Amino Acid Composition of Human Milk Is Not Unique[1,2,3]

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ABSTRACT To determine whether the amino acid pattern of human milk is unique, we compared the amino acid pattern of human milk with the amino acid patterns of the milks of great apes (chimpanzee and gorilla), lower primates (baboon and rhesus monkey) and nonprimates (cow, goat, sheep, llama, pig, horse, elephant, cat and rat). Amino acid pattern was defined as the relative proportion of each amino acid (protein-bound plus free) (in mg) to the total amino acids (in g). Total amino acid concentration was lower in primate milk than in nonprimate milk. There were commonalities in the overall amino acid pattern of the milks of all species sampled: the most abundant amino acids were glutamate (plus glutamine, 20%), proline (10%) and leucine (10%). Essential amino acids were 40%, branched-chain amino acids 20%, and sulfur amino acids 4% of the total amino acids. The amino acid pattern of human milk was more similar to those of great apes than to those of lower primates. For example, cystine was higher and methionine was lower in primate milks than in nonprimate milks, and in great ape and human milks than in lower primate milks. Because the milk amino acid patterns of the human and elephant, both slow-growing species, were dissimilar, the amino acid pattern of human milk seems unrelated to growth rate. J. Nutr. 124: 1126–1132, 1994.

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- humans • elephants

Neonatal mammals rely on a single food source, milk, to meet their nutrient needs. The molecular composition of milk can vary widely among different species, and it seems reasonable, teleologically, that these differences in milk composition may represent an evolutionary phenomenon associated with the specific nutrient needs of the young of each species (Jenness 1986, Jenness and Sloan 1970). Differences among species in the nutrient requirements of their young may arise from differences in postnatal growth rate, stage of maturity at birth, body composition at birth, and environmental peculiarities of their natural habitats. In addition, constraints imposed on the lactating female, such as litter size and lactation load, maternal diet consumed and nursing schedule, could potentially influence milk composition.

The protein concentration of milk varies more than 10-fold among species, with that of human milk at the low end of the range (~8 g protein/L, Jenness and Sloan 1970). Although the milk protein concentrations of numerous species have been well established, there has been little systematic study of the total (i.e., protein-bound as well as free) amino acid composition

of the milks secreted by different species. Human milk is generally recognized as being distinct in its amino acid composition (Heine et al. 1991); however, this conclusion has arisen principally from comparison of human milk with bovine milk, its common substitute for human infant feeding. The most distinct difference between human and bovine milk seems to be the greater concentrations of cystine and tryptophan relative to the total amino acid concentration and lower concentration of methionine relative to the total amino acid concentration in human milk. This has been ascribed to the greater α-lactalbumin content. We do not know, however, if the amino acid composition of the human milk is indeed unique or whether it is characteristic of the mammals within the same phylogenetic group (i.e., the great apes in particular and primates in general) or of slowly growing species, which would include not only the great apes but also such species as the elephant (McCullagh and Widdowson 1970). Therefore, it was our objective to determine the amino acid (protein-bound plus free) composition of human milk and to compare it with the amino acid compositions of milks of great apes, lower primates and nonprimate species.

