



# Weaned Upon A Time

Studies of the infant diet in prehistory

Rachel Howcroft

©Rachel Howcroft, Stockholm University 2013

ISSN 1400-7835

ISBN 978-91-7447-662-0

Printed in Sweden by Universitetsservice AB, Stockholm 2013

Distributor: Archaeological Research Laboratory, Stockholm University

**Cover Image:** Detail from "The Poor Kitchen", an engraving by Pieter van der Heyden after Pieter Brueghel the Elder. © Trustees of the British Museum. Reproduced with permission.

# Doctoral Thesis in Archaeological Science 2013

## Stockholm University

### Abstract

Howcroft, R. 2013. *Weaned Upon A Time. Studies of the infant diet in prehistory*. Theses and Papers in Archaeological Science 14.

This thesis is concerned with how prehistoric infants were fed in different physical and cultural environments, and in particular what impact the economic, social, and epidemiological changes associated with the development of agriculture had on infant feeding practices. In order to examine these effects, stable isotope ratio analysis has been used to assess the duration of breastfeeding and weaning in a variety of prehistoric contexts. The first study is of Pitted Ware Culture hunter-gatherers at the site of Ajvide on Gotland, Sweden. Breastfeeding usually continued for at least two years, but there was some variation in supplementary foods, which is attributed to seasonal variations in resource availability. The second study analysed a number of Neolithic and early Bronze Age sites from south-east Poland. Breastfeeding duration varied both within and between sites and ranged from six months to five years. The third study found that the infant feeding practices of two Iron Age populations on Öland, Sweden, were very varied, and infants may have been fed differently depending on their social status. The fourth study is of the childhood diet in the Únětice Culture of south-west Poland. Individual diets changed little during the lifetime, suggesting that eventual adult identity was determined early in life. A small number of infants in the study were found to have breastfed for differing lengths of time. The final paper considers the health consequences of introducing animal milks into the infant diet in a prehistoric context, and finds that their availability is unlikely to have made it possible to safely wean infants earlier.

Comparison of the results from the four stable isotope studies to those of other published studies reveals that the modal age at the end of weaning was slightly lower in agricultural communities than hunter-gatherer communities, but the range of ages was similar. Weaning prior to the age of eighteen months was rare before the post-medieval period. It is argued that the gradual reduction in breastfeeding duration since the Neolithic, and the replacement of breastmilk with animal milk products, means that on the whole the development of agriculture probably served to increase infant morbidity and mortality.

**Keywords:** *Infant Feeding, Breastfeeding, Weaning, Milk, Diet, Fertility, Neolithic, Agriculture, Hunter-Gatherer, Bronze Age, Iron Age, Prehistory, Carbon and Nitrogen Stable Isotope Ratios, Bone, Dentine*



# Acknowledgements

*Wean – from the Old English “wenian”, meaning “to accustom”*

It strikes me that the whole PhD process can in many ways be seen as a long slow process of becoming accustomed to something – to the research process, to being part of “academia”, and to deadlines that once seemed far off but then suddenly creep up from nowhere... It’s a journey that is often thrilling and rewarding, but that also brings with it its fair share of difficulties and anxiety. A huge number of people have ensured that for me the experience has been far more of the former than the latter, and without them this thesis would never have been finished.

Thanks are due first and foremost to my supervisors, Kerstin Lidén and Gunilla Eriksson, who have been unrelenting in their support throughout my time as a PhD student, from the early days when this project was struggling to find its feet, through until now, the frantic end. Their good advice, encouragement, and gentle critique have been invaluable, and without it this thesis would never have been written. Thank you too for ensuring I knew how to celebrate midsummer properly (competitive nail-hammering - practice for spikdagen perhaps?), and for doing your best to dispel the myth that Swedes don’t talk much ;-)

I’ve been incredibly fortunate in conducting my research as part of the “LeCHE” project, where I’ve found not just brilliant colleagues but also good friends. So a huge thank you to Anke, Carrie, Doris, Freder, Hege, Maanasa, Marta, Matthew, Mélanie, Michela, Nienke, Oddný, Pascale, Roz, and all the PIs - I really don’t think I could have asked for a better group of people to work with, you guys are fantastic! Thanks are also due to the EU seventh framework programme for generously funding the project.

Closer to home, my time in the Archaeological Research Laboratory has been all the more enjoyable thanks to a group of wonderful colleagues. A particular thank you to Christos Economou for being a fantastic office-mate, your calm presence has been a huge support! Thanks too to Maria Wojnar-Johansson for keeping track of all the financial and bureaucratic administration that comes with EU funding, you’ve save me many headaches! My thanks also to the other members of the AFL, past and present: Andreas Viberg, Joakim Schultzén, Ny Björn Gustafsson, Hans Ahlgren, Anita Malmius, Markus Fjällström, Elin Fornander, Anna Linderholm, Yvonne Fors, Mikael Lundin, Sylvia Sandelin Löfgren, Sven Kalmring, Lena

Holmqvist, Sven Isaksson, Anders Götherström, Ioannis Panagopoulos, Birgit Arrhenius, Margaretha Klockhoff, Kjell Persson, and our most recent arrivals Ayça Omrak and Vasiliki Papakosta – thank you for all your support, guidance, and general good humour, I shall be sad to leave! The distance between floors in the department is of course not as great as I sometime joke that it is, and I have also enjoyed the company of many other good colleagues in the building. So thank you to everyone in archaeology, classics, the CEK and the OFL for making me feel so welcome over the years.

