Mothers Milk: Evolutionary Perspectives & Cultural Contexts

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Mother's milk represents not only infant nutrition, but also important medicine and signal, consisting of thousands of "bioactives" that are highly personalized within a mother-infant dyad in a specific time and place.[1] Maternal health, nutrition, cultural ecology, reproductive history, early-life conditions, and genetics all contribute to differences in milk synthesis. Less understood are the behavioral biology of lactation and the consequences of inter-individual variation in milk bioactives for the infant.

Variation of Mother's Milk

Inter-individual variation in fats, proteins, sugars, minerals, hormones, bacteria, and other constituents in mother's milk are associated with differences in both maternal factors and infant factors (**Table 1**). Further, mother's milk is not a static substance, adapting to up-regulate or down-regulate aspects of breast milk synthesis and breastfeeding behavior, as needed.

Maternal and Infant Energy Allocation

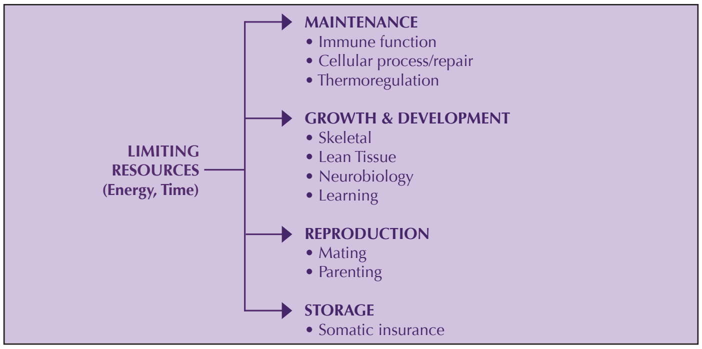
Throughout life, individuals must allocate energy among different biologic "imperatives" (**Figure 1**).[2,3] For infants, this means balancing maintenance (ie, staying alive) versus growth and development. Growth and weight gain are important goals for infants in neonatal intensive care units (NICUs); however, in some instances these infants may not achieve desired weight gains due to differential allocation of energy resources.

Differential allocation of resources also creates a parent-offspring conflict. Offspring are programed to pull as much of its mother's resources as possible, whereas mothers are programmed to provide for current offspring as well as conserve energy for future reproduction and potential offspring.[4] Thus, some mothers may not produce as much milk as their infant(s) want or need.

Table 1.
Variation in mother's milk.

Sources of variation	Magnitude of variation in breast milk	Consequences of variation
Maternal • Life history (including parity) • Nutrition/diet • Health • Body condition • Birth experience • Social support Infant • Health • Gestational age • Gender	• Macro- and micronutrients • Hormones • Bacteria • Immune factors • Stem cells	Infant • Growth and development • Behavior and temperament • Immune function • Cognition • Bacterial colonization

Figure 1.
Allocation of biologic imperatives.



The Exceptional Properties of Human Milk

The basic components of human breast milk appear to be generally similar to those of other primates. However, there are 3 key unique features of human milk: the proteome, the presence of HIV-cidal factors, and the oligosaccharide profile.

The overall protein content of human milk is lower than that of rhesus macaque monkeys, but the levels of conserved milk proteins related to digestive assistance (eg, α-1-antitrypsin), macronutrient processing (eg, haptocorrin, lactoferrin), and immune function (eg, polymeric Ig receptor, Ig κ and λ chains, secretory IgA, complement proteins) are much higher in human milk.[5]

The HIV-cidal activity of human breast milk is suggested by the high proportion (85%) of infants breastfed by HIV+ mothers who do not acquire HIV infection, despite the presence of virus in the milk. Notably, this activity is observed regardless of the mother's HIV status and is fairly unique to human milk, with milk from other species demonstrating dramatically reduced HIV-cidal activity. It is thought that multiple factors may contribute to this activity, but the mechanisms involved are not yet understood.[6]

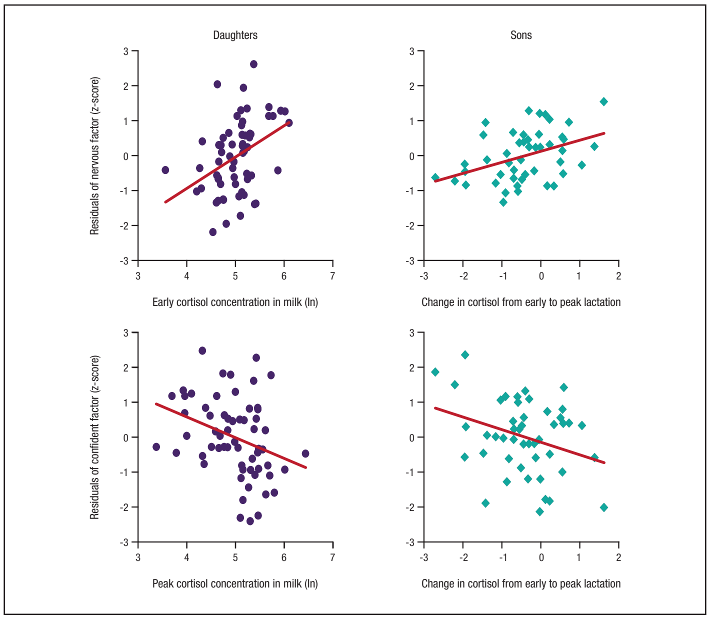
The oligosaccharides present in human milk are also unique, even in comparison with other primates, with regard to the levels of diversity and complexity.[7] Human milk oligosaccharides have evolved through selection pressures to help control bacteria in infants. Although the overall concentration of human milk oligosaccharides if fairly consistent among individuals, the presence of specific oligosaccharides varies widely.[8] Oligosaccharides competitively inhibit the attachment of pathogenic bacteria to infant intestinal epithelium and/or provide nutritive substrates for beneficial commensals that serve essential immunologic roles and contribute to the bioavailability of ingested nutrients.