MATERIALS AND METHODS

Milk collection. Milk was obtained from five species of primate: human (*Homo sapiens*, n = 6), chimpanzee (*Pan troglodytes*, n = 5), gorilla (*Gorilla gorilla*, n = 3), baboon (*Papio cynocephalus anubis* and *Papio cynocephalus anubis/Papio cynocephalus*, n = 5) and rhesus monkey (*Macaca mulatta*, n = 6). Milk was also obtained from the following ruminant and nonruminant nonprimate species: cow (*Bos taurus*, n = 4), goat (*Capra hircus*, n = 2), sheep (*Ovis aries*, n = 6), llama (*Lama glama*, n = 3), pig (*Sus scrofa*, n = 3), horse (*Equus caballus*, n = 8), elephant (*Elephas maximus*, n = 3), cat (*Felis catus*, n = 4) and rat (*Rattus norvegicus*, n = 3). Some of the primate milks were purchased from Yerkes Regional Primate Research Center, Emory University (Atlanta, GA). Some of the sheep milk was donated by W. G. Pond (Children's Nutrition Research Center, Houston, TX). Horse and cat milks were donated by S. C. Zicker and Q. R. Rogers, respectively (University of California, Davis, CA). Horse, sheep and goat milks were also donated by G. S. Smith (New Mexico State University, Las Cruces, NM). Elephant milk was donated by E. Miller (St. Louis Zoological Park, St. Louis, MO), C. L. Wallace (Burnet Park Zoo, Syracuse, NY) and J. Glazier (Dickerson Park Zoo, Springfield, MO). Llama milk was donated by E. Domatti (Sunshine Acres Llamas, Simonton, TX). Pig and bovine milk was purchased from Texas A&M University (College Station, TX). Rats were purchased from Charles River Laboratories (Wilmington, MA).

All samples were obtained from animals 10 or more days after parturition and therefore were considered "mature" milk samples. None of the samples was obtained during the late stage of lactation when offspring obtain a large proportion of their nutrients from foods other than milk. Each of the three pig milk samples was pooled from several pigs, but all other milk samples were obtained from individual animals. When possible, nipples of the animals were cleaned prior to milking. Rats and most nonhuman primates were anesthetized prior to milk collection. Oxytocin was administered to some but not all nonhuman primates and to pigs, rats and cats. The offspring had suckled just before the milk samples were obtained from some animals. Complete evacuation of the glands was not possible in some instances. In all species except the human, single samples were obtained at one milking. Human milk samples were obtained from alternate breasts during a 24-h period while the infant suckled on the contralateral breast, and then the samples were pooled. All milk samples were frozen, shipped to the laboratory on dry ice, and then frozen at –20°C until analyzed. Human milk samples were obtained after approval by the Institutional Review Committees on Human Research of Baylor College of Medicine and Texas Children's Hospital. Animal care was in compliance with the *Guide for the Use and Care of Laboratory Animals* (NRC 1985).

Milk analysis. Milk samples were warmed to 37°C and inverted several times to mix. Duplicate aliquots (~0.20 mL) were weighed and an equal volume of water was added. Samples were centrifuged at 3000 × g for 15 min and frozen for 10 min at –70°C, and the upper fat layer was skimmed from the lower frozen aqueous layer. The skimmed milk was hydrolyzed in 4 mL of 6 mol/L HCl under a blanket of nitrogen at 110°C for 24 h. The protein hydrolysates were dried under vacuum (Speedvac, Savant Instruments, Farmingdale, NJ), 1 mL of water was added and evaporated two times, and 1 mL of 4.0 mmol/L methionine sulfone was added as an internal standard. The protein hydrolysates were filtered through a 0.2-μm filter, and the amino acid compositions were determined.

Amino acid chromatography. Amino acids in the milk protein hydrolysates were pre-column derivatized with phenylisothiocyanate and separated on a PICOTAG reverse-phase column (Waters, Milford, MA). Derivatized amino acids were detected on-line spectrophotometrically and quantified by comparing the area under the sample peak against that of an amino acid standard solution (Pierce H standard, Sigma Chemical, St. Louis, MO) of known concentration.

Tryptophan is destroyed by acid hydrolysis (McKenzie 1970); therefore tryptophan values are not reported. Because glutamine was converted to

glutamate and asparagine was converted to aspartate during the hydrolysis, the values reported as glutamate include both glutamate and glutamine and those for aspartate include both aspartate and asparagine. We previously reported (Davis et al. 1993) that the recovery of amino acids, as determined by the total amino acids (corrected for the water of hydrolysis) in relation to the protein (using the assay of Lowry et al. 1951), was 97 ± 2%. The recovery rates of individual amino acids from human recombinant insulin (>98% pure; Boehringer Mannheim, Indianapolis, IN) and bovine serum albumin (>98% pure; Sigma Chemical) were 97% for lysine, phenylalanine and proline, 98% for histidine and isoleucine, 100% for valine, threonine and tyrosine, 101% for methionine and leucine, 102% for cystine, glycine, arginine and serine, 103% for aspartate and alanine, and 104% for glutamate.

