# The Milky Way: The implications of using animal milk products in infant feeding

**Rachel HOWCROFT,**
**Gunilla ERIKSSON**
**Kerstin LIDÉN**
Archaeological Research Laboratory
Stockholm University
SE-106 91 Stockholm, Sweden.
rachel.howcroft@arklab.su.se

Howcroft R., Eriksson G. & Lidén K. 2012. – The Milky Way: The implications of using animal milk products in infant feeding. *Anthropozoologica* 47.2 : 31-43.

Animal milks have been used in infant feeding for at least a few millennia, but this can only have become a common practice after the domestication of dairy animals during the Neolithic. Neolithic population increase has often been attributed to the effect of a reduction in breastfeeding duration on female fertility. It is possible, therefore, that animal milks were first introduced to the infant diet at this time as a replacement for the lost breastmilk. Milks are complex liquids and are species specific. The consumption of the milk of one species by the infants of another thus has implications for the welfare of those infants. This paper reviews some of the differences between the milks of three ruminant species and human milk and discusses what the health consequences of introducing these animal milks to the infant diet are likely to have been. It is argued that, except in extreme circumstances, animal milks would fail to adequately compensate for the reduction in breastmilk consumption. Fermented milk products could however have been valuable weaning foods if consumed alongside other iron-rich products.

**KEYWORDS**
Milk
Infant Feeding
Breastfeeding
Neolithic
Fermented Milk
Dairying, Farming
Demography,
Weaning
Complementary Foods

RÉSUMÉ
*La voie lactée : les implications de l'utilisation de produits laitiers dans l'alimentation du nourrisson*
Le lait animal a été utilisé pour nourrir les jeunes nourrissons depuis au moins quelques millénaires, toutefois ceci n'a pu devenir une pratique courante que pendant le Néolithique, après la domestication d'animaux laitiers. L'accroissement démographique observé au Néolithique a souvent été attribué à une augmentation de la fertilité des femmes, due a une diminution de la période d'allaitement. Il est donc possible que ce soit pendant cette période que le lait animal ait d'abord été introduit dans l'alimentation du nourrisson en remplacement du lait maternel. Les laits sont des liquides complexes présentant des caractéristiques différentes selon les espèces de mammifères considérées. La consommation du lait d'une espèce par le nourrisson d'une autre affectera donc la santé de ce nourrisson. Cet article présente certaines différences entre les laits de trois espèces de ruminants et le lait humain et discute des éventuelles conséquences de l'introduction du lait animal dans l'alimentation du nourrisson. Il est proposé que, excepté lors de situations extrêmes, le lait animal ne serait pas à même de compenser la diminution de la consommation du lait maternel de façon appropriée. Les produits à base de lait fermenté, accompagnés d'autres produits riches en fer, auraient toutefois pu être une nourriture de choix pour le sevrage du nourrisson.

**MOTS CLÉS**
Lait
alimentation du nourrisson
allaitement
lait fermenté
démographie
production de lait
élevage
sevrage
alimentation complémentaire

 

## INTRODUCTION

Milk is a food for babies; the ability to digest milk in adulthood is a genetically determined trait that is thought to have been under selection only during the last 10,000 years (Burger *et al.* 2007; Ingram 2009; Itan 2009; Gerbault 2011). Humans are unusual in that they regularly feed their infants with the milk of another species rather than that of their own. Today this practice is widespread; a great many human infants are fed a modified version of cow's milk in the form of infant formula and others are given raw animal milks. The consumption of animal milks by infants is also well attested historically, being traceable back to at least Greco-Roman Egypt (Fildes 1986), but it cannot have occurred on any great scale prior to the domestication of dairy species during the Neolithic. It has been hypothesised that changes in infant feeding practices were responsible for Neolithic demographic change (Buikstra 1986; Armelagos 1991), and it is possible that animal milks were incorporated into the infant diet at this time. Genetic evidence suggests that the mutation enabling adults to digest milk was extremely rare amongst European Neolithic populations (Burger 2007), and so it is possible that the first human consumers of non-human milk were infants. Milks differ in their composition between species, and the replacement of breastmilk with animal milks has significant consequences for infant health. This paper explores what these consequences are likely to have been in a prehistoric context.

## THE POSTULATED ASSOCIATION BETWEEN NEOLITHIC DEMOGRAPHY AND THE NURSING INFANT

A signature of a period of population increase following the adoption of agriculture has been identified around the globe (Bocquet-Appel 2002, 2008, 2009; Eshed *et al.* 2004). This growth is thought to have resulted from an increase in female fertility that was later curtailed by a near-equivalent increase in mortality (Bocquet-Appel 2002, 2008, 2009). Lactation is known to delay the return of post-partum fertility (a phenomenon that probably arises from its impact on a woman's overall energy balance (Valeggia & Ellison 2009)) and it has been suggested that fertility increase could have been due to a reduction in the duration of breastfeeding causing a drop in the length of the inter-birth interval (Armelagos *et al.* 1991; Bocquet-Appel 2002; Goodman *et al.* 2007). The reason for weaning earlier in the Neolithic has in turn been attributed to the availability of agricultural foods such as cereal gruels and animal milks making it technically possible to do so (Buikstra *et al.* 1986; Bocquet-Appel 2002). This assertion has been challenged, however, by ethnographic data demonstrating that, despite tending to breastfeed for longer than pastoral and farming groups, populations with extractive economies often introduce both liquid and solid supplementary foods at an earlier age and so are clearly able to obtain foods suitable for such early weaning (Sellen & Smay 2001).

