

How Breastfeeding Works

Jacqueline C. Kent, PhD

Human milk is a complex secretion that is the sole ideal food for babies for at least the first 6 months of life. The amount and composition of the milk is largely independent of the mother's diet. The composition of the milk changes during lactogenesis II, and these changes can be used as biochemical markers of the onset of copious milk secretion. After 1 month of lactation, there are few further changes in the composition of milk until the volume of milk decreases substantially as the baby weans completely. The amount of milk produced depends on the amount of milk removed from the breast. Successful, exclusively breastfeeding babies show a three-fold variation in the amount of milk they take per day, and in the frequency of breastfeeds and amount of milk consumed during each breastfeed. The fat intake of the baby is independent of the feeding frequency. If a baby is growing normally, the mother can be confident that her baby does not need to follow prescribed breastfeeding regimes. She should respond to her baby's cues for the frequency of breastfeeds, and whether the baby requires one or both breasts for a meal. Continuing research into the physiology of breastfeeding provides a foundation for evidence-based treatment of breastfeeding difficulties. *J Midwifery Womens Health* 2007;52:564–570 © 2007 by the American College of Nurse-Midwives.

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INTRODUCTION

Because milk is the sole source of food for young mammals, it must provide all the nutrients essential for their growth. Therefore, the mammary gland must synthesize and secrete sufficient milk of appropriate composition to nourish the young, and the young must be able to remove the milk to sustain their growth and ensure continued milk production. This article reviews the synthesis and secretion of breast milk, the changes in the volume and composition of breast milk after birth, the breastfeeding patterns of babies, and the methods by which babies can regulate the milk production of the mother.

MILK COMPOSITION

Breast milk is synthesized in the lactocytes that line the alveoli of the mammary gland. Blood capillaries surround the alveoli. Substrates (glucose, amino acids, fatty acids, minerals, and vitamins) diffuse from the blood to the basement membrane of the lactocytes and are used for the synthesis of milk components. These are then secreted across the apical membrane of the lactocyte into the lumen of the alveolus.¹

The milk that is secreted is composed of nitrogenous components (proteins including caseins, alpha-lactalbumin, immunoglobulins, albumin, lactoferrin, nonprotein nitrogen, enzymes, hormones, growth factors, and nucleotides), fats (triglycerides and fatty acids), carbohydrates (lactose, glucose, galactose, and oligosaccharides), minerals, electrolytes, trace elements, vitamins, and water.² Although all mammals produce milk containing similar

components, the concentrations of these components vary markedly between species. This supports the common wisdom that the milk of one species is specifically adapted to the growth of the young of that particular species,^{3,4} and breast milk is ideally adapted to the needs of the developing infant. Therefore, milk from other species is unsuitable as a substitute.

Effect of Maternal Diet on Milk Volume and Composition

There is little variation between population groups in the volume of milk produced, with mothers in developing countries producing as much milk as mothers from developed countries.⁵ Milk production and gross composition (lactose, fat, and protein) are largely independent of the mother's diet,^{5–7} even during Ramadan fasting.⁸ The energy content of the milk is determined by the concentrations of lactose, fat, and protein. The average milk production of an exclusively breastfeeding mother is about 750 mL per day and the energy required to produce that milk is about 630 kcal per day. This represents a quarter of the total energy intake of a lactating woman (2400 kcal/day).⁹ In addition, fat reserves deposited during pregnancy are reabsorbed during lactation. The degree to which this occurs will depend on the difference between the actual energy cost of lactation and the increase in the mother's energy intake.⁹ On average, breastfeeding mothers lose 2 kg more body weight over 6 months of lactation compared with mothers who do not breastfeed.¹⁰

It is particularly important for breastfeeding mothers to eat a well-balanced diet. Although the mother's diet does not affect the concentrations of lactose, fat, and protein in breast milk, diet does affect the concentrations of some vitamins and minerals in breast milk.⁸ There is a relationship between the content of vitamins A, B1 (thiamin), B2 (riboflavin), B5 (pantothenic acid), B6 (pyridoxine), B12 (cobalamin), D, and E, and selenium

