Milk Intake of Suckling Kittens Remains Relatively Constant from One to Four Weeks of Age\(^1,2\)

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**ABSTRACT** The daily milk intake of 14 domestic short-haired kittens (*Felis catus*) from five litters was estimated during wk 1–4 postpartum using the isotope dilution technique. Kittens received a single intraperitoneal injection of tritiated water, and blood samples were obtained from the jugular vein for radioactivity measurements at 2 and 96 h after injection. One kitten in each litter was used as a control to allow calculation of recycling of tritiated water. The mean (± SEM) biological half-life of tritiated water in the kittens increased from 2.4 ± 0.1 d in wk 1 to 4.9 ± 0.2 d in wk 4 postpartum. Recycling of tritiated water accounted for (mean ± SEM) 5.9 ± 0.8, 12.0 ± 0.5, 7.7 ± 1.3 and 10.0 ± 1.3% of the kittens’ daily water intake during postnatal wk 1–4, respectively. Daily milk intake of the kittens during wk 1–4 postpartum was 47.3 ± 8.8, 47.4 ± 1.5, 48.7 ± 1.6 and 43.7 ± 2.0 g, respectively. There was no effect of gender on milk intake. The daily metabolizable energy requirement of suckling kittens, estimated by multiple regression analysis, was 356 kJ/kg\(^{0.75}\), whereas the metabolizable energy required per gram of gain was estimated to be 7.8 kJ/d. The milk intake of suckling kittens remained relatively constant throughout the first 4 wk of lactation, and during this period, they seemed to have a lower energy requirement for maintenance. J. Nutr. 130: 77–82, 2000.

**KEY WORDS:** • cats • milk intake • tritiated water • water turnover

Knowledge of milk intake by neonatal mammals is of basic biological interest and is required for the estimation of daily nutrient intake during this period of an animal’s life. Additionally, accurate data on milk intake of young animals allow the milk energy output of the lactating female to be calculated.

Milk intake of suckling young has been measured indirectly by comparison of growth rates of suckling and formula-fed young (Buss and Voss 1971), and by weighing the young several times a day over an extended period before and after suckling (Mundt et al. 1981, Pettigrew et al. 1985). A more direct approach for measuring milk intake can be obtained by the water isotope dilution (WID)\(^5\) technique. This method uses an isotope of hydrogen (such as \(^2\)H or \(^3\)H) as a tracer to estimate body water turnover; together with accurate information on the composition of milk and body weight gain of the young, this allows estimation of milk intake (Coward et al. 1982, Fjeld et al. 1988, Pettigrew et al. 1987). A major advantage of the WID technique over the weigh-suckle-weigh (WSW) technique is that there is only minimal disruption of the normal maternal-offspring relationship. Furthermore, the WSW technique has been shown to underestimate milk consumption by up to 12% in pigs (Pettigrew et al. 1985), 15% in human infants (Butte et al. 1983), and 30% or more in dogs (Oftedal 1984) and mice (Baverstock and Elhay 1981).

Recently, Dobenecker et al. (1998) used the WSW method to estimate milk yield of queens nursing different sized litters over the first 9 wk of lactation. These authors estimated the degree of underestimation of the kitten’s milk intake to be ~20–25%, based on the difference in growth rates during the measurement period and when suckling normally. Jayawickrama et al. (1998) used the WSW technique and reported milk intake of 20–32 and 54–71 g/d by kittens suckling on queens fed diets containing 10 and 20% fat, respectively. To our knowledge, direct measurements of milk intake in kittens during the suckling period using the isotope dilution technique are not available.

Given the known problems associated with the WSW method, we decided to use the isotope dilution technique to increase the accuracy of estimates of milk and nutrient intake in suckling kittens. Milk intake of kittens during the first 4 wk of life was studied using tritiated water (THO) as a marker. Furthermore, at the end of the main study, the accuracy of estimates of milk and nutrient intake in suckling kittens was improved by comparison of growth rates of suckling and formula-fed young, and by weighing the young several times a day over an extended period before and after suckling. The results of this study support the use of WID as a technique for measuring milk intake in kittens.
WID technique in estimating milk intake was assessed by tube feeding six kittens over a period of 48 h.