It has been suggested more recently that Neolithic fertility increase is likely instead to have resulted from the direct influence of Neolithic diet and lifestyle on maternal energetics (Bocquet-Appel 2008). This could still have necessitated a reduction in the duration of breastfeeding, since increased family size and changed female work patterns may have required infants to be placed in the care of older offspring or other carers from an earlier age and so reduced the opportunity for suckling. Although all communities have access to foods suitable for giving to younger infants, the precise types utilised are unsurprisingly related to a community's economic base (Sellen & Smay 2001), and it thus seems plausible that in the pastoral societies of Neolithic Europe animal milks would have been used to replace or supplement breastmilk in the weanling diet (Meiklejohn 1997; Cuthbertson 1999).

## THE WEANING PROCESS IN EVOLUTIONARY CONTEXT

Based on clinical and epidemiological evidence for optimal health outcomes (Butte 2002; Kramer & Kakuma 2002) current international recommendations for infant feeding comprise a period of exclusive breastfeeding until the infant is six months of age followed by a period of complementary feeding (PAHO/WHO 2003; WHO 2003, 2005). During complementary feeding specially prepared nutritionally rich and relatively sterile complementary foods are introduced to the infant diet while breastfeeding continues. It is recommended that breastmilk should continue to contribute to the infant diet until at least the end of the second year of life. Since these recommendations are based on optimal outcomes in terms of infant growth and development they have been argued to be a model for the evolved pattern of infant and young child feeding (Sellen 2007, 2009). This suggestion is supported by the fact that, although widely variable, infant feeding practices in modern non-industrialised societies appear to more-or-less conform to this pattern (Sellen 2001; Kennedy 2005).

This evolutionary model of infant feeding involves weaning infants earlier than would be predicted by comparison to the other primates (Kennedy 2005; Sellen 2007, 2009). Early weaning has been argued to be a derived trait of the human species resulting from the nutritional demands of rapid brain development in human infants (Kennedy 2005). Given that the survival of human infants in forager communities is better than the survival of primate infants it appears that humans have managed to reduce the age at weaning without increasing infant mortality rates (Sellen 2009). This can probably be attributed to the use of complementary foods, which is unique among humans and enables infant nutritional demands to be met from sources other than breastmilk from an earlier age. Human weaning patterns are also unusually plastic; both the age at weaning and the speed with which it occurs are highly variable. This is argued to be another derived trait of the human species, which enabled mothers to vary their reproductive strategy in accordance with the varying costs and benefits of weaning (to both mother and child) in different environments (Sellen 2007, 2009). Even though plasticity and precocity in the timing of weaning appear to be evolutionary traits of the human species, diverging further from optimal infant feeding practices than the local environment will allow is to the significant detriment of infant health. Sub-optimal breastfeeding practices are thought to be responsible for an estimated 1.4 million deaths of children under five each year (Black 2008).

The health of infants is thus to a large degree dependent both on the age at which they are weaned and on the choice of foods given to them during the weaning process. If animal milks were incorporated into the infant diet during the Neolithic their impact on infant health would presumably have been dependent upon when during the infant feeding process they were introduced. Assuming that prior to the Neolithic demographic transition infants were being fed according to some approximation of the ideal model of infant feeding, there are three basic ways in which animal milk products could have been used in the infant diet that are likely to have had different effects on infant health. Firstly, they could have been introduced to the infant diet during what had previously been a time of exclusive breastfeeding, thereby reducing the duration of exclusive breastfeeding. Alternatively they could have been used in place of some or all of what had previously been the breastmilk portion of the diet at or after the time other complementary foods were introduced to the diet. Finally, they could have been used as complementary foods during the complementary feeding phase. Only the first two of these models incorporate a reduced period of breastfeeding, but the latter will also be referred to occasionally below.

| Species | Human | Cow | Goat | Sheep |
|---|---|---|---|---|
| Water (g) | 87.50 | 87.69 | 87.03 | 80.70 |
| Protein (g) | 1.03 | 3.28 | 3.56 | 5.98 |
| Carbohydrate (g) | 6.89 | 4.65 | 4.45 | 5.36 |
| Lipid (g) | 4.38 | 3.66 | 4.14 | 7.00 |
| Ash (g) | 0.20 | 0.72 | 0.82 | 0.96 |
| Energy (kcal) | 291 | 268 | 288 | 451 |

Table 1.– The composition and energy content per 100g of human, cow's, goat's and sheep's milk. Data taken from the USDA nutrient database (USDA ARS 2009).

## COMPARISON OF MILK COMPOSITION

### Bulk composition

Ideally a study of the health implications of feeding animal milks to Neolithic infants would use data on the composition of the milks of the early domesticate species, however since that information is not available data from their modern counterparts must be used as a proxy. Bovine, caprine and ovine milks have been chosen for comparison with human milk because of the widespread prevalence of these species in bone assemblages from Neolithic sites (although greater prominence is given to bovine milk due to the greater body of research into the milk of this species). Given the intensive selective breeding that has occurred since these species were first domesticated it seems unlikely that the composition of their milks would have remained unaltered, however it is assumed here that the milk of modern animals is more similar to that of their Neolithic counterparts than it is to human breastmilk and that it is thus a valid proxy. This assumption is supported by a recent genetic study which found no evidence in the bovine genome for "the apparent accelerated evolution of even a single milk protein or member of the lactation mammary gene set" (Lemay 2009).