Calculations. Total amino acid concentration (g/L of whole milk) was the sum of all individual amino acids analyzed. Tryptophan was not included in the total amino acid concentration. The amino acid pattern of milk was defined as the amount of each individual amino acid (in mg) divided by the total amino acids (in g).

Statistics. Data are presented as means ± SD. To test for differences among species, one-way ANOVA was conducted, beginning with comparisons across all species. This was followed by comparison of primates vs. nonprimates and then specific comparisons within these groups (such as humans and great apes vs. lower primates, and humans vs. great apes) using two-tailed *t* tests (Snedecor and Cochran 1967). Because of the multiple comparisons, we used a Bonferroni correction; only probability levels <0.01 were considered statistically significant.

RESULTS

The concentrations of total amino acids recovered in the milks of various species are presented in **Table 1**. These include both the amino acids contained in the proteins and those in the free amino acid form. Primate milks had significantly lower concentrations of amino acids than milks from nonprimates ($P <$ 0.001). Among the primates, the human, chimpanzee and gorilla, on average, had significantly lower concentrations of total amino acids in their milks than did the lower primates (baboon, rhesus; $P <$ 0.007), although the gorilla had a total amino acid concentration in its milk that was similar to those of the lower primates. The total amino acid concentration of human milk did not differ significantly from those of milks from the great apes. Thus, a low total amino acid concentration in milk does not seem to be peculiar to the human or the great apes, but to primates generally. Milks from nonprimates differed greatly in

TABLE 1

Total amino acids recovered in primate and nonprimate milks[1,2]

Species	n	Total amino acids
		g/L whole milk
Primate		
Human	6	8.5 ± 0.9
Chimpanzee	5	9.2 ± 1.7
Gorilla	3	11.5 ± 2.5
Baboon	5	11.5 ± 2.5
Rhesus	6	11.6 ± 1.1
Nonprimate		
Cow	4	33.6 ± 4.8
Goat	2	25.7 ± 3.1
Sheep	6	54.1 ± 2.4
Llama	3	29.6 ± 6.9
Pig	3	35.0 ± 3.5
Horse	8	15.8 ± 3.5
Elephant	3	37.1 ± 14.6
Cat	4	75.7 ± 12.7
Rat	3	86.9 ± 7.7

[1]Values are means ± SD of the sum of all individual amino acids recovered (excluding tryptophan).
[2]Primates differed from nonprimates ($P <$ 0.001), and humans and great apes differed from lower primates ($P <$ 0.007).

total amino acid concentration, with horses having the lowest and rats the highest concentration of total amino acids.

Because the total amino acid composition of milks varies so widely among species, we calculated the concentration of individual amino acids in each milk sample relative to the sample's total amino acid concentration so that the milk amino acid patterns could be compared among species. The results for each amino acid are presented in the Appendix. We report here the quantities of those amino acids with which our initial objectives were principally concerned.

The amino acids that were in greatest abundance in all milks studied were glutamate (plus glutamine), leucine and proline, which were approximately 20%, 10% and 10%, respectively, of the total amino acids present (**Table 2**). Although there were small differences among species for each of these amino acids, there was no apparent phylogenetic trend or any one species that exhibited a unique content of these particular amino acids. However, leucine was higher in primate milks than nonprimate milks (except for cat milk), and proline was uniquely low in rat milk ($P <$ 0.001). Total essential amino acids (**Table 3**) constituted ~40% of the total amino acids in milk and did not differ significantly between primate milks and nonprimate milks. Branched-chain amino acids constituted ~20% of the total amino acids and as a group were significantly higher in primate milks than in

