_4$) was administered into the coprodeum of the adult Ostrich and radiographs were taken immediately and after 10 and 20 min. The coprodeum was palpated by inserting a hand through the proctodeum, which is approximately 8 cm in diameter and 10–12 cm deep in adult males. A resistant membrane separated the proctodeum from the coprodeum, but one or two fingers could be inserted over its dorsal surface so that a finger could move anteriorly to touch a sphincter. The latter could not be penetrated. It projects aborad from the anterior coprodeum (Figs. 1, 2) and is readily displaced by efforts to penetrate it with either a finger or a polyethylene tube. A similar sphincter projects orad into the terminal colon. We referred to these as the external and internal colonic sphincters, respectively.

At the Isan Center, chicks received a radiopaque solution (1 ml/kg, Urographin, 60%; Schering AG, Berlin, 13723) intravenously via the posterior tibialis. Two normally hydrated chicks voided this material within 10 min and satisfactory radiographs of its very brief residence in the lower bowel could not be obtained. Subsequently, five chicks were deprived of food and water for 18 hr (15:00 to 09:00) and then

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FIGURE 3. Serial radiographs following injection (i.v.) of contrast medium into an eight-week-old Ostrich showing (upper) all contrast medium is in the kidney (K) and ureters (arrow); ureters connect to the coprodeum; (middle) most contrast medium has left the kidneys, ureters are still partially visible, contrast medium is leaving the coprodeum (arrow) into the proctodeum (arrow), and (lower) membrane separating the coprodeum and proctodeum is clearly evident with most contrast medium in the proctodeum (arrow); the very dark area above the contrast medium in the proctodeum is occupied by the penis.

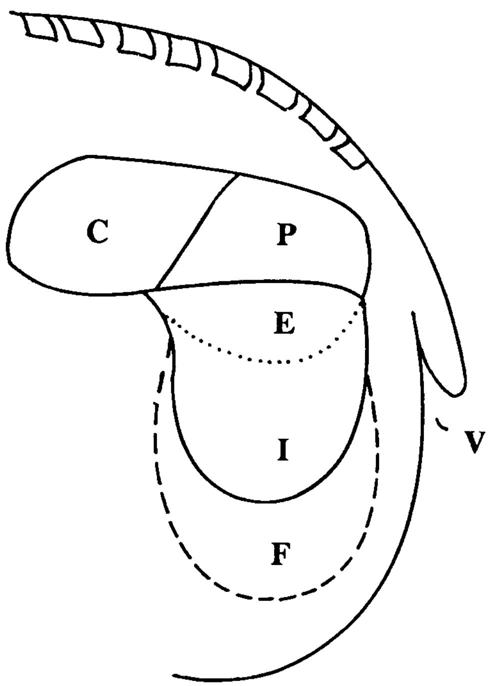

FIGURE 5. Line drawing of a composite of radiographic images showing the relative positions and sizes of the coprodeum (C) and proctodeum (P). The dotted line (E) indicates proctodeal size when empty of urine, the solid line (I) indicates an intermediate filling and the dashed line (F) indicates proctodeal size when full of urine. Vent (V).

injected. Only one of the chicks urinated during the hour after injection of the radiopaque solution. This single urine sample had a very viscous, milky appearance. A series of radiographs at approximately 0, 10, 25 and 40 min after injection were obtained. To verify our methods we applied a similar procedure to the broiler hen in which retrograde flow of urine has been reported (Akester et al. 1967).

Radiologic observations were also conducted by Image Intensification Radiology (IIR) (Philips Medical System, Inc., Model Super M100, Shelton, Connecticut) at the University of Minnesota. IIR allowed continuous video monitoring of the passage of orally administered $BaSO_4$ solution or of feed mixed with powdered $BaSO_4$ and of radiopaque solution (Conray 400, Malinckrodt Medical, Inc., St. Louis, MO 63042) administered via the posterior tibialis vein. Images were also recorded (Panasonic VCR, AC-60105, Secaucus, NJ 07094) on videotape for subsequent analysis. Selected images were captured using a digitization program (MacVision Color Digitizer, SCSI Interface version 1.1 and Mac Vision Image Processing Software version 4.0, Koala Acquisitions, Inc., San Jose, CA 95113), were printed (Laser Writer Pro 630, Apple Computer, Inc., Cupertino, CA 95014) and were photographed.