Whilst broadly similar, milks are species specific and as a result there are some key differences between human and ruminant milks. Comparison of the basic composition of the three ruminant milks with human breastmilk reveals that sheep's milk has a higher solid content than the others (Table 1). If water is excluded, however, the relative proportions of the solid components are more similar between the ruminant milks than each is to human milk. Human milk contains considerably less protein, similar amounts of lipid, and more carbohydrate than the milks of the other three species. This low-protein composition is characteristic of primate milks and is thought to have evolved in response to slower primate growth rates (Cuthbertson 1999). The high protein levels in the ruminant milks would stress the excretory and metabolic functions of human infants (Dupont 2003) potentially leading to diarrhoeal illness and acidosis (Macé 2006). It is also suspected that the high protein content of ruminant milks (and thus of most infant formulas) might be responsible for the more rapid growth of bottle fed infants and be linked to obesity in later life (Bartok & Ventura 2009)), but this is unlikely to have had any serious ramifications in prehistory.

### Protein

As well as being present in significantly higher quantities, the protein in ruminant milks differs in composition to that of human milk (Fig. 1). The protein in human colostrum, the milk produced in the first few days post-partum, is about 80% whey and 20% casein (Le Huërou-Luron *et al.* 2010). The whey component gradually declines so that in mature human milk it makes up about 60% of the total protein content. This pattern is in stark contrast to the ruminant milks, in which around 70%-80% of the protein is casein (Gurr 1981; Cuthbertson 1999; Park

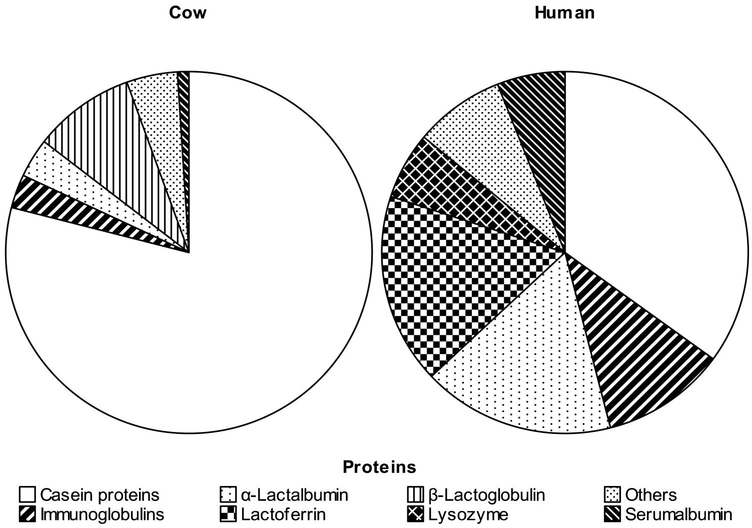


Figure 1.– Comparison of the protein composition of human milk and bovine milk. Data from Gurr (1981: Table 4 and sources therein).

*et al.* 2007: Table 1). The high casein content of cow's milk leads it to form a firm, solid curd in the infant gut, which slows digestion and so helps sustain young animals between sucklings (McClellan *et al.* 2008). Human infants suckle more frequently than calves, and as a result the solid curd formed by cow's milk can create blockages in the small intestine. This in turn can cause pain, swelling, and difficulty breathing (Thompkinson & Kharb 2007). The casein content also reduces gastric acidity, making the gastric juices less effective at combating pathogenic bacteria and so leaving the infant more vulnerable to infection. Although goat's milk contains a similar proportion of casein to cow's milk it forms a softer curd because it contains lower quantities of the $\alpha_{s1}$-casein (Haenlein 2004; Ceballos *et al.* 2009a), and it is therefore easier to digest than cow's milk.

The ruminant milks also contain significant quantities of the milk protein β-lactoglobulin. This protein is the major (although by no means the only) cow's milk allergen (Sabikhi 2007), and is absent in human milk. It is impossible to know how many infants would have been affected by cow's milk allergy in prehistory, but today it is thought to affect 2-3% of infants in developed countries. Nearly half of these infants will cease to have allergic symptoms by the end of the first year and 85-90% will have outgrown the allergy by the age of three. In its severest form, cow's milk protein allergy can cause anaphylaxis and death, but more commonly it expresses in cutaneous, gastrointestinal, or respiratory symptoms which can result in weight loss, anaemia, and a "failure to thrive" (Høst 2002).

Whilst allergies to the additional proteins in animal milks are likely to have been a serious problem for a small proportion of infants in the past, for the majority it would be the proteins these milks lack that would have been the greater health concern. Lactoferrin and Lysozyme are present only in trace quantities in the ruminant milks, and α-Lactalbumin is present in much lower quantities than in human milk (Chandan *et al.* 1968; Lönnerdal & Lien 2003; Park *et al.* 2007). These three proteins all play various roles in protecting the infant from infection and are also thought to help with mineral absorption. Lysozyme is an enzyme capable of degrading the outer cell wall of gram positive bacteria, and can also work in tandem with lactoferrin to kill gram-negative bacteria (Lönnerdal 2003). Lactoferrin has various antimicrobial properties, helps with the development of the infant small intestine, stimulates the growth of a beneficial gut flora, and plays a role in developing the infant immune system. Furthermore it is an iron-binding protein and is thought to play a role in iron metabolism (Walzem *et al.* 2002). Polypeptides produced by the breakdown of α-Lactalbumin by proteases in the gastrointestinal tract have further antimicrobial properties (Lönnerdal 2003; Lönnerdal & Lien 2003; Ebringer *et al.* 2008), and α-Lactalbumin itself may play a role in mineral absorption (Lönnerdal 2003; Lönnerdal & Lien 2003). The loss or reduction of these three components of breastmilk would accordingly leave an infant with reduced defences against infection and would probably lower the extraction of minerals from the diet.