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and iodine in human milk and the maternal diet.^{11,12} Breastfed infants of vegan mothers may need supplements of vitamin B12 if their maternal diet is inadequate.¹³ Although the total fat content of breast milk is unaffected by diet, the proportions of the different fatty acids will vary according to the types of fat the mother is consuming. For example, the proportions of omega-3 polyunsaturated fatty acids (such as docosahexanoic acid) and omega-6 polyunsaturated fatty acids (such as arachidonic acid) are very different in the breast milk of vegan and omnivorous mothers.¹⁴ This is important, because there is a positive association between the quantity of omega-3 fatty acids in the diet and infant brain development.^{15–17}

LACTOGENESIS I

Lactogenesis I is the stage in which the mammary glands develop the ability to secrete milk components during the second trimester of pregnancy.¹⁸ It has been calculated that approximately 30 mL of colostrum per day can be secreted during late pregnancy.¹⁹ The increase in one of the secreted components, lactose, is associated with an increase in the concentration of prolactin in the blood.²⁰ Because the secretion is not removed by suckling, the components are reabsorbed into the bloodstream.²¹ Lactose is not metabolized in the blood and is cleared in the urine.²² Urinary lactose can therefore be used as an indicator of lactose synthesis in the breast during pregnancy and can confirm that lactogenesis I has occurred.²³

LACTOGENESIS II

Hormonal Changes

Lactogenesis II, which is the onset of copious milk secretion, occurs soon after birth. Lactogenesis II requires adequate levels of prolactin, insulin, and adrenal cortisol,²⁴ and is triggered by the withdrawal of circulating progesterone after birth.²⁵ In addition, thyroid hormone is important, because hypothyroid animals cannot initiate lactation.^{1,26} Lactogenesis II is sensed by mothers as a sudden increase in the fullness of the breasts as the milk comes in. This occurs at about 60 hours postpartum, but can range between 24 and 102 hours after birth.^{18,27}

Each time the baby breastfeeds, oxytocin is released into the circulation (see Geddes, page 556)²⁸. Little milk can be removed from the breast unless a milk ejection involving the release of oxytocin has been triggered. The amount of milk taken by a baby is related to the number of milk ejections independent of the time spent at the breast.²⁹ Ramsay et al.²⁹ found that more than one third of the breastfeeds were terminated by the baby during

a milk ejection, suggesting that the baby is controlling its milk intake, rather than being limited by the number of milk ejections.

Volume Changes

For the first breastfeed, within 60 minutes of birth, babies take 0 to 5 mL of colostrum. In the first 24 hours after birth, babies generally have 3 to 8 breastfeeding sessions and consume between 7 and 123 mL of colostrum.^{27,30} From 2 to 6 days after birth, they have five to 10 breastfeeding sessions, and the milk intake increases rapidly to between 395 and 868 mL.^{27,30–32} By 1 month, milk intake averages 750 to 800 mL per day.^{10,33,34} Milk production on day 6 is significantly associated with milk production at week 6.³⁵

Composition Changes

Lactogenesis II is not just an increase in the volume of milk secreted, but also a stage in which the composition of milk changes dramatically. The thick colostrum secreted initially consists of high concentrations of proteins (principally the protective immunoglobulins, lysozyme, and lactoferrin), relatively high concentrations of sodium and chloride, and low concentrations of casein, lactose, potassium, citrate, calcium, and phosphate. During lactogenesis II, there are increases in the lipid content and concentrations of casein, lactose, potassium, citrate, calcium, and phosphate, while the concentrations of total protein, sodium, and chloride decrease.^{26,36–38} These changes occur within the first 5 days after birth, and the changes in the concentrations of lactose, citrate, protein, and sodium have been used as biochemical markers of lactogenesis II.^{27,39} The concentrations reached on day 5 are similar to the concentrations 1 month after birth.

ESTABLISHED LACTATION

Milk Volume and Composition

From 1 to 6 months after birth, during exclusive breastfeeding, the milk production for each baby is relatively stable.^{33,34} Milk production of mothers who are exclusively breastfeeding singletons up to 6 months old is 710 to 803 mL per day.⁹ When milk production is measured twice within 1 week, there is very little variation.⁴⁰ However, not all babies take the same amount of milk. Exclusively breastfeeding babies growing normally may have a daily intake of 440 to more than 1220 mL per day.^{33,41} The concentration of lactose shows no significant change with stage of lactation. However, there are declines in the total fat content of the milk between 1 and 2 months, in the concentration of protein between 1 and 6 months,⁴² and in the concentration of calcium between 4 and 6 months.⁴³ The growth rate of breastfed babies is related to the total amount of milk they consume, rather than the concentration of fat, protein, or lactose.^{41,44}

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Breast Volume and Storage Capacity

The development and application of the Computerized Breast Measurement System⁴⁰ has demonstrated the concepts of breast milk storage capacity, available milk, and how the baby feeds according to appetite.