Research is of course never a solitary endeavour, and I have had the pleasure of working with a number of collaborators on the projects in this thesis. Thank you to my “Polish Stone Age” colleagues Hanna Kowalewska-Marszałek, Witold Gumiński, Anita Szczepanek, Piotr Włodarczak and Karolina Bugajska for your enthusiasm for the project and allowing me to work with such fascinating material. Thank you also for making me feel so welcome on my visits to Poland, your help in showing me around and in practical matters made my visits both very easy and very enjoyable. To my other co-author, Dalia Pokutta, thank you so much for allowing me to get involved in your project, and for being such good company on your visits to the lab. Thanks also to Petra Molnar, Johan Norderäng and Paul Wallin for your help with the Ajvide material, and to Anne Ingvarsson-Sundström for the Triberga material. In addition I would like to thank Anna Kjellström and Sven Isaksson for their quick reading of and helpful comments on this manuscript. The isotope analyses were all conducted at the Stable Isotope Laboratory at the Department of Geological Sciences, and I am most grateful to Heike Siegmund for all her help there.

Life does not of course just consist of work, and for me my time as a PhD student has also involved becoming accustomed to life in a new country. Thank you to all my various “Stockholm” friends who I’ve been lucky enough to spend my time with here: in particular thanks to Sagar, Sophie, Martin, Jayne, Suat, Linda, and other SIRAP friends for helping me make the most of my time here.

The long-standing support of friends “back home” has been enormously valuable, and I am quite sure I would not have got this far without it. Thank you all for letting me “pick-up where I left off” whenever I’ve been back visiting, and sorry to those of you I’ve not managed to catch up with as often as I’d have liked. I look forward to that being easier in the near future!

My family have been a source of constant support, not just in this but in everything I do. I owe an enormous debt of gratitude to you all for your love, affection and wisdom – and of course for last-minute proof-reading (thanks Mum!).

Finally, last but nowhere near least, thank you to David, for waiting.

Stockholm, 13<sup>th</sup> March 2013

# List of Papers

- I. Howcroft, R., Eriksson, G., Lidén, K. Infant feeding practices at the Pitted Ware Culture site of Ajvide, Gotland. Manuscript accepted for publication in *Journal of Anthropological Archaeology*.
- II. Howcroft, R., Bugajska, K., Gumiński, W., Kowalewska-Marszałek, H., Szczepanek, A., Włodarczak, P., and Eriksson, G. Breastfeeding and weaning practices during the Neolithic and early Bronze Age in Poland. *Manuscript*.
- III. Howcroft, R., Eriksson, G., and Lidén, K. 2012. Conformity in diversity? Isotopic investigations of infant feeding practices in two Iron Age populations from southern Öland, Sweden. *American Journal of Physical Anthropology* 149: 217-230
- IV. Pokutta, D.A., and Howcroft, R. Children, Childhood, and Food: The diets of subadults in the Únětice Culture of Southwestern Poland. Manuscript accepted for publication in Suchowska-Ducke, P and Vandkilde, H. (eds). *Mobility of Culture in Bronze Age Europe. Proceedings of an international conference and the Marie Curie ITN 'Forging Identities' at Aarhus University June 2012*. BAR International Series.
- V. Howcroft, R., Eriksson, G., and Lidén, K. 2012. The Milky Way: The implications of using animal milk products in infant feeding. *Anthropozoologica* 47(2): 31-43.

# Contents

1	Introduction.....	11
2	Infant Feeding in an Agricultural Context.....	13
2.1	The European Neolithic.....	13
2.2	Agricultural Produce and Weaning.....	15
2.3	Neolithic Demography.....	18
2.4	<b>Women's Working Patterns</b> .....	19
2.5	Parasite and Pathogen Risks.....	19
2.6	The Neolithic as a Novel Cultural Milieu .....	20
2.7	Implications – An Infant Feeding Revolution.....	20
3	Infant Feeding in Biological Perspective.....	21
3.1	The Evolution of Lactation.....	21
3.2	Human Lactation Strategies .....	23
3.2.1	Breastfeeding Duration and the Age at Weaning.....	23
3.2.2	Human Milk Composition .....	25
3.2.3	Supplementary Foods.....	28
4	Infant Feeding in Cultural Perspective .....	31
4.1	The Social Context of Nursing .....	31
4.2	The Properties of Breastmilk .....	33
4.3	Artificial Feeding With Animal Milks.....	35
4.4	The Introduction of Non-Milk Foods .....	36
4.5	The End of Suckling.....	37
5	Assessment of Weaning in Prehistoric Populations.....	41
5.1	Inferential Approaches.....	41
5.2	Biomolecular Approaches to the Study of Weaning .....	41
5.2.1	The Skeletal Tissues .....	41
5.2.1.1	Bone .....	42
5.2.1.2	Teeth.....	43
5.2.2	Strontium: Calcium Ratios.....	44
5.2.3	Stable Isotope Ratios as Palaeodietary Indicators.....	44
5.2.3.1	Nitrogen.....	45
5.2.3.2	Carbon .....	46
5.2.3.3	Oxygen .....	48
5.2.4	Approaches to the Study of Infant Feeding.....	48



5.3	A Note About Representativity.....	50
5.4	The Methods Used in this Study. ....	51
6	Results and Discussion: Neolithic Contributions to the Infant Diet .....	53
6.1	The Results in Broader Context .....	57
6.2	Agriculture, Fertility, and Infant Feeding .....	65
6.3	Animal Milks and the Infant Diet .....	67
7	Conclusions.....	71
8	Sammanfattning.....	75
	References .....	79