### Fat

The quantity of fat in both cow's and goat's milk is similar to that in human milk, but it is appreciably higher in sheep's milk. Cow's milk contains higher quantities of saturated fatty acids and has larger fat globules than human milk, meaning it is less easily absorbed (Gurr 1981). As a result the infant derives less energy from the fat in cow's milk despite the similar quantities to that in human milk. Goat's and sheep's milks are more easily digested than cow's milk because they contain higher quantities of mono- and polyunsaturated fatty acids and medium chain fatty acids and also contain smaller fat globules (Haenlein 2004; Park *et al.* 2007; Ceballos *et al.* 2009 a; Ceballos *et al.* 2009 b).

### Carbohydrate

Human milk contains significantly more carbohydrate than the ruminant milks. The majority of this is in the form of the disaccharide lactose (McClellan *et al.* 2008). A significant amount of carbohydrate is not digested in the small intestine, but reaches the colon intact where it is fermented by the colonic bacteria. This promotes the growth of host-friendly bacteria in the colon, and also produces short-chain fatty acids (SCFAs) (Parrett and Edwards 1997). The absorption of these SCFAs provides a significant energy source and promotes water absorption thereby reducing the risk of diarrhoea.

Alongside lactose, human milk carbohydrate contains a high quantity of oligosaccharides. Human colostrum contains oligosaccharides in concentrations of 20g/L, a figure that drops to 13g/L in mature milk (Engfer *et al.* 2000). The oligosaccharides in human milk are diverse; approximately 200 different complex oligosaccharides have been identified so far. In contrast, cow's milk only contains trace quantities of oligosaccharides and these are structurally less complex (Bode 2009). Previously little understood, an increasing number of benefits related to human milk oligosaccharides (HMOs) are now being identified. The most known of these are prebiotic effects; HMOs modify the composition of the infant gut flora by promoting the growth of desirable bacteria whilst not benefiting undesired bacteria (Bode 2009). HMOs also play a more direct role in preventing infant infection and diarrhoea. By having binding sites that mimic those of the epithelial cell surface, HMOs can bind to pathogenic microorganisms and prevent them from adhering to cell walls (Bode 2009). They may also be able to prevent the attachment of pathogenic microorganisms by modifying the expression of attachment sites on the epithelial cell surface itself. It is possible that they help prevent the development of necrotizing enterocolitis, a potentially life-threatening disorder that is most commonly seen in premature infants and is six times as common in formula fed infants as breastfed infants (Lucas & Cole 1990).

### Iron

The consumption of bovine milk by infants less than one year of age is associated with increased levels of iron deficiency (Male *et al.* 2001; Levy-Costa & Monteiro 2004; Fernandes *et al.* 2008). Both bovine and human milk are poor sources of iron, but infants are born with iron reserves that supplement dietary iron supplies during early life (Butte *et al.* 2002). The exhaustion of these stores and the heavy iron demands of infant growth mean that iron is one of the first nutrients requiring complementary foods to be introduced to the diet in order to meet infant needs. The quantities of iron in bovine and human milk are similar but that in cow's milk is considerably less bioavailable; just 10% of the iron in cow's milk is absorbed compared to 49% of that in human milk (Saarinen *et al.* 1977). This is probably due in part to the higher quantities of calcium, phosphorous, and proteins in bovine milk, all of which inhibit iron absorption, and in part to the lower levels of lactoferrin (Leung & Sauve 2003). In addition to being a poorer source of iron than human milk the consumption of cow's milk amplifies iron losses because it increases the prevalence and severity of occult blood loss from the infant gastrointestinal tract (Sullivan 1993; Leung & Sauve 2003; Fernandes *et al.* 2008).

Goat's milk contains less than half as much iron as cow's milk, however it is absorbed in similar levels (51%) to that in human milk and is thus a better source of iron for the infant than cow's milk (Park *et al.* 1986). However, the common use of goat's milk in infant feeding in Europe during the 1920s and 1930s led many infants to develop a macrocytic-hyperchromatic megaloblastic anaemia that was observed to develop earlier, occur more frequently, and be more severe than anaemia caused by bovine milk. This has since been attributed to the lower levels of vitamin B12 in goat's milk in comparison to cow's milk (Collins 1962; Ziegler *et al.* 2005). The use of both cow's and goat's milk in infant feeding can thus be expected to increase the prevalence of anaemia, but from different aetiologies. Anaemia affects nearly half of all under-fives across the globe today (de Benoist *et al.* 2008). In its chronic form anaemia limits cognitive and physical development, and leaves infants more vulnerable to infection and death.