Storage Capacity

Over the course of 24 hours, there is one occasion before a breastfeed when the breast volume is at its maximum, indicating when the breast contains the most milk for the 24-hour period, or that the breast is as full as the baby allows it to get during its normal breastfeeding pattern. At another time during the 24 hours, the breast volume is at its minimum, indicating when the breast contains the least milk for the period, or that the breast is as fully drained as the baby is able to or wishes to leave it. The difference between the maximum and minimum breast volumes is attributed solely to the milk in the breast. That is, when the breast is at its maximum volume for the day, the storage capacity of the breast dictates the amount of milk available to the baby. Breastfeeding storage capacities in mothers who are exclusively breastfeeding range from 81 to 606 mL.⁴⁰ The breastfeeding storage capacity is not necessarily unchangeable for each mother. During extended lactation, as supplementary feeds are introduced and milk production decreases, the breastfeeding storage capacity decreases.⁴¹ An unusually long interval between breastfeeds will result in distension of the breast and more milk available to the baby. This will result in a potential storage capacity that is larger than the breastfeeding storage capacity.⁴⁵

Available Milk

Although milk is synthesized continuously in the breast, the breast does not always reach its maximum

volume before the baby wishes to feed again. The difference between the volume of the breast at the beginning of the feed and the minimum volume of the breast during the 24-hour period is the amount of milk available to the baby for that feed.

Appetite

Measurement of breast volume before and after each breastfeed for 24 hours has shown that babies will normally drain the breast one or more times each day, but do not drain the breast at each feed.⁴⁰ On average, the baby takes only 67% of the available milk.³³ This indicates that babies feed according to appetite and do not stop feeding because the breast is empty.

The creatocrit method, which measures the fat content of breast milk, provides a clinical assessment of volume of milk in the breast.³³ There is a strong relationship between the degree of fullness of the breast and the fat or cream content of the milk (Figure 1). The maximum breast volume (when the breast is full) is associated with the minimum fat content of the milk, and the minimum breast volume (when the breast is well drained) is associated with the maximum fat content of the milk. Although there is significant variation between mothers, if a milk sample collected before a breastfeed has a fat content of less than 4%, that indicates that the breast was reasonably full with a significant amount of milk available for the baby. Moreover, if a milk sample collected after a breastfeed has a fat content of more than 10%, this indicates that the breast was reasonably well-drained and that the baby has taken most of the available milk.

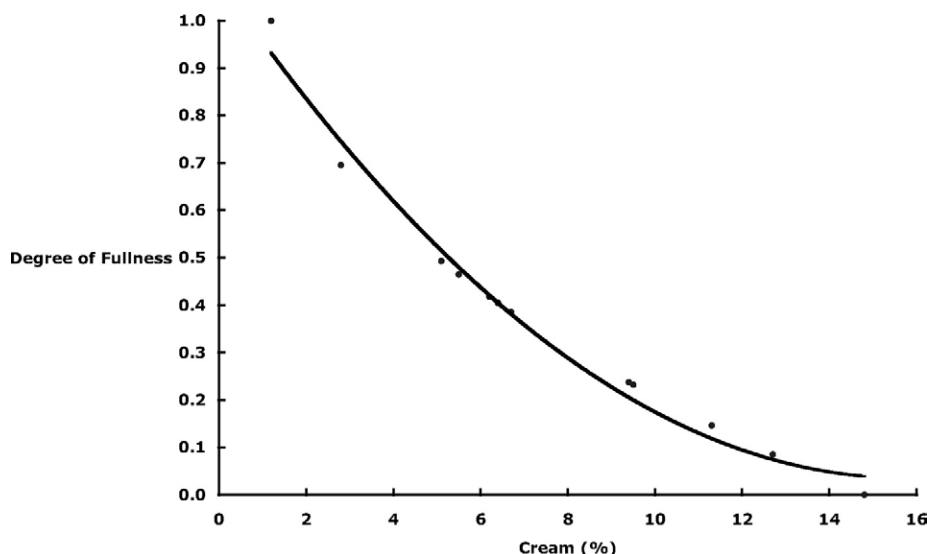


Figure 1. Milk fat content and fullness of the breast. Relationship between the degree of fullness of the breast and the fat content of the milk.