# Terminology

Breastmilk	The term “breastmilk” is often spelled as two separate words or hyphenated. The one-word form has been used here because it allows the term “non-breastmilk” to be used without confusion to refer to all foods other than breastmilk, rather than just non-human milks.
Weaning/ Weanling	The term weaning is used here to refer to a process, beginning with the first introduction of non-breastmilk foods (except for pre-lacteal feeds), and ending with the cessation of breastfeeding. Weanling refers to individuals in the process of being weaned.
Infant/ Infancy	The ages referred to by the terms infant and child vary depending on discipline. Here an evolutionary definition of infancy is used, whereby it refers to the period of time for which infants have evolved to be dependent on the mother for nutrition. In other words, “infant” is used loosely to refer to individuals under around 3 years of age, regardless of their actual breastfeeding status.
Child/ Subadult/ Juvenile	Child, subadult, and juvenile are all used to refer to individuals who have not attained full physical maturity.
BP/bp	BP has been used to refer to calibrated radiocarbon years before present (where “present”= AD 1950), the lower-case form has been used for uncalibrated radiocarbon dates.

# 1 Introduction

The title of this thesis, “Weaned Upon A Time” has been chosen because it reflects the content in a number of ways. Most obviously the title is appropriate because it invokes the image of weaning in days long since passed, and this thesis is a study of infant feeding practices in prehistory. In particular it focuses on the timing of weaning, which is defined here as a process beginning with the introduction of supplementary foods and ending with the cessation of suckling. The departure point is the adoption and spread of agriculture in the Neolithic, and the intention is to explore what impact that development - which transformed lifestyles, nutrition, settlement patterns, and social relationships - had on infant feeding practices. Did prehistoric farming populations breastfeed for less time than prehistoric hunter-gatherers? How did the use of agricultural produce in infant feeding affect infant health in a prehistoric context? This research has been conducted as part of a broader project investigating the co-evolution of dairy farming and the genetic trait of lactase persistence, which enables individuals to digest milk as adults, and particular attention is thus given to the role of animal milks in the infant diet.

Secondly, the title refers to the specific timing of weaning, which often coincides with a social transition from infancy to childhood, and with it a change in social relationships and activity patterns. The timing of weaning is also important from the point of view of an infant’s health, since the duration of breastfeeding and the age at the first introduction of supplementary foods are both major determinants of infant morbidity and mortality. Lactation meanwhile is an enormous energetic cost for a mother, and the age at which her child is weaned affects her own nutritional status and her ability to reproduce again. What therefore were the consequences of differences in the duration of breastfeeding and weaning for the health and fertility of prehistoric populations?

Thirdly, just as fairy tales are shared between members of a culture and transmitted between generations, so infant feeding practices are socially learned behaviours. Similarly, in the same way as a fairy tale alters slightly between every retelling, so the infant feeding practices in a population do not exactly replicate each other but differ between different individuals in a population. How therefore did infant feeding practices vary between different groups in a region, and how did they change over time? Are there differences in the way that different individuals in the same archaeological com-

munities were fed, and if so what can these tell us about the social identity and status of those individuals?

Finally, fairy tales are primarily associated with children, and it is with children and childhood that this thesis is concerned. Do the diets of children differ from those of adults, and at what age does eventual adult identity start being reflected in the juvenile diet?

These questions are explored in the following chapters and the five articles that comprise this thesis. The first three articles (I,II,III) present the results of stable isotope studies of the infant diet in three different time periods and geographic locations. The fourth (IV) is a stable isotope study of the childhood diet, including some evidence of the diet in infancy but primarily aimed at exploring the social identity of children in the early Bronze Age Únětice Culture. The final paper (V) explores the differences between ruminant milks and human milk, and discusses what the likely implications of their use in infant feeding would be.

In the following chapter the Neolithic background to the questions being asked is presented. Chapter 3 gives an overview of the evolution and biological implications of infant feeding, and Chapter 4 presents some examples of the broad variety of ways in which infant feeding practices are conceptualised in various historical and modern contexts. Chapter 5 explains the different methods used to obtain direct evidence of the infant diet in prehistory, focussed in particular on the stable isotope techniques used in the papers in this thesis. Finally, in Chapter 6 the results of the five articles are discussed, and put into broader context with other archaeological evidence for infant feeding practices during the past ten millennia of human history.

## 2 Infant Feeding in an Agricultural Context

For the vast majority of its history the human species obtained its food by the same means as any other – by hunting, scavenging, fishing, and foraging. Some 11,500 years ago in the Near East humans first began to domesticate plants and animals, and in doing so initiated the development of food-producing economies (Zeder 2011). During the course of the following eight millennia similar developments occurred independently in central China, the highlands of New Guinea, the Mississippi basin, the Andes, Mesoamerica, and possibly in western Africa and southern India (Bellwood 2005). From these various points of origin agricultural economies proceeded to spread throughout the rest of the globe, accompanied by new settlement and working patterns, novel pathogens and diseases, altered cognitive traits, new repertoires of material culture, and transformed demographic structures. Any or all of these factors can be expected or can be shown to have altered infant feeding practices, either in the Neolithic or thereafter, and this chapter will be devoted to expounding the reasons why. It will begin, however, with a very brief sketch of the nature and spread of the Neolithic in Europe.