## THE ANTICIPATED IMPACT OF RAW MILK ON INFANT HEALTH

It is clear, therefore, that infant health would have been negatively affected if breastmilk was substituted with raw ruminant milks. For the various reasons outlined above, the consumption of raw ruminant milks in place of breastmilk would leave the infant more likely to succumb to infectious illnesses and at a greater risk of iron-deficiency anaemia. Repeated insults of illness would slow the growth and development of infants who survived them, as well as claiming a significant number of infant lives. The magnitude of this effect would, however, depend on a number of variables such as the timing of the introduction of animal milks, the quantities in which they were used, the disease risk of the local environment, and the way in which they were consumed. Introducing animal milks during what had previously been a period of exclusive breastfeeding would have had the most detrimental effect on child health. The infant gut increases in maturity through time (Cuthbertson 1999), and hence reactions to the differing nutritional composition of animal milks would be more severe the earlier they were introduced. In addition the exclusive breastmilk diet is sterile, and the introduction of non-breastmilk foods at this time would expose infants to a new vector of infection at an earlier age (although this risk would be reduced if infants suckled directly from the animal, a practice well attested historically (Fildes 1986)). The infant immune system is also less developed at younger ages and the earlier animal milks were introduced the less able the infant would be to respond to the loss of passive immunity from breastmilk and the increased infection risks from animal milk consumption.

Replacing breastmilk with animal milks at or after the time that complementary foods had previously been introduced to the diet would have a less dramatic effect on infant health since infants would always have been exposed to increased pathogen risk at this age. Nonetheless, the breastmilk portion of the diet would previously have helped to protect the infant against this risk, an effect which would have been reduced or completely lost if breastmilk was partially or totally replaced by ruminant milk. The use of ruminant milks at this stage would thus be expected to have similar negative effects on infant health to introducing them earlier, but the magnitude of these effects would be lower.

If ruminant milks did not reduce the quantity of breastmilk in the diet but instead were used as complementary foods the negative effects on infant health would be lower still. The infant would still be receiving all the positive effects from breastmilk that it had previously, so the consequences for infant health would be limited to the quality of ruminant milk as a complementary food compared to those used previously. The biggest disadvantage of using animal milks as complementary foods would be the increased risk of anaemia, either due to iron deficiency in the case of cow's milk or a combination of iron deficiency and megaloblastic anaemia in the case of goat's milk. The association with iron deficiency leads current national recommendations to suggest that cow's milk only be introduced to the diet after 9-12 months of age, depending on country (Leung & Sauve 2003).

## CIRCUMSTANCES UNDER WHICH DAIRY PRODUCTS MIGHT HAVE BEEN BENEFICIAL TO INFANT HEALTH

As with every rule there must be exceptions, and there may have been circumstances under which dairy products could have been beneficial for infant health. A study of infant feeding in the Turkana population of Kenya has suggested that provision of butterfat to young infants may in fact be adaptive given the ecological context (Gray 1998). The Turkana are nomadic pastoralists who subsist mostly off milk and blood from their animals. Turkana infants are given unrestricted access to the breast from birth, but are also routinely given butterfat made from camel milk and a small amount of cow's milk from approximately two weeks of age. Raw camel's milk is added to the diet from around three months of age, cow's milk at 5-6months, and goat's milk a short time later. Non-dairy foods are first introduced around six months of age. Apart from dairy products, therefore, infant feeding practices conform to the World Health Organization's recommendations with non-milk foods introduced around 6months and the cessation of breastfeeding around two years. The Turkana live in a hot, arid environment with unpredictable rainfall and Turkana women have poor energy intakes and low BMIs. Poor hygiene, the lack of water, and the proximity of livestock and other vectors of infection such as flies mean that Turkana infants are at a high risk of infection almost from the womb. Gray argues that maternal milk is likely to have a low fat content, especially in the dry season, and that a diet of breastmilk alone would leave infants with insufficient fat stores to survive the dry season. The lipid in butterfat is thus a vital supplement to that in breastmilk. The endemic nature of disease is argued to negate the risks of introducing non-breastmilk foods to the diet since infants are at such a high risk of illness anyway. The Neolithic pastoralists of Europe would not have been living in the hot, arid environments occupied by the Turkana, but it is possible that the nutritional status of women in early Neolithic communities may have been poor and the disease burden high. An equivalent use of dairy products may thus have been an adaptive behaviour.

Dairy products do not, of course, have to be consumed as raw milk, and their fermentation alters them in key ways that might have made them more suitable for use in infant feeding.

The nutritional properties of fermented milks are similar to those of raw milk (Branca & Rossi 2002), and issues relating to differences in protein composition and the quantities of fat, carbohydrate and minerals would thus still be problematic for infants. However, the use of bacterial strains such as *Bifidobacteria* and *Lactobacilli* to ferment milk results in the presence of the live bacteria in the product. The gut flora of breastfed infants is rich in *Bifidobacteria*, and so the consumption of fermented milk products containing this bacterial strain can provide continuity in gut flora over the transition from the breastmilk to post-weaning diet (Branca & Rossi 2002). The fermentation process produces lactic acid and other organic acids, which leads to the product having a lower pH than raw milk. This provides a less hospitable environment for the growth of pathogenic bacteria (Ross *et al.* 2002), making fermented milk products safer for children than raw animal milks. The lower pH also increases the absorption of minerals such as iron and calcium from the diet (Branca & Rossi 2002), and the use of fermented milk products alongside other foods helps to prevent iron-deficiency. The use of fermented dairy products to replace breastmilk can still be expected to impact negatively upon infant health, but to a lesser extent than with raw milks. In contrast, however, fermented milks could have made excellent complementary foods if fed alongside other iron-rich foods. Indeed, the use of fermented milks as complementary foods after the age of six months has been recommended for children in European "transition" countries today (Branca & Rossi 2002).