**MATERIALS AND METHODS**

The studies reported here complied with the Massey University Code of Ethical Conduct for the use of Live Animals for Teaching and Research (Anonymous 1992).

**Animals, housing and diets.** Five lactating domestic short-haired queens (Felis catus) and their offspring were maintained in standard metabolism cages (described in Hendriks et al. 1999) normally used for the rearing of kittens in a closed colony (Heinz-Wattie’s Companion Animal Nutrition Research Unit, Massey University, Palmerston North, New Zealand). All queens had been vaccinated against feline rhinotracheitis, calicivirus and panleukopenia using a modified live vaccine (Felocell CVR, Norden Laboratories, München, Germany). Feline leukemia and feline immunodeficiency virus have not been detected in the colony since its establishment in 1976. One queen gave birth to three kittens and four queens gave birth to four kittens. The range in body weights of the 19 kittens (10 males and 9 females), measured within 24 h after birth, was 100–140 g (mean ± SEM, 120 ± 2 g). On postnatal day 3, the kittens in each litter were weighed accurately and a sterile microchip (Life Chip, Animal ID Electronic Systems, Kiama, NSW, Australia) was inserted subcutaneously for individual identification before subsequent experimental procedures such as weighing, injection of tritiated water and blood sampling. The queens were given free access to a homogenized mixture of moist canned cat foods and lactose-free milk throughout the study. Table 1 shows the analyzed composition of the mixture of canned cat foods and the lactose-free milk. Fresh drinking water was available at all times. The body weights of the queens and kittens were recorded at regularly preset intervals throughout the study.

**Experimental procedures.** The queens and their offspring were considered healthy on the basis of clinical examination and hematologic status before the start of the study. In the morning of postnatal days 3, 10, 17 and 24, each kitten was weighed and given an accurately weighed amount (~2 mL/kg body weight) of sterile isotonic (9 g/L) saline containing 25 mCi (925 MBq)/L of THO (Life Sciences Technologies, Auckland, N.Z.) by intraperitoneal injection. In each litter, one blank kitten served as a control for the calculation of recirculation of THO, due to the uptake of kittens’ urinary and fecal water by the queen (Baverstock and Green 1975); that kitten, therefore, received only an intraperitoneal injection of sterile isotonic saline. After injection, the kittens were physically separated from the queen for 2 h to allow full equilibration of the injected isotope and to prevent any water exchange between the queen and the kittens. After the 2-h equilibration period, a blood sample from the jugular vein was taken from each kitten using a 1-mL syringe mounted with a 27-gauge needle; the kittens and queen were then returned to the metabolism cage. A further blood sample of each kitten was obtained 4 d after injection. Handling of the kittens was kept to a minimum, and efforts were made to reduce the disturbance of the mother-young relationship.

**Measurement of blood plasma THO.** Each blood sample (0.2–0.4 mL) of a kitten was immediately transferred into a 0.5-mL heparinized Eppendorf tube. The blood was then used to fill 3–5 mL hematocrit capillary tubes and centrifuged at 14,800 × g for 15 min using a Heraeus hemofuge (Heraeus Sepatech GmbH, Österode, Germany). The hematocrit values were recorded; then the capillary tubes were cut, and the plasma was used to fill two 50-μL calibrated micropipettes (Vitrex, Hounisen, Risskov, Denmark). Each micropipette was transferred directly into a scintillation vial containing 8 mL of scintillation fluid (67 parts toluene and 33 parts triton X-100 containing 0.4% 2,3-diphenyloxazole (PPO)), and the radioactivity was counted using a Wallac 1414 liquid scintillation spectrometer (Wallac OY, Turku, Finland). Any remaining plasma samples of the kittens were pooled per period (3–7, 10–14, 17–21 and 24–28 d postpartum) for dry matter analysis. Standards were made up by dilution (1:1000) with distilled water of the THO solution used for injection, and corrections were made for the quenching effect of the plasma samples. The average counting efficiency of tritium was 42%.