### 2.1 The European Neolithic

Agriculture first arrived in southeastern Europe from its origins in the Near-East during the ninth millennium BP, and formed part of a loosely-wrapped “Neolithic package” that included ceramics, polished stone axes, timber or stone housing, and village dwelling (Zilhão 2001, Tresset and Vigne 2011). From here it spread throughout Europe by two main routes, one around the Mediterranean coast and one through central Europe (see Fig. 1) (Rowley-Conwy 2011, Tresset and Vigne 2011). The spread of the Neolithic Cardial Ware Culture along the former of these routes appears to have involved a leapfrog establishment of “Neolithic enclaves” by boat along the Mediterranean coast; arriving in southeastern Italy around 8000BP, along the coast of northwestern Italy some two or three centuries later, and then dispersing along the Iberian coast in to the western coast of Portugal in less than two centuries (Zilhão 2001, Zeder 2008). The spread into the interior was probably via riverine routes, and there was a delay of some two centuries before agriculture reached the northern coast of Iberia (Rowley-Conwy 2011).

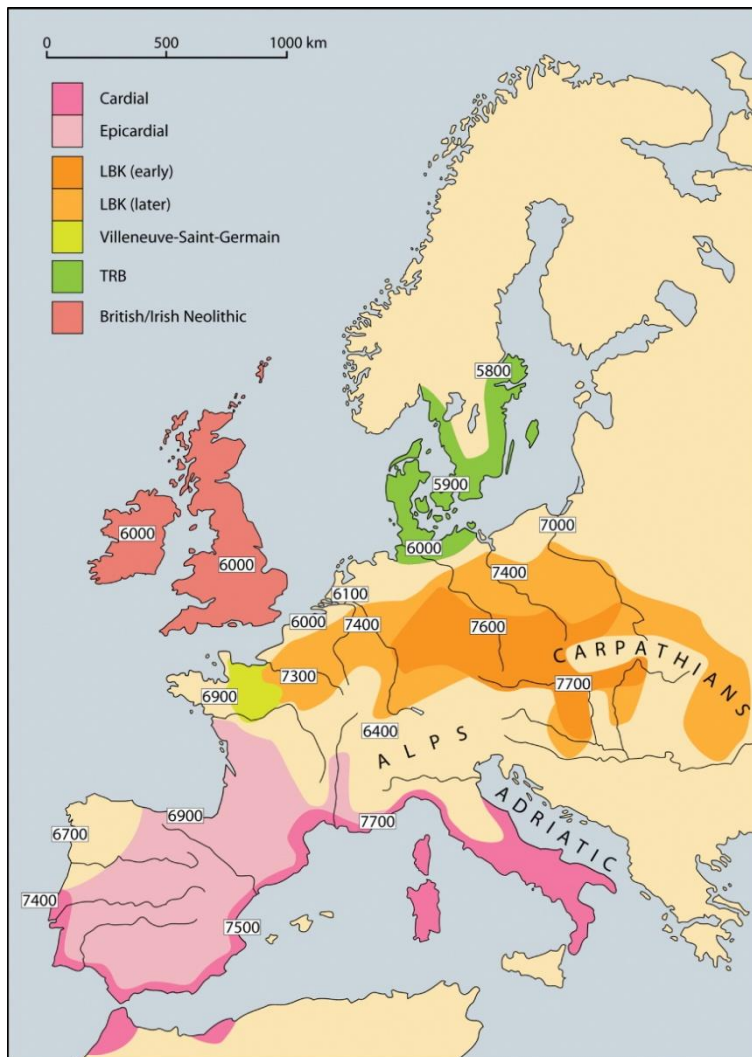


Figure 1: Map showing the major farming “spread events”. Dates are in calibrated years BP. Reprinted from Rowley-Conwy (2011). Copyright © 2011, The University of Chicago Press.

The central European route begins with the development of the Linera-bandkeramik Culture (LBK) in the Carpathian basin around 7500 BP. From here it dispersed along the Danube and Elbe rivers to much of central Europe in just 150 years (Shennan 2008, Rowley-Conwy 2011). It expanded further still over the following centuries to eventually cover an area stretching from the Paris Basin to Ukraine (Gronenborn 1999). As with southeastern Europe, the early Neolithic settlements did not saturate the whole region, but rather were restricted to “settlement cells” on the loess soils (Whittle 1996, pp.

144–177). The LBK Culture is characterised by its long-houses and cattle based economy, and is remarkable for its uniformity (Whittle 1996).

Although Neolithic economies spread rapidly through southern and central Europe, it was not until the start of the sixth millennium that they reached northern Europe, Scandinavia, and the British Isles. This slow-down is likely to have been due to the higher density of hunter-gatherer populations already in northern Europe (Zvelebil and Rowley-Conwy 1984, Isern and Fort 2012). Other aspects of the “Neolithic package”, such as ceramics and stone adzes, were adopted by the hunter-gatherer populations in Scandinavia in the early seventh millennium BP, but it is not until the start of the sixth that the farming Funnel Beaker Culture appeared in the south of the region (Malmer 2002). The Funnel Beaker Culture rapidly spread out as far north as central Sweden and onto the Baltic islands of Öland and Gotland. In contrast to most other regions of Europe, farming and hunter-gathering settlements coexisted in this region throughout the Middle Neolithic.

Agriculture also appears to have arrived in the British Isles at the turn of the sixth millennium BP, probably via a number of separate routes (Rowley-Conwy 2004, 2011). The nature of the transition from Mesolithic to Neolithic in the British Isles has been the subject of intense debate, with some arguing for a varied early Neolithic economy (e.g. Thomas 2004), and others that dietary change at least was rapid (Richards and Hedges 1999, Richards *et al.* 2003b, Richards and Schulting 2006).

