MACRONUTRIENT COMPOSITION OF MILK FROM THREE CERCOPITHECOIDEA SPECIES: OLIVE BABOONS (*PAPIO ANUBIS*), RHESUS MACAQUE (*MACACA MULATTA*), AND PIG-TAILED MACAQUE (*MACACA NEMESTRINA*)

Virginia J. Glick, BS* and Michael L. Power, PhD

Center for Species Survival, Smithsonian National Zoological Park and Conservation Biology Institute, 2001 Connecticut Ave., NW Washington, DC 20008, USA.

Abstract

Milk composition is critical to proper growth and development of mammalian infants as well as the reproductive success of the mother. The relative proportions of milk macronutrients can vary drastically across different species. The objectives of this study were to 1) characterize the macronutrient composition of the milk from olive baboons (*Papio anubis*), rhesus macaques (*Macaca mulatta),* and pig-tailed macaques (*Macaca nemestrina*) and 2) assess the similarity between the milks of these three cercopithecids. A single milk sample was obtained from 8 olive baboons between 47 and 129 days of lactation and 6 rhesus macaques between 15 and 92 days of lactation, living at the same institution under identical management conditions. Two milk samples each one month apart were obtained from 5 pig-tailed macaques (at 10 weeks and at 14 weeks of lactation) living at a separate institution. Baboon milk on average contained 86.0±0.6% water, 4.7±0.5% fat, 1.6±0.04% protein, 7.3±0.07% sugar, and 0.165±0.007% ash. Rhesus macaque milk on average was 86.1±0.3% water, 4.1±0.4% fat, 1.69±0.05% protein, 7.71±0.08% sugar, 0.19±0.01% ash. Finally, pig-tailed macaque milk was 82.8±0.6% water, 7.3±0.5% fat, 1.8±0.08% protein, 7.6±0.1% sugar, and 0.217±0.01% ash. These milks are similarly high sugar, moderate to high fat, and low protein with moderate energy density. This is consistent with their common lactation strategy characterized by frequent, on-demand nursing and relatively slow life history compared to non-primate mammal taxa. The strong similarity in the milks of these three monkey species suggests that other cercopithecid species living under human management might produce similar milk.

Introduction

Milk composition is critical to providing adequate nutrients for proper growth and development of mammalian infants. Across different species, milk composition can vary substantially (Oftedal & Iverson, 1995). A large comparative analysis of 130 species' milks suggested that this variation is primarily described by phylogeny followed by diet and lactation length (Skiebel *et al.*, 2013). Cercopithecoidea is a family of anthropoid primates comprised of several monkey species including macaques and baboons. This study was designed to 1) characterize the macronutrient composition of the milk from olive baboons (*Papio anubis*), rhesus macaques (*Macaca mulatta),* and pig-tailed macaques (*Macaca nemestrina*) and 2) assess the similarity between the milks of these three cercopithecids.

Methods

A single milk sample was collected by manual expression from eight lactating olive baboons ranging between 47- and 129-days post parturition and six rhesus macaques from 15- and 92-days living under identical management conditions at the same institution, Texas Biomedical Research Institute in San Antonio, TX. Two milk samples were obtained from five pig-tailed macaques at 2

months (70-72 days) and 3 months (98-100 days) post parturition living at a breeding colony in Mesa, Arizona managed by the Washington National Primate Research Center. Macronutrient composition (water, fat, protein sugar, and mineral) was determined using standard techniques that have been validated using over 200 mammal species at the Nutrition Laboratory at the Smithsonian National Zoological Park (Hood *et al.*, 2009). Gross energy was calculated from the macronutrient composition as the sum of energy provided by protein, fat, and sugar using the following energy values: 5.86 kcal/g for protein, 9.11 kcal/g for fat, and 3.95 kcal/g for sugar (Perrin, 1958). Results are presented as the average for the species ± standard error of the mean (SEM).

Milk constituents were compared between species using Bonferroni correction for multiple comparisons. Correlation was used to examine the relationships among constituents. A *P*-value of 0.05 or less was considered to indicate a significant effect.