RESULTS AND DISCUSSION

The terminal colon and the external colonic sphincter form a bulbous projection into the coprodeum (Fig. 1), thus the general anatomy of the Ostrich cloaca is considerably different from that of the fowl (Fig. 2). von Rautenfeld and Budras (1982) and Skadhauge et al. (1984) described a distinct urodeum, coprodeum and proctodeum in the Ostrich. We could not discern a distinct urodeum; ureters emptied into the coprodeum. In chicken, ureters connect to the urodeum and urine must move retrogradely to enter the coprodeum.

Removal and handling of the cloaca and terminal portion of the colon from slaughtered birds generally resulted in some movement of urine back and forth between coprodeum and proctodeum so it was not possible to determine the amount of urine in each chamber. Most uric acid was, however, found in the coprodeum (Fig. 1). A pasty mass approximately 1 × 1.5 × 0.5 cm was found in the coprodeum of one bird. Skadhauge et al. (1984) described the coprodeum as a "cloacal bladder" filled with milky colored urine.

Mean osmolality of the cloacal fluid was 395.4 mOsm/l (SD = 167.5; range = 185–715; $n = 10$), which is approximately 1.2–1.3 times plasma osmolality (assuming plasma osmolality of 300–330 mOsm/l; Louw et al. 1969, Skadhauge et al. 1984, Withers 1983). In general, the urine was relatively clear at low osmolalities (about 200

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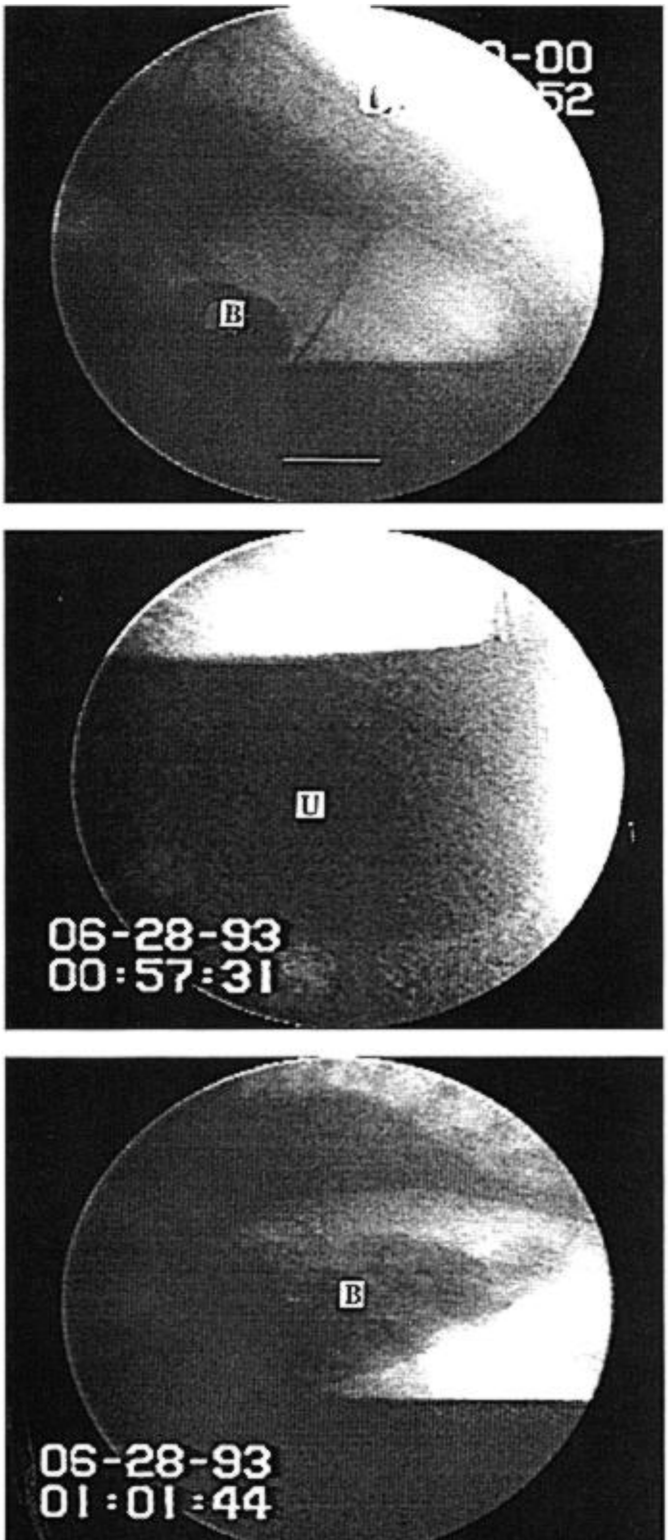
FIGURE 6. Image showing (upper) coprodeum with one fecal bolus (B) and proctodeum partially filled with urine (U), (middle) lower portion of the proctodeum and (lower) coprodeum filled with boli (B) during defecation when the contents are lifted dorsally and moved caudally to eventually be pushed out of the coprodeum and through the proctodeum. The white scale-bar in the upper photograph represents 2 cm.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mOsm/l) and more viscous and milky at higher osmolalities (about 700 mOsm/l). Osmolality was similar to that reported for wild Ostriches (Skadhauge et al. 1984) and fell between that of hydrated and dehydrated domesticated Ostriches (Louw et al. 1969, Withers 1983).