TABLE 2

Amino acids of greatest abundance in primate and nonprimate milks[1,2]

Species	n	Glutamate	Leucine	Proline
		mg amino acid/g total amino acid		
Primate				
Human	6	190 ± 8	104 ± 1	95 ± 5
Chimpanzee	5	221 ± 3	104 ± 2	104 ± 2
Gorilla	3	203 ± 8	102 ± 3	99 ± 6
Baboon	5	194 ± 6	105 ± 3	107 ± 6
Rhesus	6	191 ± 5	111 ± 3	112 ± 4
Nonprimate				
Cow	4	208 ± 2	99 ± 1	100 ± 4
Goat	2	209 ± 15	96 ± 3	106 ± 8
Sheep	6	203 ± 4	90 ± 4	102 ± 2
Llama	3	220 ± 1	99 ± 1	102 ± 2
Pig	3	208 ± 5	89 ± 4	117 ± 3
Horse	8	217 ± 8	93 ± 3	91 ± 8
Elephant	3	195 ± 8	98 ± 3	102 ± 4
Cat	4	208 ± 1	118 ± 1	94 ± 2
Rat	3	221 ± 8	92 ± 2	75 ± 3

[1] Values are means ± SD calculated from the content of each individual amino acid (in mg) divided by the total amino acid content (in g, excluding tryptophan).

[2] Primates differed from nonprimates for glutamate and leucine ($P < 0.001$), humans and great apes differed from lower primates for proline ($P < 0.001$), and humans differed from great apes for glutamate ($P < 0.001$).

TABLE 3

Total essential amino acids (EAA) and total branched-chain amino acids (BCAA) in primate and nonprimate milks[1,2]

Species	n	EAA	BCAA
		mg amino acid/g total amino acid	
Primate			
Human	6	400 ± 11	209 ± 5
Chimpanzee	5	392 ± 7	209 ± 2
Gorilla	3	408 ± 7	212 ± 5
Baboon	5	408 ± 4	214 ± 3
Rhesus	6	421 ± 8	220 ± 4
Nonprimate			
Cow	4	427 ± 4	199 ± 3
Goat	2	433 ± 12	206 ± 4
Sheep	6	422 ± 5	196 ± 5
Llama	3	443 ± 1	209 ± 2
Pig	3	379 ± 11	175 ± 7
Horse	8	377 ± 6	178 ± 3
Elephant	3	411 ± 11	203 ± 6
Cat	4	400 ± 3	208 ± 3
Rat	3	371 ± 6	176 ± 4

[1] Values are means ± SD calculated from the sum of individual essential amino acids or branched-chain amino acids (in mg) divided by the total amino acids (in g, excluding tryptophan).

[2] Branched-chain amino acids differed in primates vs. nonprimates ($P < 0.001$) and in humans and great apes vs. lower primates ($P < 0.001$).

nonprimate milks ($P < 0.001$). They were lowest in horse, pig and rat milks.

Although total sulfur amino acids in milk did not differ among species (except for rat milk and cat milk, which were rich in total sulfur amino acids), the relative contributions of methionine and cystine to the total sulfur amino acids in milk varied widely among species (Table 4). Primate milks had lower methionine and higher cystine than nonprimate milks ($P < 0.001$). Among the primates, the milks of the great apes and humans were lower in methionine but higher in cystine ($P < 0.001$) than the milks of lower primates, which in turn were similar to the milks of the nonprimates. In addition, human milk was significantly higher in cystine than the milks of the great apes ($P < 0.002$). However, rat milk had the highest cystine content of all the milks sampled.

Table 5 shows the amino acids that were in unique proportions in the milks of some species (although there were no statistically significant differences between primates and nonprimates for these individual amino acids). Glycine was uniquely high in pig milk. Serine and cystine were high and proline was low in rat milk. Arginine was highest in the milk of the cat but was also high in horse milk.