MAINTAINING LACTATION

Demand and Supply

The mechanisms for matching the milk production and infant appetite are still unclear. It has been suggested⁴⁶ that prolactin plays a role in the control of the amount of milk produced. When the baby breastfeeds, prolactin is released from the anterior pituitary in the brain and reaches a peak in concentration in the blood 45 minutes after the commencement of suckling.⁴⁷ However, over the first 6 months of lactation, basal prolactin concentrations decrease from 119 to 59 $\mu\text{g/l}$, and similarly, peak concentrations decrease from 286 to 91 $\mu\text{g/l}$,³⁴ while daily milk production remains constant. Therefore, prolactin does not control the amount of milk produced³⁴ once lactation is established.

Because babies feed according to appetite, the mother's milk production is regulated to match the baby's milk intake, rather than the baby's consumption all of the milk that the breast produces. The rate of milk synthesis has been shown to be related to the degree to which the breast has been drained after a feed; the subsequent rate of milk synthesis is higher if the breast is well-drained.⁴⁸ This is consistent with animal studies that have shown that the short-term rate of milk synthesis is controlled within the mammary gland by autocrine (local) factors, such as the feedback inhibitor of lactation, that respond to how much milk has been removed from the gland.⁴⁰

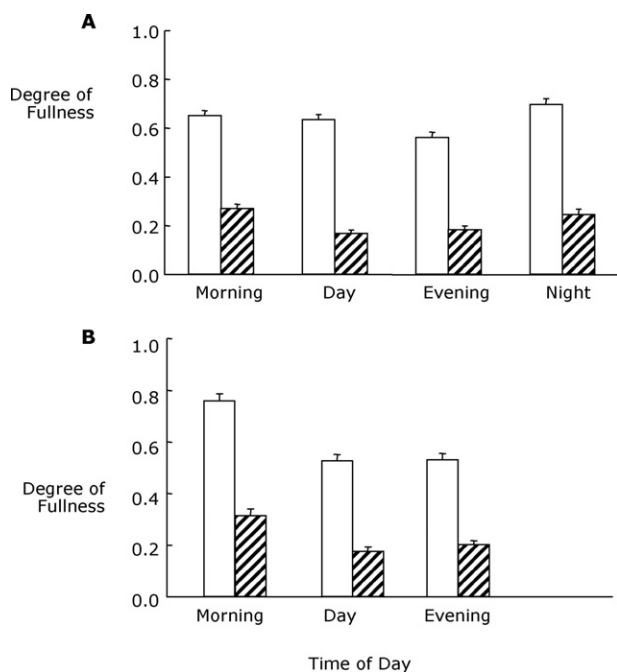


Figure 2. Time of day and fullness of the breast. The degree of fullness of the breast before (white bars) and after (striped bars) breastfeeds at different times of day for babies who do feed at night (A) and who do not feed at night (B). Morning is considered to be 0401–1000 hours, day is 1001–1600, evening is 1601–2200, and night is 2201–0400.

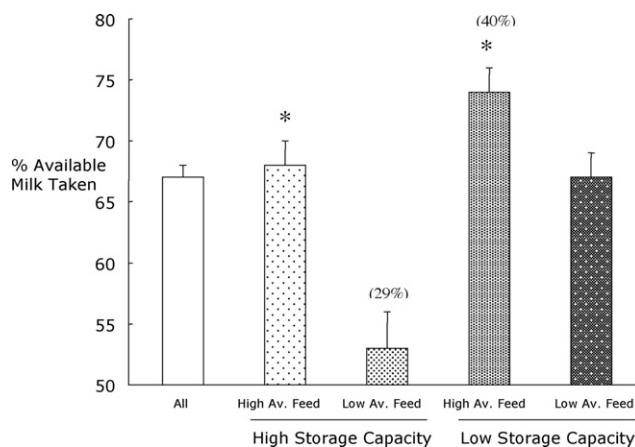


Figure 3. Breast milk storage capacity and milk intake. The mean \pm SEM percent of available milk taken at a breastfeed by babies who take breastfeeds >76 mL (high av. feed) or <76 mL (low av. feed) of mothers with total (left and right) breast milk storage capacity >360 mL (high storage capacity) or <360 mL (low storage capacity). Numbers in parentheses are % of babies in category.