## CONCLUSIONS

For the occasional infant who could not be breastfed due to maternal death or similar, the development of dairying in the Neolithic would have offered a better chance of survival than was available previously. Unless Neolithic populations were living in marginal environments like that of the Turkana, however, at the population level the use of animal milks as a replacement for breastmilk can be presumed to have increased rates of infant morbidity and mortality. These effects would have been most severe if animal milk use reduced the duration of exclusive breastfeeding, and less dramatic the later milks were introduced. Given the overall similarity between animal milks and human milk it is difficult to imagine that any other replacement for breastmilk available during the Neolithic could have adequately compensated an infant for the loss of breastmilk from the diet. This does not rule out a reduction in breastfeeding duration as part of the mechanism behind the Neolithic fertility increase, but means that population growth would almost certainly have been at the expense of infant health. Many scholars have indeed argued that Neolithic farmers suffered higher levels of infection than hunter-gatherers (Cohen & Armelagos 1984; Armelagos *et al.* 1991; Cohen 2008; Eshed *et al.* 2010), and the Neolithic demographic transition is argued to have involved an increase in mortality as well as fertility (Bocquet-Appel 2002, 2008, 2009). Increased infant morbidity is, therefore, an entirely plausible component of the Neolithic demographic transition, provided that resultant increases in infant mortality did not outweigh the corresponding rise in fertility.

It is still possible, however, that animal milk products could have increased child survival. The use of fermented milks along with other iron-rich foods such as blood products could have provided a balanced, nutritious weaning diet that also helped to protect the infant from infection. Both milk and blood are secondary products and, since fermenting milk helps to preserve it, they could have provided Neolithic pastoral populations with a predictable, reliable source of nutrition that buffered them against food shortages. This could have been particularly important for infants and young children, but might also have improved adult survival.

Fermented milks contain less lactose than raw milk but still contain substantial amounts, and being lactase persistent could have conferred an important advantage in times when other foods were scarce. In conclusion, therefore, although the milky way may have been bad for prehistoric infants, the yoghurty way could have been good both for them and for the spread of lactase persistence.

## REFERENCES


Armelagos G.J., Goodman A.H. & Jacobs K.H. 1991. – The origins of agriculture: Population growth during a period of declining health. *Population and Environment* 13(1): 9-22.

Bartok C.J. & Ventura A.K. 2009. – Mechanisms underlying the association between breastfeeding and obesity. *International Journal of Pediatric Obesity* 4(4): 196-204.

Black R.E., Allen L.H., Bhutta Z.A., Caulfield, L.E., de Onis M., Ezzati M., Mathers C. & Rivera J. 2008 – Maternal and child undernutrition: global and regional exposures and health consequences. *The Lancet* 371(9608): 243-260.

Bocquet-Appel J-P. 2002. – Paleoanthropological Traces of a Neolithic Demographic Transition. *Current Anthropology* 43(4): 637-650.

Bocquet-Appel J-P. 2008. – Explaining the Neolithic Demographic Transition., *in* Bocquet-Appel, J-P. & Bar-Yosef, O. (eds), *The Neolithic Demographic Transition and its Consequences*. Springer, Dordrecht: 35-55.

Bocquet-Appel J-P. 2009. – The Demographic Impact of the Agricultural System in Human History. *Current Anthropology* 50(5): 657-660.

Bode L. 2009. – Human milk oligosaccharides: prebiotics and beyond. *Nutrition Reviews* 67 (Suppl 2): S183-191.

Branca F. & Rossi L. 2002. – The role of fermented milk in complementary feeding of young children: lessons from transition countries. *European Journal of Clinical Nutrition* 56(Suppl 4): S16-20.

Buikstra J.E., Konigsberg L.W. & Bullington J. 1986. – Fertility and the Development of Agriculture in the Prehistoric Midwest. *American Antiquity* 51(3): 528-546.

Burger J., Kirchner M., Bramanti B., Haak W. & Thomas M.G. 2007. – Absence of the lactase-persistence-associated allele in early Neolithic Europeans. *Proceedings of the National Academy of Sciences of the United States of America* 104(10): 3736-3741.

Butte N.F., Lopez-Alarcon M.G. & Garza C. 2002. – *Nutrient adequacy of exclusive breastfeeding for the term infant during the first six months of life*. World Health Organization, Geneva.

Ceballos L.S., Morales E.R., Martínez L.P., Extremera F.G., & Sampelayo M.R.S. 2009a. – Utilization of nitrogen and energy from diets containing protein and fat derived from either goat milk or cow milk. *The Journal of Dairy Research* 76(4): 497-504.

Ceballos L.S., Morales E.R., de la Torre Adarve G., Castro J.D., Martínez L.P., & Sampelayo M.R.S. 2009b. – Composition of goat and cow milk produced under similar conditions and analyzed by identical methodology. *Journal of Food Composition and Analysis* 22(4): 322-329.

Chandan R.C., Parry R.M., & Shahani K.M. 1968. – Lysozyme, Lipase, and Ribonuclease in Milk of Various Species. *Journal of Dairy Science* 51(4): 606-607.