Perhaps the most common debate in European Neolithic archaeology during recent decades has been the question of whether the spread of the Neolithic represents the spread of peoples, or an indigenous adoption by hunter-gatherer groups. Genetic evidence has now decisively shown that the domestic plants and animals of Neolithic economies were descended from wild ancestors in the Near East (Heun *et al.* 1997, Ladizinsky 1999, Badr *et al.* 2000, Troy *et al.* 2001, Pedrosa *et al.* 2005, Bollongino and Burger 2007, Edwards *et al.* 2007, Naderi *et al.* 2008, Gerbault *et al.* 2012, Ottoni *et al.* 2013). The human picture is more complex, however genetic evidence increasingly suggests that a substantial population replacement did take place (Bramanti *et al.* 2009, Haak *et al.* 2010, Patterson *et al.* 2012, Skoglund *et al.* 2012), but with greater admixture with indigenous hunter-gatherer populations in the north (Patterson *et al.* 2012).

## 2.2 Agricultural Produce and Weaning

The development of agriculture changed not just the means by which food was obtained, but also made novel types of foods available. These foods include those that have historically been associated most closely with infant feeding in Europe, namely cereal-based foods and animal milks. Historical evidence shows that the use of these products in infant feeding goes back to

the ancient world. A survey of Graeco-Roman, Byzantine and Arabian medical advice on infant feeding reveals that the most commonly recommended weaning foods for infants were cereal porridges, bread, and animal milks (Fildes 1986 Table 1.1.). The Talmud similarly instructs that women who become pregnant whilst breastfeeding should wean their children from the breast and instead rear them on cows' milk and eggs (Fildes 1986). An Egyptian wet-nursing contract from the Ptolemaic period meanwhile requires that an infant was breastfed for the first six months, and then nourished on "the best cow's milk" for a further eighteen months (Garrison 1923, pp. 15–16). The use of these products has continued to this day; dairy products are the substrate of most formula milks and feature prominently in international complementary feeding guidelines (Dewey 2003, 2005). Cereals meanwhile are still commonly used in weaning, usually in the form of fortified porridges and gruels.

The utilisation of the milks of other species in human infant feeding has had such profound consequences for infant health and survival that it should be considered a revolutionary step in the evolution of infant feeding. Animal milks are more similar to human milks than other foods, and prior to the development of modern formulas would have been the safest alternative to breastmilk when breastfeeding was not possible. Data from the British town of Derby show that at the turn of the twentieth century the mortality of infants raised on cows' milk and water was around thirty percent lower than it was for infants given condensed milk or cereal-based foods (Howarth 1905). Animal milks were also used to prevent the spread of infection, for instance during the syphilis epidemic in sixteenth century France, when it became common for infants to be suckled by goats in order to prevent either infant or nurse infecting the other (Fildes 1986, pp. 267–270).

On the other hand, however, animal milks are not human milk (see Paper V), and their use where infants might otherwise have been breastfed has had devastating consequences for infant health and survival. Modern formula milks, which have developed out of the practice of modifying cows' milk to make it more similar to human milk (Castilho and Filho 2010), are still associated with higher rates of morbidity than breastfeeding, particularly due to gastrointestinal disease (Nommsen-Rivers 2004, Gartner *et al.* 2005, Lauer *et al.* 2007, Ip *et al.* 2009, Robinson and Fall 2012). Prior to their development, the use of unmodified animal milks as replacements for breastmilk could have catastrophic consequences. This is exemplified by the case of Reykjavik in the first half of the eighteenth century. Iceland at this time had a strong tradition of artificial feeding, and infant mortality in Reykjavik was as much as twice as high amongst the children of the wealthy and farmers than amongst the children of the poor, who could not afford cows' milk and so breastfed their infants at least briefly (Garðarsdóttir 2002). The situation in Derby was similar: although the infants reared on diluted cows' milk fared better than those on other artificial foods, infant mortality amongst their



number was still 177/1000 compared to 69.8/1000 for breastfed infants (Howarth 1905). Whether or not the use of animal milks in infant feeding was a positive or negative development in the history of human nutrition thus depends on whether it has encouraged the development of infant feeding traditions in which artificial feeding was used to replace breastfeeding, or whether these practices already existed.

In recent years the analysis of livestock slaughter profiles, isotopic evidence for the early weaning of cattle (Balasse 2002), and the identification of dairy lipid residues in early Neolithic pottery (Copley *et al.* 2003, Craig *et al.* 2005, 2011, Evershed *et al.* 2008, Isaksson and Hallgren 2012, Salque *et al.* 2013) have provided conclusive evidence that dairying was an integral part of early Neolithic economies (Vigne 2008), and was not developed some millennia later as part of a “secondary products revolution” as had previously been proposed (Sherratt 1981). The digestion of the milk sugar lactose depends on the production of the gut-enzyme lactase, which in all other mammals is downgraded after the time of weaning. In humans, however, around 35% of human individuals worldwide possess one of a handful of single nucleotide polymorphisms (SNPs) that mean they continue producing lactase in adulthood (Ingram *et al.* 2009). Selection for the allele associated with lactase persistence in Europe (13910\*T) is thought to have begun around 7500 years ago in a region between the Balkans and central Europe, which correlates well with the spread of the early Neolithic Linearbandkeramik culture (Itan *et al.* 2009). Since the majority of early Neolithic individuals did not carry this allele (Burger *et al.* 2007, Plantinga *et al.* 2012) the consumption of raw milk would have caused them to suffer gastric symptoms of varying severity, such as abdominal pain, flatulence, and diarrhoea (Mattar *et al.* 2012). With few exceptions therefore, the only individuals able to consume raw milk in the early Neolithic would have been infants and young children.