Mother's Milk and Infant Behavior

While the immunologic and nutritional impacts of breast milk and microbiota are increasingly well understood, the consequences for infant behavior are less clear. Dr. Hinde and colleagues proposed that interactions among bioactives in mother's milk and microbes in the infant gut contribute to infant behavioral phenotype. To test this theory, milk was collected from 108 lactating rhesus macaque monkeys at 1 month (when infants first started walking and playing) and at 3 to 4 months (when infants initiate exploration of solid foods) after giving birth, and analyzed for energy density, yield, and cortisol concentration. Morphometrics and biobehavioral assessments were also performed.[9]

High cortisol concentrations in the mothers' milk at 1 month after giving birth corresponded with more nervous and less confident offspring at 3 to 4 months, and low cortisol concentrations corresponded with more confident, less nervous offspring. Interestingly, male and female offspring responded differently to changes in cortisol levels, with sons more sensitive to dynamic changes and daughters more sensitive to absolute changes (**Figure 2**).[9]

Figure 2.
Influence of milk cortisol on infant temperament factors by infant sex.[9]



Maternal parity also predicts the cortisol concentration of milk and thus offspring behavior. Lower-parity rhesus macaque mothers (younger, early pregnancy) had higher concentrations of cortisol and lower available energy density in their milk than mothers with higher parity.[9] The elevated cortisol level may help to program a "less costly" infant that requires a lower activity budget by inhibiting exploration behavior (more nervous, less confident temperament), thereby conserving energy for future offspring.

Constraints, such as ample/absent social support, low/high pathogen or predator risk, and easy/difficult food acquisition, can also impact the mother-infant dyad and the contents of mother's milk. In situations of minimal constraint, resources can be allocated to promote both growth and behavioral development of infants; conversely, in situations of severe constraint, both growth and behavior will be delayed. In situations of mild constraint, however, either growth or behavioral development will need to be prioritized, as resources are not available to prioritize both. Mother's milk may be able to help drive necessary prioritization of resources directly through cortisol concentration and indirectly through influence on the infant's gut microbiome.[10]

Looking Toward Optimization of Human Milk

An evolutionary perspective is essential to better understand mother's milk and to enhance personalized clinical recommendations and health optimization for mothers and their infants. As clinicians think about "precision human milk" for newborn infants, particularly preterm infants with increased needs, there are several questions that require consideration:

- Should donor milk be matched to the time of day? Gender? Across genotypes?
- Should human milk be enhanced (eg, increasing the complexity of the oligosaccharide profile)?
- How might co-opting non–human milk bioactives help to solve specific infant challenges?
- What impacts might adjustment of specific human milk components have on infant development (eg, immune function, neural development)?

References

1. Hinde K, German JB. Food in an evolutionary context; insights from mother's milk. *J Sci Food Agric*. 2012;92(11):2219-2223.
2. Gadgil M, Bossert WH. Life historical consequences of natural selection. *Amer Naturalist*. 1970;104:1-24.
3. Stearns SC. *The Evolution of Life Histories*. London: Oxford Press, 1992.
4. Trivers RL. Parent-offspring conflict. *Amer Zoologist*. 1974;14(1):249-264.
5. Beck KL, Weber D, Phinney BS, et al. Comparative proteomics of human and macaque milk reveals species-specific nutrition during postnatal development. *J Proteome Res*. 2015;14(5):2143-2157.
6. Wahl A, Baker C, Spagnuolo RA, et al. Breast milk of HIV-positive mothers has potent and species-specific in vivo HIV inhibitory activity. *J Virol*. 2015;89(21):10868-10878.
7. Tao N, Wu S, Kim J, et al. Evolutionary glycomics: characterization of milk oligosaccharides in primates. *J Proteome Res*. 2011;10(4):1548-1557.
8. Smilowitz JT, O'Sullivan A, Barile D, et al. The human milk metabolome reveals diverse oligosaccharide profiles. *J Nutr*. 2013;143(11):1709-1718.
9. Hinde K, Skibiel AL, Foster AB, et al. Cortisol in mother's milk across lactation reflects maternal life history and predicts infant temperament. *Behav Ecol*. 2015;26(1):269-281.
10. Allen-Blevins CR, Sela DA, Hinde K. Milk bioactives may manipulate microbes to mediate parent-offspring conflict. *Evol Med Public Health*. 2015;2015(1):106-121.