Cohen M.N., & Armelagos G.J. (eds), 1984. – *Paleopathology at the origins of agriculture*. Academic Press, Orlando.

Cohen M.N. 2008. – Implications of the NDT for World Wide Health and Mortality in Prehistory., *in* Bocquet-Appel J-P, & Bar-Yosef O., (eds), *The Neolithic Demographic Transition and its Consequences*. Springer, Dordrecht: 481–500.

Collins R.A. 1962. – Goat's milk anemia in retrospect. *The American Journal of Clinical Nutrition* 11(4): 169-170.

Cuthbertson W.F.J. 1999. – Evolution of infant nutrition. *British Journal of Nutrition* 81(5): 359-371.

DE BENOIST B., MCLEAN E., EGLI I. & COGSWELL M. 2008. – *Worldwide prevalence of anaemia 1993-2005*, World Health Organization Global Database on Anemia, Geneva.

DUPONT C. 2003. – Protein requirements during the first year of life. *The American Journal of Clinical Nutrition* 77(6): 1544S-1549S.

EBRINGER L., FERENCÍK M., & KRAJCOVIC J. 2008. – Beneficial health effects of milk and fermented dairy products--review. *Folia Microbiologica* 53(5): 378-94.

ENGFER M.B., STAHL B., FINKE B., SAWATZKI G. & DANIEL H. 2000. – Human milk oligosaccharides are resistant to enzymatic hydrolysis in the upper gastrointestinal tract. *The American Journal of Clinical Nutrition* 71(6): 1589-1596.

ESHED V., GOPHER A., GAGE T.B. & HERSHKOVITZ I. 2004. – Has the transition to agriculture reshaped the demographic structure of prehistoric populations? New evidence from the Levant. *American Journal of Physical Anthropology* 124(4): 315-329.

ESHED V., GOPHER A., PINHASI R. & HERSHKOVITZ I. 2010. – Paleopathology and the origin of agriculture in the Levant. *American Journal of Physical Anthropology* 133(1): 121-133.

FERNANDES S.M.R., DE MORAIS M.B. & AMANCIO O.M.S. 2008. – Intestinal blood loss as an aggravating factor of iron deficiency in infants aged 9 to 12 months fed whole cow's milk. *Journal of Clinical Gastroenterology* 42(2): 152-156.

FILDES. V. 1986. – *Breasts, bottles and babies: A history of infant feeding.* Edinburgh University Press, Edinburgh.

GERBAULT P., LIEBERT A., ITAN Y., POWELL A., CURRAT M., BURGER J., SWALLOW D.M. & THOMAS M.G. 2011. – Evolution of lactase persistence: an example of human niche construction. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences* 366(1566): 863-877.

GOODMAN A.H. & ARMELAGOS G.J. 2007. – Childhood Stress and Decreased Longevity in a Prehistoric Population Childhood Stress and Decreased Longevity in a Prehistoric Population. *American Anthropologist* 90(4): 936-944.

GRAY S. 1998. – Butterfat feeding in early infancy in African populations: New hypotheses. *American Journal of Human Biology* 10(2): 163-178.

GURR M.I. 1981. – Review of the progress of dairy science: human and artificial milks for infant feeding. *The Journal of Dairy Research* 48(3): 519-554.

HAENLEIN G. 2004. – Goat milk in human nutrition. *Small Ruminant Research* 51(2): 155-163.

HØST A. 2002. – Frequency of cow's milk allergy in childhood. *Annals of Allergy, Asthma & Immunology* 89(6 suppl.1): 33-37.

INGRAM C.J.E., MULCARE C. A, ITAN Y., THOMAS M.G. & SWALLOW D.M. 2009. – Lactose digestion and the evolutionary genetics of lactase persistence. *Human Genetics* 124(6): 579-591.

ITAN Y., POWELL A., BEAUMONT M.A., BURGER J. & THOMAS M.G. 2009. – The origins of lactase persistence in Europe. *PLoS Computational Biology* 5(8): e1000491.

KENNEDY G.E. 2005. – From the ape's dilemma to the weanling's dilemma: early weaning and its evolutionary context. *Journal of Human Evolution* 48(2): 123-145.

KRAMER M.S. & KAKUMA R. 2002. – Optimal duration of exclusive breastfeeding. *Cochrane database of systematic reviews* 2002(1): CD003517.

LE HUËROU-LURON I., BLAT S. & BOUDRY G. 2010. – Breast- v. formula-feeding: impacts on the digestive tract and immediate and long-term health effects. *Nutrition Research Reviews* 23(1): 23-36.

LEMAY D.G., LYNN D.J., MARTIN W.F., NEVILLE M.C., CASEY T.M., RINCON G., KRIVENTSEVA E.V., BARRIS W.C., HINRICHS A.S., MOLENAAR A.J., POLLARD K.S., MAQBOOL N.J., SINGH K., MURNEY R., ZDOBNOV E.M., TELLAM R.L., MEDRANO J.F., GERMAN J.B. & RIJNKELS M. 2009. – The bovine lactation genome: insights into the evolution of mammalian milk. *Genome Biology* 10(4): R43.

LEUNG A.K., & SAUVE R.S. 2003. – Whole cow's milk in infancy. *Paediatrics & Child Health* 8(7): 419-421.

LEVY-COSTA R.B., & MONTEIRO C.A. 2004. – Cow's milk consumption and childhood anemia in the city of São Paulo, southern Brazil. *Revista de Saúde P*ública 38(6): 797-803.