DISCUSSION

Bovine milk is the most common milk source for infant formula feeding even though it has been widely established that the amino acid patterns of human and bovine milk differ (Heine et al. 1991, Renner 1983). Although discussions in the literature on milk protein pattern are dominated by a comparison of human and bovine milk and it is implied that human milk is unique, the uniqueness of human milk has not been established in any systematic way. Thus, our principal objective was to determine whether the general conclusion that human milk is different from the milk of other species in its amino acid pattern is indeed valid. We hypothesized that there would be similarities in milk amino acid patterns within a phylogenetic order. Therefore, we chose to compare human and bovine milk to milk from species that were close in the phylogenetic order (i.e., human, chimpanzee, gorilla, baboon and rhesus monkey on one hand, and cow, goat, sheep and llama on the other). We further questioned whether the amino acid pattern of human milk might be related to the slow growth rate of the species; for this reason, we compared human milk with that of another slow-growing species, the elephant (McCullagh and Widdowson 1970). Other species were chosen because of specific

TABLE 4

Sulfur amino acids in primate and nonprimate milks[1,2]

Species	n	Methionine	Cystine	Total sulfur amino acids	Methionine to cystine ratio
		mg amino acid/g total amino acid			
Primate					
Human	6	16.1 ± 0.9	20.2 ± 2.6	36.3 ± 3.3	0.81 ± 0.09
Chimpanzee	5	17.0 ± 2.2	16.2 ± 1.7	33.2 ± 3.6	1.06 ± 0.11
Gorilla	3	19.8 ± 1.7	15.5 ± 1.2	35.3 ± 0.7	1.28 ± 0.20
Baboon	5	21.2 ± 1.8	10.1 ± 1.7	31.2 ± 3.2	2.13 ± 0.29
Rhesus	6	24.8 ± 2.0	11.7 ± 2.5	36.5 ± 4.1	2.18 ± 0.39
Nonprimate					
Cow	4	26.3 ± 0.9	8.9 ± 0.8	35.2 ± 0.9	2.97 ± 0.30
Goat	2	25.5 ± 2.2	8.6 ± 1.1	34.1 ± 3.3	2.97 ± 0.14
Sheep	6	28.7 ± 0.7	7.5 ± 0.5	36.3 ± 0.8	3.82 ± 0.28
Llama	3	31.1 ± 1.0	7.3 ± 0.9	38.4 ± 0.3	4.29 ± 0.66
Pig	3	21.7 ± 0.4	15.6 ± 1.3	37.3 ± 1.4	1.40 ± 0.11
Horse	8	22.0 ± 0.7	11.3 ± 2.3	33.4 ± 2.5	2.03 ± 0.46
Elephant	3	21.8 ± 2.7	10.6 ± 3.9	32.4 ± 2.6	2.36 ± 1.28
Cat	4	32.0 ± 0.6	12.1 ± 0.8	44.0 ± 1.2	2.65 ± 0.17
Rat	3	25.0 ± 0.5	25.7 ± 0.3	50.7 ± 0.6	0.97 ± 0.02

[1]Values for methionine and cystine are means ± SD calculated from the sum of each amino acid (in mg) divided by the total amino acids (in g, excluding tryptophan). Total sulfur amino acids are means ± SD of the sum of methionine and cystine values.

[2]Methionine differed in primates vs. nonprimates, humans and great apes vs. lower primates, and humans vs. elephants ($P < 0.001$). Cystine differed in primates vs. nonprimates ($P < 0.01$), humans and great apes vs. lower primates ($P < 0.001$), humans vs. great apes ($P < 0.01$), and humans vs. elephants ($P < 0.01$). The methionine to cystine ratio differed in primates vs. nonprimates, humans and great apes vs. lower primates, humans vs. great apes, and humans vs. elephants ($P < 0.001$).