The identification of dairy lipids in early Neolithic LBK ceramic vessels that strongly resemble modern cheese strainers points to the processing of milk into low-lactose forms digestible by lactose intolerant adults (Salque *et al.* 2013). Bowl forms associated with these strainers were however also found to contain dairy lipids, implying the collection of the lactose rich whey produced as a by-product of this method of cheese production (Salque *et al.* 2013). Whey would have been easier for infants to digest than whole cow’s milk, since it completely lacks the casein proteins that cause digestive problems for human infants (see Paper V). Whilst it may have been processed further, used to feed young animals, or simply discarded, one possibility is therefore that whilst the adults and older children consumed cheese, infants and young children drank the whey.

## 2.3 Neolithic Demography

It has long been recognised that the adoption and then spread of agriculture was associated with an increase in the size of the human population, and this has now been identified in both genetic (Gignoux *et al.* 2011) and cemetery (Bocquet-Appel 2011) data. An increase in the proportion of juvenile individuals (five to nineteen years) in early Neolithic cemeteries from south-western Asia, mainland Asia, Europe and North Africa, and the north and southwest of America (Bocquet-Appel 2002, 2009, 2011, Bocquet-Appel and Naji 2006, Bellwood and Oxenham 2008, Guerrero *et al.* 2008) indicates that this population expansion resulted from an increase in female fertility (Bocquet-Appel 2002, 2009, 2011). This is supported by a greater relative increase in caries rates in females than in males, a phenomenon attributed to hormonal changes during pregnancy (Lukacs 2008). The increase in fertility is thought to have been of the order two extra offspring born to each female, and exponential population growth must have been curtailed shortly after by a similar increase in mortality (Bocquet-Appel 2002, 2009, 2011). This demographic transition is thus the direct mirror-image of the Contemporary Demographic Transition documented in industrialised societies over recent centuries, whereby a decline in mortality has been followed by a drop in the fertility rate (Bocquet-Appel 2011).

The cause of increased fertility during the Neolithic has frequently been attributed to a change in infant feeding patterns (Buikstra *et al.* 1986, Armelagos *et al.* 1991, Bocquet-Appel 2002). Although influenced by a number of factors, the duration of post-partum amenorrhoea is positively correlated with the duration of post-partum infertility (World Health Organization Task Force on Methods for the Natural Regulation of Fertility 1998, Vaggia and Ellison 2009). For this reason it has been suggested that Neolithic population increase may have been due to a reduction in the duration of breastfeeding in response to the availability of the agricultural foods discussed above, which, it is argued, could have been fed to younger infants (Buikstra *et al.* 1986, Armelagos *et al.* 1991, Molleson *et al.* 1993, Ellison 2001, pp. 293–294, Bocquet-Appel 2002). Research over the past decade means that the “weaning foods availability” hypothesis no longer seems likely as a motivation for reducing breastfeeding. Whilst new foods certainly were available, ethnographic evidence reveals that hunter-gatherers and fishers use a similarly large range of weaning foods as agriculturalists and pastoralists (Sellen and Smay 2001). They also introduce both liquids and solids rather earlier on average than pastoralists and agriculturalists (Sellen and Smay 2001). Whilst this need not mean that Mesolithic hunter-gatherer populations introduced supplementary foods earlier than early Neolithic farmers, it does suggest that they would have been entirely capable of finding suitable supplementary foods to use had they wished to.

## 2.4 Women's Working Patterns

Sellen and Smay did find that, whilst extremely variable, the overall duration of breastfeeding was shorter on average in agricultural populations than in hunter-gatherer populations (2001). It is still entirely possible, therefore, that early Neolithic population growth was caused by a decrease in either the duration or intensity of breastfeeding, but that this was motivated by factors other than the availability of weaning foods. One suggestion for this is a change in women's working pattern requiring that infant care be shared by individuals other than the mother at an earlier age (Sellen and Smay 2001, Sellen 2007). Ethnographic data do suggest that women living in subsistence economies breastfeed less as their participation in subsistence activities increases (Nerlove 1974, Piperata and Mattern 2011). The extent to which women's work patterns interferes with breastfeeding depends not just on overall workload, but also whether work can be done in or near the home, how easily it can be interrupted or rescheduled, and the extent to which either workload or childcare can be shared with other individuals (Huffman 1984, Piperata and Mattern 2011). The physical effort involved in carrying a toddler to the fields has been reported by women working in farming as a reason for weaning children early (Fouts *et al.* 2005, Ghosh *et al.* 2006). Although hunting and foraging also entail carrying nursing infants, lower overall workloads and increased levels of sharing of subsistence activities with other individuals may mean that this places less physical burden on mothers than it does amongst farmers (Fouts *et al.* 2005). It may therefore have been more common for infants in agricultural communities to be left in the care of elderly relatives or older siblings whilst their mothers worked, which would necessitate the earlier introduction of supplementary foods and possibly the earlier cessation of breastfeeding.