*Significantly different from low av. feed ($P < .001$).

The left and right breasts rarely produce the same amount of milk. Anecdotally, mothers often refer to having one “good” breast, or that the baby prefers one breast to the other. Data on 24-hour milk production of individual breasts confirm that one breast is usually more productive than the other—in seven out of 10 mothers, it is the right breast that is more productive. This difference is not associated with handedness, nor do the mothers favour the more productive breast by preferentially offering it before the other.³³

Breastfeeding Patterns

Current recommendations are to feed babies “on demand,”⁴⁹ therefore, there is no prescribed pattern for breastfeeding babies. Detailed studies show that not only do babies show a three-fold variation in the amount they take per day, they also show a wide variation in their patterns of milk intake.^{33,50} During a meal or a breastfeeding session, the baby may feed from one breast only (an unpaired breastfeed), feed from both breasts within 30 minutes (two paired breastfeeds), or the baby may have a cluster of breastfeeds (feeding again from the first breast within 30 minutes of feeding on the second). In a recent study of exclusively breastfeeding babies between 1 and 6 months old in Western Australia,³³ 13% of babies always took paired breastfeeds, 30% of babies always took unpaired breastfeeds, and most babies had paired and unpaired breastfeeds. On average, the babies took 11 breastfeeds per day, but ranged from six to 18 feeds per day. They took these breastfeeds as eight meals (or breastfeeding sessions) per day on average, but ranged

from four to 13 meals per day. That is, it was normal for these babies to have a breastfeeding session of one or two breastfeeds as often as once every 1 hour 50 minutes, or as widely spaced as once every 6 hours.

Not all breastfeeds are equivalent. While the average amount of milk taken from one breast was 76 mL, a breastfeed can range from being negligible to 240 mL. For individual babies the average intake from a breastfeed over a 24-hour period ranged from 30 to 135 mL. The amount of milk taken at a breastfeed depended on whether the feed was from the more productive or less productive breast, whether the feed was unpaired or paired, the fullness of the breast, and the time of day. Two-thirds of the babies fed at night, and for these babies this was often the time of the biggest breastfeed from a full breast. Babies who did not feed at night usually had their largest breastfeed in the morning, and that was when the breasts were usually full. The amount of milk remaining in the breast after morning feeds was higher than during the remainder of the day (Figure 2).

Calculations of breast milk storage capacity of mothers range from 74 to 382 mL.^{33,41} There is a significant tendency ($P < .01$) for babies of mothers with smaller storage capacities to feed more frequently than babies of mothers with larger storage capacities. On average, babies take 67% of the available milk. However, 29% of babies of mothers with high storage capacity choose to take smaller feeds even though more milk is available, and 40% of babies of mothers with low storage capacity choose to take larger feeds and drain the breast more thoroughly at each breastfeed (unpublished data; Figure 3).

Mothers of babies who take frequent small breastfeeds are concerned that the baby is not getting the high fat hind-milk. When babies take six to nine large breastfeeds (95 ± 3 mL, mean \pm standard error of the mean [SEM]) each day, the breast changes from full or nearly full to quite well-drained during each breastfeed, and the fat content of the milk changes from low fat fore-milk ($4.3\% \pm 0.2\%$ cream) to high fat hind-milk ($10.7\% \pm 0.23\%$ cream). When babies take 14 to 18 small breastfeeds (49 ± 2 mL) each day the fore-milk of these mothers is significantly higher in fat ($4.8\% \pm 0.14\%$ cream) and the hind-milk is lower in fat ($8.2\% \pm 3.0\%$ cream) compared to the less-frequent feeders (unpublished results). However, there is no significant difference between the two patterns of feeding and the total fat intake of the baby (33 ± 2 g and 28 ± 3 g, for low and high frequency feeders, respectively). Mothers can be reassured that the fat intake of babies is independent of the frequency of breastfeeding.³¹ Examples of these two patterns of fat changes are shown in Figure 4.