taxonomic relationships of interest (Jenness 1986, Jenness and Sloan 1970). We chose species born at similar stages of maturity (such as the cow, llama, horse and pig), species that share similar ecological niches (such as the cow and horse), species that nurse on demand (such as primates and the horse), species that vary in litter size (human and cow vs. rat and pig), species that as adults have radically different dietary amino acid patterns (omnivores, herbivores and carnivores), and species that differ in site and extent of digestion (ruminants, nonruminant herbivores and nonruminants). We further questioned whether the unique amino acid needs of a species might be reflected in the amino acid pattern of the milk of that species. These unique needs include the cat's essential requirement for arginine and the sheep's, llama's and rat's need to synthesize large amounts of a tissue (i.e., hair or wool) with a radically different amino acid pattern from that of other tissues.

To determine the amino acid pattern of milk samples from a large number of species, different sampling techniques had to be used. However, it seems unlikely that the use of different sampling techniques influenced the results. For example, within one species (baboon), two of the five individual animals suckled their young just prior to sampling and three did not. Although the total amino acid concentration tended to be higher in the milk of those allowed to suckle their young before sampling (13.9 ± 0.4 vs. 10.0 ± 1.6 g/L), the amino acid pattern of the milk was the same for all baboons (data not shown). The lack of effect of sampling technique on amino acid pattern is also reflected in the small CV for each species (<10% for all amino acids).

The results of the present study show a remarkable commonality in the general amino acid pattern of milk despite the 10-fold difference in the total amino acid concentrations of the milks that we analyzed. The amino acids in greatest abundance in the milks of all species were glutamate (plus glutamine), leucine and proline, which together were 40% of the total amino acids in milk. Essential amino acids together were ~40%, branched-chain amino acids ~20%, and sulfur amino acids ~4% of the total amino acids in the milks of all species. If one accepts the idea of coevolution of milk and neonate, these results suggest a commonality in the pattern of amino acid requirements of the young of the species that we surveyed.

Nevertheless, differences in the pattern of individual amino acids were observed among species, and these differences were principally among species of different phylogenetic orders. Thus, the amino acid pattern of human milk did not seem to be unique but was similar to those of the milks of the great apes

TABLE 5

Unique differences in milk amino acid patterns among species[1]

Species	n	Glycine	Serine	Cystine	Proline	Arginine
				mg amino acid/g total amino acid		
Primate						
Human	6	22 ± 2	61 ± 4	20 ± 3	95 ± 5	36 ± 3
Chimpanzee	5	20 ± 1	41 ± 4	16 ± 2	104 ± 2	35 ± 2
Gorilla	3	22 ± 2	47 ± 3	16 ± 1	99 ± 6	35 ± 2
Baboon	5	14 ± 1	53 ± 1	10 ± 2	107 ± 6	56 ± 2
Rhesus	6	14 ± 1	48 ± 3	12 ± 3	112 ± 4	47 ± 4
Nonprimate						
Cow	4	18 ± 1	56 ± 1	9 ± 1	100 ± 4	34 ± 1
Goat	2	18 ± 2	49 ± 5	9 ± 1	106 ± 8	29 ± 1
Sheep	6	18 ± 1	52 ± 1	8 ± 1	102 ± 2	34 ± 1
Llama	3	14 ± 1	41 ± 2	7 ± 1	102 ± 2	36 ± 1
Pig	3	32 ± 1	51 ± 3	16 ± 1	117 ± 3	44 ± 1
Horse	8	16 ± 1	52 ± 8	11 ± 2	91 ± 8	60 ± 2
Elephant	3	13 ± 2	68 ± 5	11 ± 4	102 ± 4	48 ± 3
Cat	4	10 ± 1	44 ± 1	12 ± 1	94 ± 2	64 ± 1
Rat	3	15 ± 1	85 ± 2	26 ± 1	75 ± 3	33 ± 1

[1]Values are means ± SD of each amino acid (in mg) divided by the total amino acids (in g, excluding tryptophan).

and, to a lesser degree, similar to those of the milks of lower primates. The milk of the cow was most similar to those of the goat and sheep (which are of the same phylogenetic suborder) and, to a lesser degree, was similar to the milk of the llama, which is of the same order (Artiodactyla) but different suborder.