Small amounts of uric acid were found on the surface of (or occasionally within) feces in the terminal colon (Fig. 1). This was not observed by Skadhauge et al. (1984). Of 16 Ostriches we examined visually, three had no evidence of uric acid in the lower colon, five had very minimal traces, two had traces throughout the terminal 5 cm of the lower colon, four had traces in the terminal 2 cm and observations from two birds were discarded due to probable contamination of lower intestine contents during handling.

Most of the $BaSO_4$ suspension administered into the coprodeum of the adult Ostrich moved into the proctodeum within 20 min. Similarly, the contrast medium administered (i.v.) to the Ostrich chicks was cleared from the blood by the kidneys, passed through the ureters and quickly aborad through the coprodeum into the proctodeum within 25–40 min (Fig. 3). Ureters terminated in the distal one fourth of the coprodeum near the dorsal surface. The contrast medium administered to the broiler hen was cleared by the kidneys and, unlike that in Ostriches, moved orad into and throughout the entire colon (Fig. 4). We observed (via IIR) that urine collected in the proctodeum rather than in the coprodeum, as previously described by Skadhauge et al. (1984), and that the proctodeum expanded like a bladder (Fig. 5). Upon urination, the cranial and ventral parts of the proctodeum contracted to move the urine upward and distally through the vent (Fig. 5). IIR observations also showed that fecal boli collected in the coprodeum prior to defecation.

When deprived of water, Ostriches are able to concentrate their ureteral urine to about 800 mOsm or 2.5–2.7 times that of plasma (Louw et al. 1969, Withers 1983). If urine of such concentrations refluxes into the lower colon, net movement of water would be from the plasma into the colonic lumen resulting in an overall loss of body water. Therefore, urinary reflux would be undesirable for the water balance of these birds. Net water absorption can occur in the lower colon if the rate of Na^+-linked water absorption is greater than osmotic water loss. Dehydrated fowl are able to achieve a net water gain until luminal fluid osmolality reaches 480 to 530 mOsm or a plasma to lumen osmolality difference of 180 mOsm/kg (Binslev and Skadhauge 1971).

Indeed, free-living Sand Partridges and Chukars, two desert phasianids, excreted fluids which were similar in osmolality to their respective ureteral urine when the ureteral urine osmolality was considerably higher than that of plasma, indicating little post-renal modification and that little (if any) urinary reflux (Thomas et al. 1984) occurred. In House Sparrows, urinary reflux was greatly reduced during dehydration when compared to hydrated birds. Ureteral urine in the dehydrated sparrows reached 826 mOsm/kg about 2.06 times that of plasma (Goldstein and Braun 1988). In our study, only 18 hours of water deprivation (including night-time when they do not drink anyway; Degen et al. 1989) was sufficient to stimulate water conservation and the excretion of a viscous, milky fluid.

Ostriches urinate then defecate, whereas other birds excrete a mixture of urine (or uric acid) and feces (Duke 1989). Separate excretion of urine and feces by Ostriches is probably a result of the anatomy of the terminal bowel since urine in the proctodeum must be emptied before feces from the terminal colon and/or coprodeum can be voided. Both adult and immature Ostriches are coprophagic; presumably this allows recovery of some water from feces as well as providing nutrients made available by microbial activity in the lower bowel.

We conclude that in the Ostrich: (1) the proctodeum contains most of the urine and acts as a bladder; (2) retrograde movement of urine in the lower intestine is negligible; and (3) the final composition of voided fluid is mainly a consequence of kidney function and little, if any, postrenal modification occurs.

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