Results

The mean values for all milk constituents by species are given in Table 1. Baboon milk demonstrated strong similarity in composition to rhesus macaque milk, though with slightly lower sugar content. However, there was no statistical difference between baboon and rhesus macaque milk in the proportions of energy from fat, sugar, and protein.

Pig-tailed macaque milk was higher than the other species in fat (7.3±0.5%; $P < 0.01$) and GE (1.1±0.04 kcal/g; $P < 0.01$), was intermediate in sugar, but did no differ from the other species in protein content (Table 1). Ash content of pig-tailed macaque milk was higher than baboon milk but not different from rhesus macaque milk. There was no difference in milk calcium and phosphorus content between any species. On average pig-tailed milk had the highest proportion of energy from fat and lowest from sugar and protein; however, the differences were only significant between the two macaque species (Table 1).

Fat provided the most milk energy and protein the least for all three species (Figure 1). Milks higher in energy had a greater proportion of energy from fat, both within and between species ($r > 0.95$, $P < 0.001$ for all comparisons).

Discussion

The contributions to milk gross energy from fat and sugar were greater and more variable than the contribution from protein for baboons and both macaque species. Milk that was higher energy had a larger proportion of energy coming from fat. The low protein content on an energy basis is representative of the relatively slow growth rate and life history of cercopithecids monkey species compared to many other non-primate mammal taxa. Across all three species the combined average percent of gross energy from protein (11.2±0.004%**)** was less than protein milk energy of platyrrhine species (16.0–23.2%; Milligan 2007, 2010; Milligan *et al.*, 2008; Power *et al.*, 2002, 2008), indicative of their slower growth rates compared to these monkeys (Kirkwood, 1985).

The milks were also high in water content, which is consistent with their common lactation strategy. These monkeys carry their infants allowing for frequent, on-demand nursing. Increased suckling stimulates lactose production and osmotically draws water into the mammary gland. Other mammals that share this lactation strategy produce similarly dilute milks with high sugar (Shaul, 1962) while mammal species with near opposite lactation strategies, such as leaving their

young in a burrow or nest for an extended time between nursing, produce higher energy milks with greater fat content (Iverson, 2007; Hinde & Milligan, 2011; Tilden & Oftedal, 1997).

Higher fat content results in greater energy density. The pig-tailed macaque milk had the highest gross energy (1.1±0.04 kcal/g) among the three species and, notably, also had the greatest percentage of energy coming from fat (61.6±1.9%). The pig-tailed macaque samples ranged from 4.8% to 11.3% fat. More observation and research into lactation of this species is necessary to understand the source of this variation but some factors may be limited sample size, maternal body condition, maternal diet, or specific management practices at the individual institution.

Previously published data for rhesus macaque milk using much larger sample sizes are similar to the results reported here (Hinde, 2007; Hinde *et al.*, 2009, 2013). Published baboon milk values (Buss, 1968) were similar to our results. To our knowledge, this is the first report of the macronutrient composition of milk from pig-tailed macaques.

Conclusions

These milks can broadly be described as high sugar, moderate to high fat, and low protein milk with moderate energy density, which is consistent with their common lactation strategy characterized by frequent, on-demand nursing and relatively slow life history compared to non-primate mammal taxa (Iverson, 2007; Hinde & Milligan, 2011; Shaul, 1962). These data show strong similarity between baboon and macaque milk compositions and imply that other cercopithecid species living under human management might produce similar milk.

Acknowledgements

The project was supported in part by a Smithsonian Scholarly Studies award (MLP).

Literature cited

Buss D (1968) Gross composition and variation of the components of baboon milk during natural lactation. *J Nutr* 96(4): 421-426.

Hinde K. (2007) First-time macaque mothers bias milk composition in favor of sons. *Curr Biol* 17(22): R958-R959.

Hinde K, Foster AB, Landis LM, Rendina D, Oftedal OT, and Power ML (2013). Brief communication: Daughter dearest: Sex-biased calcium in mother's milk among rhesus macaques. *Am J Phys Anthropol* 151(1): 144-150.