## 2.5 Parasite and Pathogen Risks

The closer interaction between humans and animals during the Neolithic, along with larger group sizes, and the greater sedentism of those groups all increased the prevalence of infectious disease (Armelagos *et al.* 2005). Theoretical modelling of the rate of human population dispersals has also found that female fecundity and infant mortality are more significant predictors of the rate of spread than adult mortality is, and that the rate of advance of the European Neolithic predicts a relatively high infant mortality rate of 50-63% (Pérez-Losada and Fort 2010). The risk of infants not surviving to adulthood would thus appear to have been relatively high during the early Neolithic, and life-history theory predicts that in the face of increased mortality risks parents will invest less in each individual child and more in repeated reproduction. Furthermore, mortality risks are to some extent unpre-

dictable, and it is thus hypothesised that where the cost of ending up with fewer than the optimal number of adult offspring is greater than that of ending up with too many, fertility rates will increase above that needed to compensate for the mortality rate (Leslie and Winterhalder 2002, Winterhalder and Leslie 2002). There may also be an association with increasing adult mortality rates and earlier weaning: Kachel, Premo and Hublin (2011) have argued that as adult mortality rates increase so will the pressure to reduce birth spacing, in order to reduce the chances of women dying prior to achieving their reproductive potential. Somewhat counter-intuitively, therefore, the expected response of Neolithic populations to the increased pathogen load of Neolithic environments is to have diverted energy from lactation to future reproduction by reducing the duration of breastfeeding.

## 2.6 The Neolithic as a Novel Cultural Milieu

Infant feeding practices are not just influenced by ecological and practical decisions, but are also firmly embedded in cultural norms. As will be reviewed in Chapter 4, breastfeeding and supplementary feeding are culturally meaningful in ways that have little or nothing to do with the nutrition and protection of an infant, and these meanings can differ wildly between different populations. Given the sweeping cultural changes associated with the spread of Neolithic populations throughout Europe it is entirely plausible that these early farmers may also have had different idea about infant feeding to the hunter-gatherer populations that preceded them. Infant feeding practices may thus have changed for reasons that had little to do with the ecological context of agriculture.

## 2.7 Implications – An Infant Feeding Revolution

Prior to the arrival of agricultural economies in Europe, no infant could have been fed with the animal milks and cereal gruels that have been so widely used in infant feeding during at least the last two millennia of European history. As such, the Neolithic can be seen as something of a defining moment in the evolution of human infant feeding practices. This need not mean that infant feeding practices were any different during the Neolithic itself - the use of agricultural products in weaning might not have begun until later. As discussed above, however, it has long been hypothesised that Neolithic population increase was due to earlier weaning, and it is thus plausible that a revolution in infant feeding occurred during the Neolithic itself.

## 3 Infant Feeding in Biological Perspective

### 3.1 The Evolution of Lactation

Lactation, the nourishment of young with milk secreted via the mammary gland, is a trait unique to the mammalian order and common to all species within it. A lack of fossil evidence means that the process by which lactation and the mammary gland evolved is still unclear and subject to some controversy (Lefèvre *et al.* 2010). It is now widely accepted, however, that the process was gradual and has very ancient origins that long precede the development of the mammalian order (McClellan *et al.* 2008, Lemay *et al.* 2009, Lefèvre *et al.* 2010, Hinde and German 2012, Oftedal 2012). It has even been suggested that some milk constituents may have developed prior to the split of the synapsids (the phylogenetic branch that gave rise to mammals) and the sauropsids (the branch that gave rise to reptiles and birds) approximately 310 million years ago (Oftedal 2012). An early attempt to explain lactation's evolutionary development was made by Darwin himself in the sixth edition of "On the Origin of Species", in which he suggests that the young of mammalian ancestors may have been nourished in a brood pouch by cutaneous secretions. More recent explanations have included the suggestion that lactation developed out of fluid secreted by Permian Synapsids to prevent the desiccation of their parchment-shelled eggs (Oftedal, 2002, 2012), and that it has its origins in the innate immune system (Vorbach *et al.* 2006, McClellan *et al.* 2008). Whatever its origins, a system of complex milk production, complete with casein and whey proteins, lactose, lipids, and possibly oligosaccharides, had developed by the Jurassic period at the latest (Lefèvre *et al.*, 2010; Lemay *et al.*, 2009; Oftedal, 2002, 2012).

Milk provides mammalian infants with all the nutrients they need to sustain early growth in an easily digestible form (McClellan *et al.* 2008). Furthermore, they enable the nourishment of young to be divorced in time and place from the acquisition of nutrients (Oftedal 2012). This enables young animals to receive nourishment even when food resources are in short supply, and is particularly exploited by species that nurse their young during periods of hibernation or fasting. An extreme example is the blue whale. The female of the species lays down huge blubber stores whilst feeding in polar and cold-temperate waters, and later migrates to warm or tropical areas to give birth. She then transfers 220kg of milk per day to her young whilst fast-

ing herself, equating to sufficient energy over the course of the six month lactation period to feed 200 people for a year (Ofstedal 2012).

Mammals today exhibit an enormous variety of lactation strategies, which are adapted to maximise fitness according to the different physiologies, life-history characteristics, and living environments of each species (Sellen 2009). Broadly speaking, the duration of lactation correlates with body mass for most species, and ranges from as little as four or five days in spiny rats (*Proechimys guairae*), and elephant shrews (*Macroscelides proboscideus*), to over 900 days in the chimpanzee (*Pan troglodytes*) and orangutan (*Pongo pygmaeus*) (Hayssen 1993). Short lactation lengths (under ten days) are relatively rare, but long lactation of over a year is common in large-bodied species that give birth to single offspring (Hayssen 1993). The age at the introduction of solid foods also increases with rising age at weaning, but the ratio of exclusive lactation to mixed feeding decreases (Hayssen 1993). Lactation length is also related to milk composition. Species that nurse for short periods of time have lipid-rich milks capable of rapidly transferring large amounts of energy to the young (Hinde and German 2012). Similarly, the milks of species that suckle infrequently are highly concentrated in order to sustain infants between suckling bouts (Sellen 2009, Hinde and Milligan 2011). In species with accelerated infant growth rates, the young are nourished by milks with high protein concentrations and in which protein provides much of the energy in milk (Power *et al.* 2002, Sellen 2009, Hinde and Milligan 2011).