**Chemical analysis.** Dry matter (DM) of plasma samples was determined in duplicate by freeze drying and subsequent oven drying at 105°C. Dry matter of the diets and the milk replacer was determined in duplicate by desiccation at 105°C. Ash was determined by heating samples at 550°C for 16 h. Total nitrogen was determined using the Kjeldahl method with crude protein calculated by multiplying total nitrogen by 6.25. Lipid was determined by petroleum ether extraction of freeze-dried samples (AOAC 1980). Amino acids were determined as described by Hendriks et al. (1996). All measurements were performed in duplicate and the chemicals used were analytical grade.

**Total body water and biological half-life of body water turnover.** The body water content of the kittens at various ages, which is required in the calculation of water intake, was estimated using the following regression line [values are: estimate (2SEM)]:

\[
\text{Total body water} (\%) = 79.9 (\pm 0.4) - 0.22
\]

\[=(\pm 0.03) \times \text{age (d)} \quad (r = 0.81, n = 28) \quad (1)\]

The regression line was obtained by least-squares regression of the water content of newly born to 6-wk-old kittens published by Thomas (1911), Widdowson (1950) and Stratmann (1988). The biological half-life ($T_{1/2}$) of body water in the kittens was calculated from rates of elimination from the body water pool of the injected THO over the 4-d observation period. The tritium radioactivity in plasma water at 2 and 96 h after injection of THO and the equations published by Coward et al. (1982) were used to calculate water intake in THO-injected kittens. Recycling of THO between the queen and her kittens during wk 1 was accounted for by subtraction of the plasma

**TABLE 1**

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Queen Diet¹</th>
<th>Milk²</th>
<th>Kitten milk replacer³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude protein</td>
<td>493</td>
<td>347</td>
<td>409</td>
</tr>
<tr>
<td>Lipids</td>
<td>283</td>
<td>234</td>
<td>186</td>
</tr>
<tr>
<td>Ash</td>
<td>93</td>
<td>52</td>
<td>43</td>
</tr>
<tr>
<td>Taurine</td>
<td>3.1</td>
<td>0</td>
<td>0.3</td>
</tr>
<tr>
<td>Methionine</td>
<td>12.3</td>
<td>6.5</td>
<td>12.3</td>
</tr>
<tr>
<td>Aspartic acid</td>
<td>41.4</td>
<td>19.1</td>
<td>31.7</td>
</tr>
<tr>
<td>Threonine</td>
<td>20.9</td>
<td>11.3</td>
<td>19.8</td>
</tr>
<tr>
<td>Serine</td>
<td>21.0</td>
<td>13.6</td>
<td>23.6</td>
</tr>
<tr>
<td>Glutamic acid</td>
<td>64.7</td>
<td>48.6</td>
<td>94.0</td>
</tr>
<tr>
<td>Glycine</td>
<td>43.2</td>
<td>4.9</td>
<td>7.7</td>
</tr>
<tr>
<td>Alanine</td>
<td>32.6</td>
<td>7.8</td>
<td>12.4</td>
</tr>
<tr>
<td>Valine</td>
<td>25.6</td>
<td>16.0</td>
<td>29.1</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>17.9</td>
<td>12.7</td>
<td>22.0</td>
</tr>
<tr>
<td>Leucine</td>
<td>40.9</td>
<td>24.3</td>
<td>41.7</td>
</tr>
<tr>
<td>Tyrosine</td>
<td>16.4</td>
<td>11.6</td>
<td>21.5</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>21.7</td>
<td>12.1</td>
<td>22.0</td>
</tr>
<tr>
<td>Histidine</td>
<td>15.9</td>
<td>7.0</td>
<td>12.6</td>
</tr>
<tr>
<td>Lysine</td>
<td>30.4</td>
<td>19.3</td>
<td>34.6</td>
</tr>
<tr>
<td>Arginine</td>
<td>30.1</td>
<td>8.4</td>
<td>14.6</td>
</tr>
</tbody>
</table>

¹ Mixture of commercial canned cat foods (Chef, Heinz Wattie’s, Auckland, New Zealand).
² Pets Own lactose free milk, Appetite Foods (Lysterfield, Victoria, 3156, Australia).
³ Made up from a mixture of 33.5 g goat’s milk powder (Karicare Goat Follow-On, Nutricia, Auckland, New Zealand) and 16.5 g sodium caseinate (Alanate 180, New Zealand Dairy Board, Wellington, New Zealand) in 500 mL demineralized water.