Hinde K and Milligan L (2011) Primate milk: Proximate mechanisms and ultimate perspectives. *Evol Anthropol* 20(1): 9-23.

Hinde K, Power ML, and Oftedal OT (2009) Rhesus macaque milk: magnitude, sources, and consequences of individual variation over lactation. *Am J Phys Anthropol* 138(2): 148-157.

Hood WR; Volture MB; Oftedal OT (2009) Methods of measuring milk composition and yield in small mammals. In: Kunz, TH; Parsons, S, Eds. Ecological and Behavioral Methods for the Study of Bats. pp 529-553.

Iverson, S (2007) Milk composition and lactation strategies across mammalian taxa: implications for hand-rearing neonates. In: Ward A, Hunt A, Maslanka M, Eds. *Proceedings of the Seventh Conference on Zoo and Wildlife Nutrition*, AZA Nutrition Advisory Group, Knoxville, TN. pp 1-7.

Kirkwood JK (1985) Patterns of growth in primates. *J Zool* 205(1): 123-136.

Milligan L (2007) Nonhuman primate milk composition: Relationship to phylogeny, ontogeny, and ecology. Doctoral Thesis, University of Arizona. 1-401.

Milligan L, Gibson SV, Williams LE, and Power ML (2008) The composition of milk from Bolivian squirrel monkeys (*Saimiri boliviensis boliviensis*). *Am J Primatol* 70(1): 35-43.

Milligan L (2010) Milk composition of captive tufted capuchins (*Cebus apella)*. *Am J Primatol* 72(1): 81-86.

Oftedal OT and Iverson SJ (1995) Phylogenetic variation in the gross composition of milks. RG Jensen, Ed. The Handbook of Milk Composition. pp 749-789.

Power ML, Oftedal OT, and Tardif SD (2002) Does the milk of callitrichid monkeys differ from that of larger anthropoids? *Am J Primatol* 56(2): 117-127.

Power ML, Verona CE, Ruiz-Miranda C, and Oftedal OT (2008) The composition of milk from free-living common marmosets (Callithrix jacchus) in Brazil. *Am J Primatol* 70(1): 78-83.

Perrin D (1958) The calorific value of milk of different species. *J Dairy Res* 25(2): 215-220.

Shaul B (1962) The composition of the milk of wild animals. *Int Zoo Yearb* 4: 333-342.

Skibiel A; Downing L, Orr T; Hood R (2013) The evolution of the nutrient composition of mammalian milks. *J Anim Ecol* 82(6): 1254-1264.

Tilden CD; Oftedal OT. (1997). Milk composition reflects patterns of maternal care in prosimian primates. *Am J Primatol* 41(3): 195-211.

Table 1. Milk macronutrient composition and gross energy for Olive baboon, Rhesus macaque, and Pig-tailed macaque. Results are presented as average ± SEM.

Constituent	Olive Baboon (n = 8)	Rhesus Macaque (n = 6)	Pig-tailed Macaque (n = 10)	***P*-value**
Fat, %	4.72 ± 0.5[a]	4.10 ± 0.4[a]	7.32 ± 0.5[b]	< 0.01
Protein, %	1.60 ± 0.04	1.69 ± 0.05	1.77 ± 0.08	ns
Sugar, %	7.27 ± 0.07[a]	7.71 ± 0.08[b]	7.57 ± 0.1[ab]	0.010
DM, %	14.0 ± 0.6	13.9 ± 0.3	17.2 ± 0.6	ns
GE kcal/g	0.811 ± 0.04[a]	0.777 ± 0.03[a]	1.07 ± 0.04[b]	< 0.01
GE from Protein, %	11.8 ± 0.7[ab]	12.8 ± 0.3[a]	9.82 ± 0.6[b]	0.025
GE from Sugar, %	36.2 ± 2.0[ab]	39.7 ± 2.0[a]	28.6 ± 1.4[b]	0.009
GE from Fat, %	51.9 ± 2.6[ab]	47.5 ± 2.3[a]	61.6 ± 1.9[b]	0.008
Ash, %	0.165 ± 0.007[a]	0.192 ± 0.01[ab]	0.217 ± 0.01[b]	0.015
Ca, %	0.048 ± 0.001	0.054 ± 0.002	0.060 ± 0.004	ns
P, %	0.033 ± 0.002	0.031 ± 0.001	0.032 ± 0.0010	ns
Ca:P	1.5 ± 0.09	1.8 ±0.02	1.8 ± 0.09	ns