Lönnerdal B. 2003. – Nutritional and physiologic significance of human milk proteins. *The American Journal of Clinical Nutrition* 77(6): 1537S-1543S.

Lönnerdal B. & Lien E.L. 2003. – Nutritional and physiologic significance of alpha-lactalbumin in infants. *Nutrition Reviews* 61(9): 295-305.

Lucas A. & Cole T.J. 1990. – Breast milk and neonatal necrotising enterocolitis. *Lancet* 336(8730): 1519-1523.

Macé K., Steenhout P., Klassen P. & Donnet A. 2006. – Protein quality and quantity in cows milk-based formula for healthy term infants: past, present and future., *in* Rigo J. & Ziegler E.E. (eds), *Protein and Energy Requirements in Infancy and Childhood*. Nestlé Ltd, Vevey: 189-205

Male C., Persson L.A., Freeman V., Guerra A., vant Hof M.A. & Haschke F. 2001. – Prevalence of iron deficiency in 12-mo-old infants from 11 European areas and influence of dietary factors on iron status (Euro-Growth study). *Acta Paediatrica* 90(5): 492-498.

McClellan H.L., Miller S.J. & Hartmann P.E. 2008. – Evolution of lactation: nutrition v. protection with special reference to five mammalian species. *Nutrition Research Reviews* 21(2): 97-116.

Meiklejohn C. 1997. – Healthy but mortal: human biology and the first farmers of western Europe. *Antiquity* 71(273): 639–658

*PAHO/WHO* (Pan American Health Organization/World Health Organization). 2003. – *Guiding principles for complementary feeding of the breastfed child*. World Health Organization, Washington DC.

Park Y., Juarez M., Ramos M., & Haenlein G. 2007. – Physico-chemical characteristics of goat and sheep milk. *Small Ruminant Research* 68(1-2): 88-113.

Park Y.W., Mahoney A.W. & Hendricks D.G. 1986. – Bioavailability of Iron in Goat Milk Compared with Cow Milk Fed to Anemic Rats. *Journal of Dairy Science* 69(10): 2608-2615.

Parrett AM. & Edwards CA. 1997. – In vitro fermentation of carbohydrate by breast fed and formula fed infants. *Archives of Disease in Childhood* 76(3): 249-253.

Ross R.P., Morgan S. & Hill C. 2002. – Preservation and fermentation: past, present and future. *International Journal of Food Microbiology* 79(1-2): 3-16.

Saarinen U.M., Siimes M.A. & Dallman P.R. 1977. – Iron absorption in infants: high bioavailability of breast milk iron as indicated by the extrinsic tag method of iron absorption and by the concentration of serum ferritin. *The Journal of Pediatrics* 91(1): 36-39.

Sabikhi L. 2007. – Designer Milk. *Advances in Food and Nutrition Research* 53(7): 161-198.

Sellen D.W. & Smay D.B. 2001. – Relationship between subsistence and age at weaning in "preindustrial" societies. *Human Nature* 12(1): 47-87.

Sellen D.W. 2001. – Comparison of infant feeding patterns reported for non-industrial populations with current recommendations. *Journal of Nutrition* 131(10): 2707-2715.

Sellen D.W. 2007. – Evolution of infant and young child feeding: implications for contemporary public health. *Annual Review of Nutrition* 27:123-148.

Sellen D.W. 2009. – Evolution of human lactation and complementary feeding: Implications for understanding contemporary cross-cultural variation, *in* Goldberg G.R., Prentice A., Prentice A., Filteau, S. & Simondon, K. (eds), *Breastfeeding: early influences on later health*. Springer, Dordrecht: 253-282.

Sullivan P.B. 1993. – Cows milk induced intestinal bleeding in infancy. *Archives of Disease in Childhood* 68(2): 240-245.

Thompkinson D.K., & Kharb S. 2007. – Aspects of Infant Food Formulation. *Comprehensive Reviews in Food Science and Food Safety* 6(4): 79-102.

USDA ARS (U.S. Department of Agriculture, Agricultural Research Service). 2009. – *USDA National Nutrient Database for Standard*

*Reference, Release 22. Nutrient Data.* Nutrient Data Laboratory Home Page, http://www.ars.usda.gov/ba/bhnrc/nd

VALEGGIA C. & ELLISON P.T. 2009. – Interactions between metabolic and reproductive functions in the resumption of postpartum fecundity. *American Journal of Human Biology* 21(4): 559-566.

WALZEM R.L., DILLARD C.J. & GERMAN J.B. 2002. – Whey components: Millennia of evolution create functionalities for mammalian nutrition: what we know and what we may be overlooking. *Critical Reviews in Food Science and Nutrition* 42(4): 353-375.

*WHO/UNICEF* (WORLD HEALTH ORGANIZATION/UNICEF). 2003. – *Global strategy for infant and young child feeding*. World Health Organization, Geneva.

*WHO* (WORLD HEALTH ORGANIZATION) 2005. – *Guiding principles for feeding non-breastfed children 6-24 months of age*. World Health Organization, Geneva.

ZIEGLER D.S., RUSSELL S.J., ROZENBERG G., JAMES C., TRAHAIR T.N. & OBRIEN T.A. 2005. – Goats' milk quackery. *Journal of Paediatrics and Child Health* 41(11): 569-571.

*Submitted on March 14, 2011;*
*accepted on April 3, 2012*