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Milk output remained constant in growing kittens. The calculated milk intake of kittens was calculated from total water intake (TWI):...

Calculation of milk intake. The daily milk intake was calculated from the water intake data using the equations published by King et al. (1993). Because the changes in the composition of the major constituents in queen’s milk appear to be rather small within the first 4 wk of lactation (Adkins et al. 1997, Dobenecker et al. 1998), and because such changes cause only very small errors in the calculated value for daily milk intake (Pettigrew et al. 1987), the following composition of queen’s milk (compiled from literature values) was used for calculations in this study: 79.4% water, 8.2% crude protein, 5.5% fat and 5.5% lactose. The digestibility of milk protein, fat and lactose was assumed to be close to 100% (Kienzle and Kamphues 1991). Full oxidation of one gram of protein, fat and lactose in vivo was taken to yield 0.41, 1.07 and 0.60 mL of water, respectively (Brody 1945). Potential metabolic water deposited as protein and fat (King et al. 1993) was calculated using the body dry matter gain (DMgain) of each kitten over the measurement period and values of 1.08, 2.07 and 3.05 g/d for protein and fat, and 0.60 g/d for lactose.

Statistical analysis. The body weight data of the kittens were subjected to repeated-measures ANOVA with litter and gender as variables and days postpartum as the repeated measure (Cody and Smith 1987). The milk intake data were subjected to ANOVA (split-plot) using the General Linear Model with queen, gender, sex and kitten as fixed variables and kitten within queen and sex as the error term to account for the repeated measurements of milk intake (Cody and Smith 1987). The data on the biological half-life of body water were subjected to a least-squares linear regression analysis with body weight as the independent variate and the biological half-life as the dependant variate. A no-intercept multiple regression analysis was performed on the milk intake data with milk intake (g/d) as the dependent variable and metabolic body weight (kg0.75) and body weight gain (g/d) as the independent variates. All statistical analyses were performed using the SAS statistical package (SAS version 6.12, SAS Institute, Cary, NC), and effects were considered significant at P < 0.05. Values in the text are means ± SEM.

RESULTS

The kittens and queens remained healthy throughout the 4-wk experimental period. The kittens were not observed to leave their nest box and were never found in the area where the food for the queen was presented during the study. The kittens gained weight throughout the study although body weight gain decreased as the study progressed (Table 2). There was a significant (P < 0.001) effect of time and no significant (P > 0.05) effect of litter and gender on the body weight of the kittens as determined by repeated-measures ANOVA. There was a significant (P < 0.001) interaction between litter and time on the body weights of the kittens. The queens lost weight throughout the study, particularly during wk 3 and 4 postpartum. The average daily intake of ME of the queens increased during the first 3 wk of the study from 392 kJ/kg body weight during wk 1 to 513 kJ/kg body weight during wk 3. During wk 4, the daily ME intake of the queens decreased to 477 kJ/kg body weight.

The hematocrits of the kittens decreased throughout the 4-wk study period, with the largest decline occurring in the first 2 wk (Fig. 1). At the end of the study, the hematocrit of the kittens was 0.19 ± 0.01. The dry matter content of the kittens’ plasma, as measured using the pooled samples, remained constant throughout the 4-wk study (6.8 ± 0.1%). Recirculation of THO as measured at 96 h after injection during wk 1–4 accounted for

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**Table 2**

Weekly body weight, metabolizable energy (ME) intake and milk yield of the queens and body weight and weight gain of the kittens during the study period