The relationship between phylogenetic order and amino acid pattern of milk is most apparent for the amino acids cystine and methionine. The primates as a whole had lower methionine and higher cystine contents in their milk compared with the artiodactyles. The human and the great apes had lower methionine and higher cystine in their milks than did the lower primates, and indeed the lower primates had methionine and cystine contents in their milks that were more similar to those of the nonprimates than to those of the great apes. Human milk had the highest cystine content of all the primate milks. Because the requirement for cystine, as a proportion of total amino acids, is higher for maintenance than for growth (Fuller et al. 1989), and because maintenance contributes a greater proportion of the nutrient requirements of slow-growing species, we questioned whether the high cystine content in the milks of the human and the great apes might be related to the slow growth of these species. However, comparison of the cystine content of milks from the human and the elephant, another slow-growing species (McCullagh and Widdowson 1970), suggests that the amino acid pattern of human milk is unrelated to growth rate. This conclusion is supported by the lack of close similarity between human and elephant milk for

other individual amino acids, as well as the observation that milk from the rat, a rapidly growing species, had the highest cystine content in its milk of all species surveyed.

Although comparison of milk amino acid patterns among species by specific classifications such as stage of maturity at birth, litter size and nursing schedule revealed little relationship, there did seem to be some relationship between milk amino acid content and the unique amino acid needs of some species. The high content of arginine that we found in cat milk and that others have found in the milk of the tiger (Bock 1984) may be related to the high arginine requirement of felines (Morris 1985). However, milk from the horse was also relatively high in arginine. Because we (Davis et al. 1993) had previously found the serine content of rat milk to be higher than available literature values for the milks of other species except the sheep (USDA 1976), we speculated that a high serine content in milk might be related to the need to synthesize large quantities of hair or wool; serine is required for the synthesis of cystine, and there is a proportionally high abundance of cystine in hair and wool proteins. However, in the current study we found that sheep and llama milks were not serine rich, and thus the rat was unique among species sampled in its high serine content in milk. This high serine and cystine but low proline content in rat milk is in agreement with a previously published description of the amino acid composition of rat casein (Woodward and Messer 1976). Additionally, pig milk was unique in its high glycine content, consistent with previously reported values for sow milk (Elliott et al. 1971).

We conclude that human milk is not unique in its amino acid pattern but is similar to the milks of other primates, particularly the great apes. Because the vast majority of milk amino acids are derived from milk proteins, our results support a recent study that showed that the protein compositions of rhesus monkey milk and human milk are similar (Kunz and Lonnerdal 1993). On the same basis, however, we would predict that the similarity in the protein composition of the milks of the great apes and that of human milk would be even closer.

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APPENDIX TABLE 1

Amino acids in primate and nonprimate milks[1]