EXTENDED LACTATION AND INVOLUTION

The World Health Organization recommends exclusive breastfeeding for the first 6 months of life, and partial breastfeeding into the second year.⁴⁹ During extended

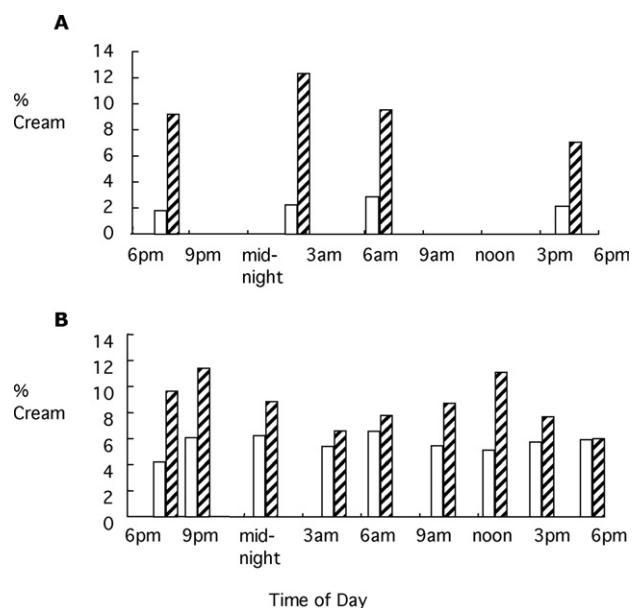


Figure 4. Breastfeeding frequency and milk fat content. The fat content (expressed as % cream) of the milk of a mother who breastfeeds infrequently (A) and a mother who breastfeeds frequently (B) before (white bars) and after (striped bars) each breastfeed.

lactation, beyond the 6-month period of exclusive breastfeeding, there are changes in the volume and composition of breast milk. As complementary feeds are introduced, milk production decreases to reach 95 to 315 mL per day at 15 months,^{37,41} but can remain as high as 300 mL per day up to 30 months.⁵¹ During this gradual weaning after 6 months, there are decreases in the concentrations of glucose, citrate, phosphate, and calcium, and increases in the concentrations of fat, lactose, protein, and sodium.

The amount of breast tissue remains constant from 1 to 6 months of lactation, but decreases significantly between 6 and 9 months, when there is a only a small decrease in milk production. The breasts return to their preconception size by 15 months of lactation.⁴¹ Therefore, mothers can be reassured that a decrease in the feeling of fullness of the breasts does not mean that there is little or no milk production. Involution of the breast occurs in two phases: the lactocytes are first removed by apoptosis, and then the surrounding stroma is remodelled and the adipocytes redifferentiate.⁵² After complete weaning,⁵³ some mammary secretion can still be expressed for at least 6 weeks. During this time, the concentrations of lactose and potassium decrease while sodium, chloride, fat, and total protein increase, with the concentrations of casein, alpha-lactalbumin, immunoglobulins, albumin, and lactoferrin contributing to the increase in total protein.⁵³

SUMMARY

Human milk is a complex secretion that is the sole ideal food for babies for at least the first 6 months of life. The

amount and composition of the milk is largely independent of the mother's diet. The composition of the milk changes during lactogenesis II, and these changes can be used as biochemical markers of the onset of copious milk secretion. After 1 month of lactation, there are few further changes in the composition of milk until the volume of milk decreases substantially as the baby weans completely. The amount of milk produced depends on the amount of milk removed from the breast. Successful, exclusively breastfeeding babies show a three-fold variation in the amount of milk they take per day, and in the frequency of breastfeeds and amount of milk consumed during each breastfeed. The baby's fat intake is independent of feeding frequency. If a baby is growing normally, the mother can be confident that her baby does not need to follow prescribed breastfeeding regimes. She should respond to her baby's cues for the frequency of breastfeeds, and whether the baby requires one or both breasts for a meal.

Continuing research into the physiology of breastfeeding provides a foundation for evidence-based treatment of breastfeeding difficulties.

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“If a multinational company developed a product that was a nutritionally balanced and delicious food, a wonder drug that both prevented and treated disease, cost almost nothing to produce and could be delivered in quantities controlled by the consumers’ needs, the very announcement of their find would send their shares rocketing to the top of the stock market. The scientists who developed the product would win prizes and the wealth and influence of everyone involved would increase dramatically. Women have been producing such a miraculous substance, breast milk, since the beginning of human existence. . .”

–Gabrielle Palmer, *The Politics of Breastfeeding*, First Edition: Pandora Press, an imprint of Unwin Hyman, London 1988.

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