<table>
<thead>
<tr>
<th>Week</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Queens, n = 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body weight, kg</td>
<td>3.31 ± 0.13</td>
<td>3.05 ± 0.12</td>
<td>2.91 ± 0.10</td>
<td>2.60 ± 0.13</td>
</tr>
<tr>
<td>ME intake, kJ/kg · d</td>
<td>382 ± 23</td>
<td>459 ± 24</td>
<td>515 ± 59</td>
<td>477 ± 70</td>
</tr>
<tr>
<td>Milk output, %/kg</td>
<td>5.1 ± 0.3</td>
<td>5.5 ± 0.3</td>
<td>6.1 ± 0.4</td>
<td>6.0 ± 0.4</td>
</tr>
<tr>
<td>Milk output, %/kg (75</td>
<td>7.0 ± 0.4</td>
<td>7.4 ± 0.3</td>
<td>8.0 ± 0.5</td>
<td>7.8 ± 0.5</td>
</tr>
<tr>
<td>Kittens, n = 19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body weight, g</td>
<td>214 ± 3</td>
<td>284 ± 5</td>
<td>347 ± 7</td>
<td>382 ± 11</td>
</tr>
<tr>
<td>Body weight gain, g/d</td>
<td>15.0 ± 0.4</td>
<td>9.5 ± 0.5</td>
<td>8.1 ± 0.7</td>
<td>3.4 ± 0.8</td>
</tr>
</tbody>
</table>

1 Values are mean ± SEM.
2 Weight on the last day of the week.
3 Milk yield in percentage of queen’s body weight.

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**Appendix A**

The kittens and queens remained healthy throughout the 4-wk experimental period. The kittens were not observed to leave their nest box and were never found in the area where the food for the queen was presented during the study. The kittens gained weight throughout the study although body weight gain decreased as the study progressed (Table 2). There was a significant (P < 0.001) effect of time and no significant (P > 0.05) effect of litter and gender on the body weight of the kittens as determined by repeated-measures ANOVA. There was a significant (P < 0.001) interaction between litter and time on the body weights of the kittens. The queens lost weight throughout the study, particularly during wk 3 and 4 postpartum. The average daily intake of ME of the queens increased during the first 3 wk of the study from 392 kJ/kg body weight during wk 1 to 513 kJ/kg body weight during wk 3. During wk 4, the daily ME intake of the queens decreased to 477 kJ/kg body weight. The hematocrits of the kittens decreased throughout the 4-wk study period, with the largest decline occurring in the first 2 wk (Fig. 1). At the end of the study, the hematocrit of the kittens was 0.19 ± 0.01. The dry matter content of the kittens’ plasma, as measured using the pooled samples, remained constant throughout the 4-wk study (6.8 ± 0.1%). Recirculation of THO as measured at 96 h after injection during wk 1–4 accounted for
The following significant regression line was obtained [values are: estimate (±SEM)]:

\[
T_{1/2} \text{ body water (d)} = 0.90 (±0.33) + 9.52
\]

\[
(±1.08) \cdot \text{bwt (kg)} \quad (r = 0.76, n = 56)
\]  

(3)

The slope and the intercept of the regression line were significant at \( P < 0.01 \). The biological half-life of body water increased during wk 1–4 and was 2.4 ± 0.1, 3.4 ± 0.1, 4.0 ± 0.1, and 4.9 ± 0.2 d, respectively.

Milk intake of the kittens remained relatively constant throughout the study (Fig. 3) although there were significant (\( P < 0.05 \)) effects of litter, time, and the interaction between litter and time on milk intake. There was no effect of gender on milk intake. Daily milk intake of the kittens (\( n = 14 \)) during wk 1–4 were 47.3 ± 0.8, 47.4 ± 1.5, 48.7 ± 1.6, and 43.7 ± 2.0 g, respectively. Multiple regression of the milk intake data on metabolic body weight (MBW) and body weight gain (gain) yielded the following significant (\( P < 0.001 \)) equation [values are: estimates (±SEM)]:

\[
\text{MI} \quad (\text{g/d}) = 77.9 \quad (±2.4) \cdot \text{MBW} \quad (\text{kg}^{0.75})
\]

\[+ 1.7 \quad (±0.1) \cdot \text{gain (g/d)} \quad (r = 0.73, n = 56)
\]  

(4)

Both coefficients of the multiple regression line were significant (\( P < 0.001 \)).