Species	n	Asp	Glu	Ser	Gly	His	Arg	Thr	Ala	Pro	Tyr	Val	Met	Cys	Ile	Leu	Phe	Lys
							mg amino acid/g total amino acid											
Primate																		
Human	6	86 ± 9	190 ± 8	61 ± 4	22 ± 2	23 ± 2	36 ± 3	44 ± 1	40 ± 2	95 ± 5	46 ± 2	51 ± 2	16 ± 1	20 ± 3	53 ± 3	104 ± 3	37 ± 1	71 ± 6
Chimpanzee	5	88 ± 4	221 ± 4	41 ± 4	20 ± 1	22 ± 1	35 ± 2	39 ± 2	38 ± 2	104 ± 2	43 ± 1	56 ± 2	17 ± 1	16 ± 2	50 ± 3	104 ± 3	37 ± 2	68 ± 3
Gorilla	3	89 ± 2	203 ± 8	47 ± 3	22 ± 2	25 ± 1	35 ± 2	43 ± 4	39 ± 2	99 ± 6	42 ± 1	56 ± 2	20 ± 2	16 ± 1	54 ± 1	102 ± 3	38 ± 1	71 ± 2
Baboon	5	80 ± 4	194 ± 6	53 ± 1	14 ± 1	21 ± 2	56 ± 2	39 ± 1	38 ± 2	107 ± 6	40 ± 1	55 ± 3	21 ± 2	10 ± 2	54 ± 1	105 ± 3	43 ± 2	69 ± 6
Rhesus	6	73 ± 8	191 ± 5	48 ± 3	14 ± 1	20 ± 2	47 ± 4	40 ± 2	40 ± 2	112 ± 4	41 ± 1	52 ± 2	25 ± 2	12 ± 3	57 ± 3	111 ± 3	44 ± 1	72 ± 6
Nonprimate																		
Cow	4	70 ± 5	208 ± 2	56 ± 1	18 ± 1	24 ± 1	34 ± 1	42 ± 1	32 ± 1	100 ± 4	47 ± 1	52 ± 2	26 ± 1	9 ± 1	47 ± 1	99 ± 1	50 ± 1	86 ± 2
Goat	2	75 ± 1	209 ± 15	49 ± 5	18 ± 1	26 ± 1	29 ± 1	49 ± 1	34 ± 5	106 ± 8	38 ± 1	61 ± 1	25 ± 1	9 ± 1	48 ± 1	96 ± 3	47 ± 1	80 ± 10
Sheep	6	75 ± 2	203 ± 4	52 ± 1	18 ± 1	26 ± 1	34 ± 1	41 ± 1	40 ± 1	102 ± 2	47 ± 2	57 ± 2	29 ± 2	8 ± 1	49 ± 1	90 ± 4	48 ± 1	83 ± 3
Llama	3	71 ± 1	220 ± 1	41 ± 2	14 ± 1	29 ± 1	36 ± 1	44 ± 1	25 ± 1	102 ± 2	40 ± 1	55 ± 1	31 ± 1	7 ± 1	55 ± 1	99 ± 1	46 ± 1	83 ± 3
Pig	3	78 ± 5	208 ± 5	51 ± 3	32 ± 1	24 ± 1	44 ± 1	37 ± 1	36 ± 2	117 ± 3	39 ± 1	46 ± 1	22 ± 1	16 ± 1	40 ± 2	89 ± 4	43 ± 3	79 ± 5
Horse	8	95 ± 5	217 ± 3	52 ± 8	16 ± 1	22 ± 2	60 ± 2	39 ± 2	37 ± 1	91 ± 8	45 ± 4	47 ± 2	22 ± 1	11 ± 1	39 ± 1	93 ± 3	43 ± 3	73 ± 5
Elephant	3	64 ± 10	195 ± 8	68 ± 5	13 ± 1	22 ± 1	48 ± 3	41 ± 1	39 ± 1	102 ± 4	52 ± 5	55 ± 2	22 ± 3	11 ± 4	50 ± 3	98 ± 3	48 ± 1	75 ± 3
Cat	4	86 ± 4	208 ± 1	44 ± 1	10 ± 1	27 ± 1	64 ± 1	46 ± 1	37 ± 1	94 ± 2	45 ± 1	47 ± 1	32 ± 1	12 ± 1	43 ± 1	118 ± 1	30 ± 1	57 ± 1
Rat	3	88 ± 4	221 ± 8	85 ± 1	15 ± 1	22 ± 1	33 ± 1	40 ± 1	59 ± 2	75 ± 3	36 ± 1	44 ± 1	25 ± 1	26 ± 1	40 ± 2	92 ± 2	39 ± 4	68 ± 1

[1] Values are means ± SD of each amino acid (in mg) divided by the total amino acids (in g, excluding tryptophan).