

## Water Recycling in Lactation

**Abstract.** During lactation, female rodents, dingoes, and kangaroos consume urine and feces excreted by the young. Studies with tritiated water as a tracer for native water showed that roughly one-third of the water secreted as milk was returned to the mother. The results are cogent to studies of water balance of lactation and to current methods used for estimating milk production.

Because desert mammals have limited access to free water under natural conditions, their water metabolism has received considerable attention. However, the water balance of lactating females has been largely ignored, although there is some evidence that lactation is accompanied by an increase in water turnover (1).

We have been studying desert mammals to determine the extent of the burden that lactation places on the water balance. In doing so, we have found that much of the water that is lost from the mother in milk secretion is returned to her through consumption of the urine and feces of the young.

Milk production was estimated by frequent, successive determinations of loss of injected tritiated water (THO), a technique that has been found to be valid for lambs (2) and calves (3). Tritiated water was injected into suckling young, and its rate of turnover was measured. This rate was equated with water turnover of the young; and since milk is the only water supply for the young, the milk production of the mother is derived. When this technique was applied to the young of the rodents *Notomys alexis*, *N. cervinus*,

*N. mitchellii*, *Pseudomys australis*, and *Mus musculus*, the dingo *Canis familiaris dingo*, and the macropod marsupials *Macropus robustus* and *M. giganteus*, it was found that THO appeared in the maternal bloodstream and milk within a few hours.

Close observation of the rodents and dingoes showed that, during suckling, the mothers spend a great deal of time licking the anal and urethral areas of the young. This action elicits defecation and urination in the young, and the mothers immediately consume the urine and feces.

A revised experimental procedure was adopted for rodents and dingoes to determine whether the excreted water taken in by the mothers contributed significantly to water economy. Here, all but one of the litter young were injected with THO, and the tritium in the body fluids of mother and young was then followed. The model on which the analysis is based is shown in Fig. 1, and typical activity curves for rodents and dingoes are shown in Fig. 2. From these data it is possible, with the use of a few assumptions, to calculate the approximate milk production and water uptake from the urine and feces of the young by the mother.

Let the quantity of THO at  $t$  days after injection be  $a_t$  in the mother,  $b_t$  in each injected young, and  $c_t$  in the uninjected young. Hence  $a_0 = c_0 = 0$ . The rate of decline of THO in the injected young should be less than would be expected if no THO entered via the mother's milk. If it is assumed that all juveniles receive the same quantity of THO through the milk, then each injected juvenile contains  $c_t$  units of THO from milk. Hence each injected juvenile would contain  $b_t - c_t$  units of THO if no extra THO had entered from the milk. Hence the water turnover (in milliliters per day) of each injected young would be given by

$$Q \left( \frac{\ln b_0 - \ln (b_t - c_t)}{t} \right)$$

where  $Q$  ml is the total body water (TBW) of the juvenile. This equation assumes that  $Q$  remains constant (4). The TBW of the young did increase, and the water loss was calculated from the formula suggested by Nagy (5),

which assumes that the rate of change of body water is constant. Thus water lost (in milliliters) per day is equal to

$$\left[ \frac{b_0 - (b_t - c_t)}{Q_0} - \frac{b_t - c_t}{Q_t} \right] \left[ \ln b_0 - \ln (b_t - c_t) \right]$$

where  $Q_t$  is the TBW of the injected young at time  $t$ . Then water intake is represented by

$$\text{water lost} + (Q_t - Q_0)$$

The amount of THO that has entered the mother over the first 24 hours has been derived entirely from urine and feces from the injected young, and therefore it indicates the quantity of water she has derived from that source. After 24 hours, the mother contains  $a_1$  units of THO and has secreted, in milk,  $c_1$  units of THO to each young. Hence at least  $a_1 + nc_1$  (where  $n$  is the number of young in the litter) units of THO have entered the mother over the first 24 hours. Thus, over the first 24 hours the water taken up by the mother from the young is (in milliliters per young)

$$\frac{a_1 + nc_1}{b_0} (n - 1)$$

This amount is an underestimate because additional THO will have entered the mother and will have been lost to the environment.

The values in Table 1 were obtained by applying the above calculations to the THO activity curves shown in Fig. 2 (6). The results show that about

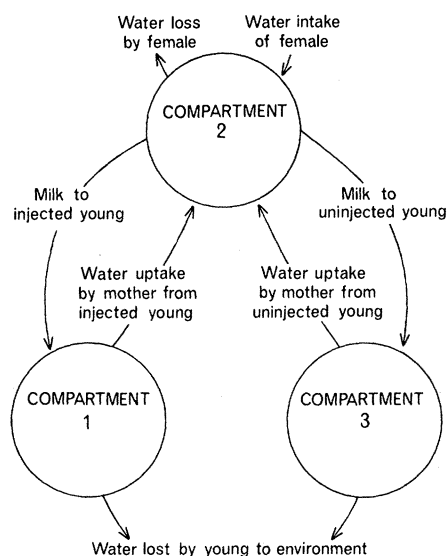


Fig. 1. Model showing the proposed routes of exchange of water during recycling. Compartment 1 is the TBW of the injected juveniles; compartment 2 is the TBW of the lactating female; and compartment 3 is the TBW of the uninjected juvenile.