Figure 2: Biological half-life of tritiated water turnover in suckling kittens (\( n = 14 \)) measured over 4-d periods during postnatal wk 1–4 and plotted as a function of body weight (\( r = 0.76, P < 0.05 \)).

Figure 3: Milk intake of individual kittens (\( n = 14 \)) during the four experimental periods. Horizontal bars indicate mean values. Means (±SEM) for wk 1–4 were 47.3 ± 0.8, 47.4 ± 1.5, 48.7 ± 1.6 and 43.7 ± 2.0 g, respectively.

Four of the six kittens used in the validation study (wk 5) gained weight (mean: 5.5 g/d), whereas two kittens lost body weight (mean: −1 g/d). Diarrhea was not observed during the 48-h period when the kittens were fed the milk replacer. The daily intake of milk replacer, estimated using the WID technique, ranged from 0.3% underestimation to 7.2% overestimation with an average overestimation of daily milk intake of 2.4 ± 1.2%.

**DISCUSSION**

All of the queens and kittens in this study remained healthy, and the average weight gain of the kittens, recorded during the first 3 wk postpartum, was comparable to the data of Loveridge (1987) for a total of 100 kittens. In wk 4, the average weight gain of the kittens was lower than the values reported by Loveridge (1987), which could be attributed to the failure of two kittens to gain body weight. At the end of the study, however, the average body weight of the kittens was higher than the average body weights of (373 ± 5 g, \( n = 128 \)) kittens of a similar age recorded in the colony. The failure of two kittens to gain body weight in the final week of the study was due to a low milk intake (75 and 70 g per kg MBW). There was no effect of litter or gender on the body weight of the kittens in this study as analyzed by repeated-measures ANOVA. Loveridge (1987) also found no effect of gender on the body weight of kittens until 6 wk of age; the male kittens were significantly heavier after that time. The body weight of the queens in this study decreased throughout lactation and at the end of wk 4, the average body weight of the queens was reduced to 79% of the value recorded at the start of lactation. The mean daily energy intake of the queens in this study was similar to that reported by Loveridge (1986), except for wk 4 when a decrease in the intake of ME was recorded. At the same time, the queens experienced heavy weight loss, indicating that body reserves were mobilized to provide energy and nutrients to maintain milk production. In this situation, the reduced intake of ME by the queens is likely to have caused a lower milk production, resulting in a lower weight gain of the kittens in the last week of the study.

In the kittens the decreasing hematocrits observed throughout the study (Fig. 1) document the development of “suckling anemia,” a phenomenon that has been observed in rapidly growing suckling young of other species (Garcia 1957, Widdowson 1963). By measuring iron levels in the body of suckling kittens, McCance and Widdowson (1951) showed that...
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...blood iron levels decreased from birth to 3 wk of age. Garcia (1957) showed that the rapid body growth of suckling rats leads to a marked decrease in the hematocrit value and the hemoglobin concentration of whole blood during early postnatal life. This occurred in spite of a marked increase in total red cell volume and whole-body hemoglobin, indicating a continual high rate of erythropoiesis, exceeded by higher rates of body fluid accretion and body mass gain (Garcia 1957). The repeated blood sampling in this study also affected the hematocrits, but the effect is believed to be of minor importance because the amount of blood taken (0.2–0.4 mL) represented only a small fraction of the kittens’ total blood volume.

In applying the WID technique to studies of water turnover in the mammalian body, a number of basic assumptions have to be fulfilled, including water isotope equilibration, size of the body water pool, sources and rates of water exchange and loss of isotopes. The assumptions, prerequisites and the potential errors inherent in using this technique for determinations of water fluxes in animals and humans and its implications for reliable estimates of the milk intake in various species have been reviewed (Coward et al. 1982, Fjeld et al. 1988, Nagy and Costa 1980). In this study, a 2-h period for THO equilibration was used because this seems to be a commonly accepted equilibration time for water isotopes in small mammals weighing < 10–20 kg (Fjeld et al. 1988, Macfarlane et al. 1969, Oftedal 1984, Pettigrew et al. 1985, Pluske et al. 1998). At the end of the study, an equilibration time curve was obtained from the use of six kittens injected with THO, and it was shown that full equilibration of THO in kitten’s body water was attained in < 1 h (Hendriks, unpublished observations). In this study, the recirculation of THO due to the uptake of urine and feces by the queen was measured in unlabelled kittens during wk 1; these values, therefore, can be expected to be accurate. To allow repeated measurements on the same litter and take into account recirculation of THO, a previously THO-injected kitten was used as a “blank” during wk 2 to 4. In these cases, the calculations of recirculated THO were corrected for residual THO radioactivity in plasma water from the previous measurement period, and the calculated values for wk 2–4, therefore, are theoretically slight overestimates.