[ab]Values with different superscripts are significantly different (P < 0.05)

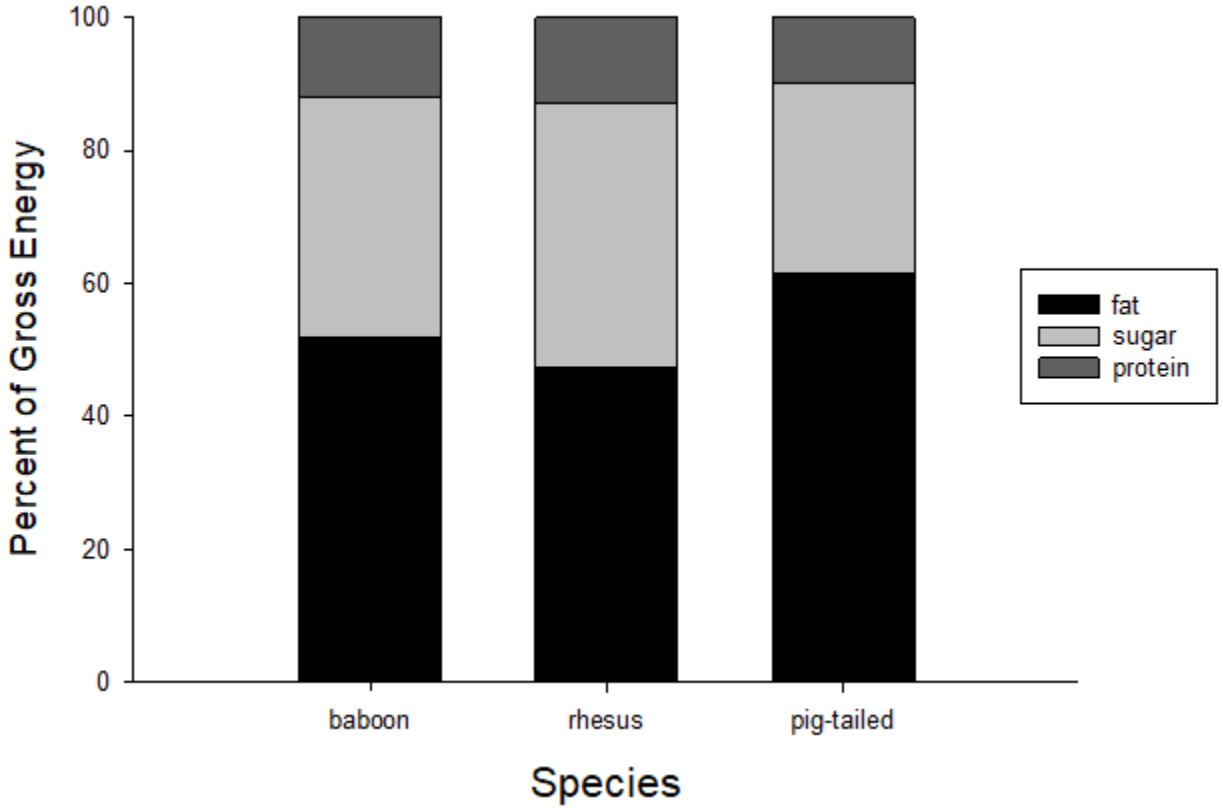

Figure 1. The proportion of milk gross energy from fat, sugar, and protein for three Cercopithecoidea species: Olive baboons (*Papio anubis*), rhesus macque (*Macaca mulatta*), and pig-tailed macaque (*Macaca nemestrina*).