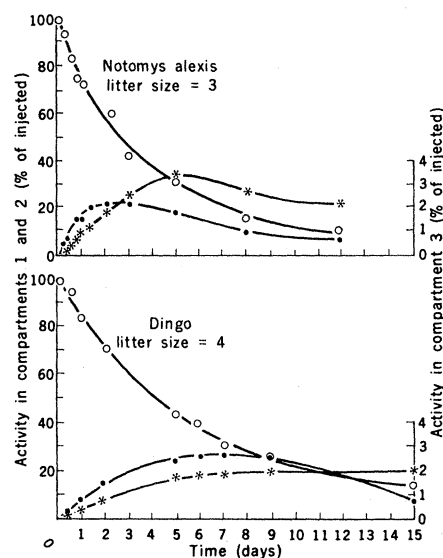


Fig. 2. Observed activity curves, expressed as a percentage of the activity injected, in compartments 1 (○), 2 (●), and 3 (\*) in lactating *N. alexis* and the dingo. Note the expanded scale for compartment 3.

Table 1. Milk output and urine uptake by lactating females during a 24-hour period.

Species	No. in litter	Water (grams per young)			Milk recycled (%)	Water lost by young recycled (%)
		In milk	Total lost by young	Uptake of excreted		
<i>M. musculus</i>	3	0.89	0.43	0.34	38	79
<i>N. alexis</i>	3	1.46	0.80	0.46	32	58
Dingo	4	95.3	67.7	31.8	33	47

50 percent of the total water lost by the young is retrieved by the mother.

Since the kangaroos had only one pouch young each, the revised experimental procedure could not be employed. However, recycling of water is clearly indicated, as approximately 5 percent of the injected THO was present in the mother after 24 hours and 10 percent after 48 hours. Several conclusions may be drawn from our study.

1) In desert species in which it occurs, water recycling is likely to be important in the water economy of a lactating female under natural conditions. The osmotic concentration of the urine of suckling young is well below that of urine which the mother is able to produce (roughly one-fifth in *N. alexis* and one-third in dingoes). Consequently, the solutes contained in the urine of the young can be excreted by the mother in a smaller volume of water, leaving free water available to the mother. For example, lactating *N. alexis* with litters of four were found to consume no more water than non-lactating adults, and restricting the amount of drinking water of the lactating animals to half the amount taken when water was freely available did not significantly affect the growth rates of the young. In addition, one female *N. alexis* receiving only seed containing 10 percent free water and no drinking water successfully reared a single young while maintaining her own body weight. In the dingo, bitches that were lactating consumed only 25 percent more water than when they were pregnant (842 ml/day prepartum and 1056 ml/day postpartum), and this difference would not be sufficient to cover the increased water losses in milk secretion.

2) In animals that recycle water, milk production cannot be estimated by the THO procedure in the usual manner. At least one control young must be used so that the quantity of THO present in the injected young that is derived from milk can be determined.

3) Milk production in animals that recycle water cannot be determined by weighing the female and the young

immediately before and immediately after a short period of lactation. This method has been used frequently in studies of the effects of hormones and drugs on lactation in laboratory animals (7), particularly in rats and rabbits, and may lead to serious errors of interpretation of results. We have found that lactating *Rattus norvegicus* do recycle significant amounts of water. However, lactating rabbits do not appear to do so. The absence of recycling in rabbits may be related to their reduced maternal behavior.

The appearance of water recycling in many species suggests that its function is not primarily that of water economy. The behavior pattern may have evolved for "nest" hygiene, or as a means of communication, by which the mother receives information about the physiological state (such as age) of the young

via the composition of the urine. Thus, in desert species the saving of water by recycling during lactation is seen as probably a by-product of a behavior pattern that has evolved for some other purpose.

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#### References and Notes

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6.  $\bar{Q}$  was estimated from the dilution of a known amount of THO injected into mothers and young and averaged 67 percent of the body weight for *N. alexis* and the dingo.
7. A. T. Cowie and J. S. Tindal, *The Physiology of Lactation* (Arnold, London, 1971).
8. We thank Dr. C. H. S. Watts for constructive criticism and Miss A. Olnier, Mrs. L. Spencer, Mr. J. Lemon, and Mr. K. Newgrain for excellent technical assistance. Mr. F. Knight drew the diagrams.

27 February 1974; revised 18 October 1974

## Stroke in Rats Produced by

### Carotid Injection of Sodium Arachidonate

**Abstract.** *Unilateral cerebrovascular occlusion was produced in heparinized rats within 60 seconds after an injection of sodium arachidonate (in doses exceeding 0.45 milligram per kilogram) into the carotid artery. Electroencephalographic activity over the affected cerebral hemisphere was suppressed, and cerebral blood flow decreased by half. Microscopic examination revealed complete obstruction of the hemispheric microcirculation by platelet aggregates.*

Platelet aggregation is a fundamental component of thrombus formation in atherosclerotic cerebrovascular disease (1). Pathologic evidence indicates that platelets adhere to ulcerated atheromata because of local factors in the diseased artery (2); however, the degree to which intravascular humoral agents participate in the involvement by platelets remains to be precisely defined. Recent work has shown that arachidonic acid when injected into the ear veins of rabbits causes sudden death, associated with occlusion of the microcirculation in the lungs by platelet aggregates (3). Additionally, labile endoperoxide intermediates generated during the endogenous conversion of

arachidonic acid into prostaglandins  $E_2$  and  $F_{2\alpha}$  have been shown to act as powerful biochemical triggers of platelet aggregation in vitro (4). These experimental findings suggested that intracarotid injection of arachidonate might produce acute cerebrovascular occlusion and thus serve as a model for investigating the pathogenesis and treatment of stroke.

To explore this possibility, 35 adult male albino rats of the Sprague-Dawley strain (150 to 175 g) were curarized (5) under light chloroform anesthesia and mechanically ventilated on room air via a tracheostomy. After intravenous injection of heparin (6), the left external carotid artery of each rat