THO recirculation values found for wk 1–4 were 5.9 ± 0.8, 12.0 ± 0.5, 7.7 ± 1.3 and 10.0 ± 1.3%, respectively.

The biological half-life of body water in the kittens increased from 2 d in wk 1 to 4 d in wk 4 (Fig. 2); the latter value is similar to that observed in 3-wk-old suckling puppies (4.2–4.6 d) (Oftedal 1984). In suckling mink kits, weighing 20–140 g, the biological half-life increased from < 1 d to ~ 2 d (Wamborg and Tauson 1998), whereas in 1- to 3-wk-old blue fox cubs (Alopex lagopus), the T1/2 value of body water ranges from 1.7 to 2.2 d (Wamborg and Tauson 1998). In suckling rat pups, T1/2 was ~ 1.5 d (Coward et al. 1982); in human infants weighing 7.8 kg, Fjeld et al. (1988) reported a mean value of T1/2 of 2.7 d. These values underscore the rapid turnover rate of body water in suckling young animals.

The isotope dilution technique has been used extensively to measure milk intake in a number of mammalian species, including humans (Butte et al. 1983), baboons (Buss and Voss 1971), sheep (Macfarlane et al. 1969), rats (Coward et al. 1982), dogs (Oftedal 1984), pigs (Pluske et al. 1998) and mink (Wamborg and Tauson 1998). In this study, we have applied the WID technique for the first time to study milk intake in suckling kittens and determine the accuracy of this technique to measure milk intake in kittens. The measurement of milk intake by the WID technique in the tube-fed kittens showed a high degree of accuracy. The mean difference between the predicted and actual milk intake of the six measurements was 2.4%. This value is similar to the recovery values reported in infants of 2.0% (Fjeld et al. 1988), calves 2.5% (Hollemann et al. 1975), lambs 3.3% (Macfarlane et al. 1969), and pigs 2.9% (Pettigrew et al. 1987). These results indicate that the results presented on the milk intake of kittens in this study were accurate.

The average daily milk intake of the kittens remained surprisingly constant throughout the first 4 wk postpartum (Fig. 3). However, there was a significant effect of time on milk intake and a significant interaction between milk intake and litter, indicating that milk production patterns of the five queens were different over time. The body weight gain of the kittens also showed a significant effect of time; the kittens were found to grow at a different rate as indicated by the significant interaction of time and litter. Jayawickrama et al. (1998) found a significant difference between the milk intakes of kittens for wk 1 and 4 and statistically similar milk intakes among other weeks. Dobenecker et al. (1998) also used the WSW technique to measure milk intake of kittens during three periods (wk 1, 2–4, 5–9) and found a higher milk yield of queens during the wk 2–4 period compared with wk 1 and a lower milk yield during the wk 5–9 period. The results in this study are in contrast to the increasing milk intake with increasing age observed in the suckling young of baboons (Buss and Voss 1971), rats (Coward et al. 1982), dogs (Oftedal 1984) and mink (Wamborg and Tauson 1998). In pigs, Pluske et al. (1998) found a significant decrease in milk intake with increasing age. Many factors may influence milk production throughout lactation in mammals, including factors such as stage of lactation, the number of suckling animals, suckling intensity, temperature, season, dietary protein and energy intake (Dobenecker et al. 1998, Jayawickrama et al. 1998, King et al. 1993, Pluske et al. 1998).

Milk intake and the growth of the suckling offspring are highly correlated because milk is the sole source of nutrients for the young animal. The milk ingested by the kittens in this study would have been used first for the maintenance of body mass; any intake of milk in excess of maintenance would have been used for growth of body tissue. The average body weights of the kittens in this study increased with age, whereas the growth rate decreased with age (Fig. 2), indicating that the amount of milk available for body gain decreased throughout the 4-wk lactation period. The multiple regression equation obtained in this study (Eq. 4) shows that 77.9 g of milk were required per unit metabolic body weight per day for maintenance and 1.7 g were required per gram of body growth.

Assuming that milk energy contains 4.6 kJ ME/g, this equates to sucking kittens requiring 356 kJ/(kg0.75) for maintenance. This value is close to the basal metabolic rate of kittens [288 kJ/(kg0.75)] as measured by oxygen uptake of 1- to 6-wk-old kittens (Hill 1959). Similar values [300 and 334 kJ/(kg0.75)] for maintenance have been found in suckling dogs (Crighton and Pownall 1974, Mundt et al. 1981). This value, however, is considerably lower than values normally found for pigs of 458 kJ/(kg0.75) (Lawrence and Fowler 1997) and adult cats (NRC 1986) and dogs (NRC 1985) of 438 and 552 kJ/(kg0.75), respectively. Kittens and dog puppies are born with a dense hair coat and exhibit very low physical activity because they sleep most of the day. They huddle together and are kept warm by the queen or bitch most of the time. All of these factors will reduce the energy requirement for maintenance to a level closer to the basal metabolic rate of the animal. The efficiency of ME deposition may be calculated using the data in this study. Per gram of body growth, 1.7 g of milk or 7.8 kJ ME is required per day. Assuming that the body weight gain consisted of 76.6% water, 14.4% protein and 5.8% fat (Stratmann...
1988), the energy stored per unit of growth was 5.5 kJ/d. The efficiency ($k_v$-value) with which metabolizable energy was converted to net energy in the kittens in this study was 0.71. This is similar to other animals such as pigs, in which $k_v$-values of 0.65 and 0.69 have been reported (Lawrence and Fowler 1997, Van der Hel and Verstegen 1987). It has been noted by several authors that in doubling its body weight in <8 d, the cat is one of the fastest growing mammals (Bernhart 1961, Thomas 1911, Widdowson 1965). This study indicates that the high growth rate of cats may be due mainly to the lower energy requirement for maintenance, −360 kJ/(kg$^{0.75} \cdot$ d), whereas the ME requirement per unit of body growth is similar to that of other mammals.

The average daily milk production of the queens in this study (as a percentage of the queens’ body weight) ranged from 5.1 ± 0.3% during wk 1 to 6.1 ± 0.4% and 6.1 ± 0.4% during wk 3 and 4, respectively. Dobenecker et al. (1998) measured milk production of queens using the WSW technique and reported corrected estimates of milk production of queens nursing litters of 3–4 kittens during wk 1 of 4.0% and during wk 2–4 of 5.7%. However, the expression of the daily milk yield as a percentage of body mass may be misleading because queens may lose a considerable amount of body mass during lactation. Estimates made by Dobenecker et al. (1998) for wk 1 of lactation are lower than the estimates obtained in this study, and their data show a distinct relationship in the milk yield and lactation stage, which is likely to be caused by the WSW technique used to measure milk intake. The differences between these two techniques in estimating milk intake have been attributed to stress resulting from repeated interference and frequent handling of the young, to lack of suckling stimulus, small errors in frequent weighings, loss of excreta and to the effects of water recycling (Baverstock and Elhay 1981, Coward et al. 1982, Ofedal, 1984, Pettigrew et al. 1987). Similarly, in recent studies of the milk intake of suckling kittens using the WSW technique, Dobenecker et al. (1998) and Jayawickrama et al. (1998) found lower growth rates of the kittens during the measurement period than those of the same kittens in periods in which they were not separated from the queens. These lower growth rates are likely to have resulted from stress of the queens and kittens, lower milk output of the kittens, lower milk output by the queen, water recirculation or a combination of these factors.

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