The primate species typically have slow life-histories, including a long period of lactation relative to their body size, and frequent suckling (Sellen 2007). Primate milks are thus dilute with low energy, fat, and protein contents and high carbohydrate content (Sellen 2007, Hinde and Milligan 2011, Hinde and German 2012). This reduces the daily costs of lactation on the mother, enabling her to sustain lactation over long periods and buffering both mother and infant against short-term resource shortages (Pond 1977, Hinde and Milligan 2011). Generally speaking, the energy density of primate milks increases as adult female body mass decreases, and there is a positive association between energy from protein and growth rate amongst the anthropoid primates (Hinde and Milligan 2011). Most primates are weaned rapidly, however the duration of transitional feeding has been found to increase with maternal body size (Sellen 2009).

## 3.2 Human Lactation Strategies

### 3.2.1 Breastfeeding Duration and the Age at Weaning

Clinical and epidemiological evidence suggest that the pattern of human lactation that is predictive of optimal health outcomes for infants involves:

- six months of exclusive breastfeeding, initiated within an hour of birth
- the introduction of nutrient-dense and pathogen-poor complementary foods at the age of six months<sup>11</sup>
- the continuation of breastfeeding into at least the third year of life, during which time high-quality family foods should be gradually introduced to the diet (Kramer and Kakuma 2002, 2012, Dewey 2003, 2005, World Health Organization and UNICEF 2003, Agostoni *et al.* 2008).

Since this lactation pattern produces the best outcomes for infant health it has been argued to be a model of the evolved pattern of infant feeding in *Homo sapiens* (Sellen 2007), and it forms the basis of international infant feeding recommendations today (World Health Organization and UNICEF 2003). Ethnographic data reveal that human lactation strategies do not necessarily conform to this ideal pattern, however. Observations of the age at which weaning is initiated (introduction of non-breastmilk foods) in non-industrial societies suggest that this is extremely variable and often occurs much earlier than the four to six months suggested by optimal health outcomes (Sellen 2001, 2009, Sellen and Smay 2001, Kennedy 2005). Sellen (2001) found that over seventy percent of all infants were given liquids other than breastmilk prior to six months of age, with their introduction during the first month being common. The central tendency of the age at the introduction of solid foods was around six months, but the range of ages spanned the entirety of the first eighteen months of life. The range of ages at which weaning is completed (cessation of suckling) in human societies is also extremely variable, spanning from a few hours (if breastfeeding is ever initiated at all) to more than six years, and is nearly as great as that observed in all the other mammalian species put together (Sellen 2001, Dettwyler 2004, Kennedy 2005). Nonetheless, studies of ethnographic data have found that the majority of infants in non-industrial societies do breastfeed for more than two years and that weaning is most commonly completed during the third year (Sellen 2001, Kennedy 2005).

Although humans have the slowest life histories of all the ape species, the timing of end of weaning given in this model is precocious compared to that predicted by comparison to the other apes (Kennedy 2005, Robson *et al.*

---

<sup>11</sup> Although some researchers argue that for some infants complementary foods should be introduced at as early as four months (Fewtrell *et al.* 2007, Reilly and Wells 2007)

2006, Sellen 2006). Suckling in chimpanzees and orang-utans, for example, ceases around 4.5 and 7 years of age respectively, despite these species having earlier ages at first birth and significantly shorter average life spans than humans (Robson *et al.* 2006). Various measures proposed for estimating the “expected” age of weaning in a species, including the attainment of specific multiples of birth or maternal weight and the timing of the eruption of the first molar, predict that humans will cease nursing around 5-6 years (Dettwyler 1995, 2004, Robson *et al.* 2006, Humphrey 2010). Recent modelling has however found that the increased carnivory of the human species is both a necessary and sufficient explanation for the earlier weaning of humans compared to the other apes (Psouni *et al.* 2012). The human trait of ceasing suckling at just two to three years thus means that weaned human infants are immature compared to other species, and humans are the only primate species to completely wean their infants before they are able to forage for themselves (Robson *et al.* 2006, Sellen 2006, 2007).

It has been argued that the driving force behind earlier weaning was the immense nutritional demands of human brain development during childhood, since even at high levels of milk production an infant’s energy requirements cannot be satisfied by breastmilk alone beyond the end of the first year (Kennedy 2005). Supplementing the infant diet at an early age would therefore have become necessary, but would increase the risk to infants of being infected by parasitic and pathogenic agents at an earlier stage of development. Despite this, survival of infants and weanlings is better in the human species than in other apes, which is presumed to be due to human complementary feeding practices (Sellen 2007). Complementary feeding, or the provisioning of human infants with specially prepared nutritionally rich and relatively sterile complementary foods over a long period, is a uniquely human trait (Knott 2001). Meat and other animal products such as eggs could have provided sufficient energy and high-quality protein to maintain brain development (Kennedy 2005). The use of food processing techniques such as heat processing and premastication would then have altered these foods into a form consumable by infants and improved the digestibility of the nutrients within them (Sellen 2007). Heat processing and premastication are also likely to have lowered the infection risk of complementary foods, and premastication may have played a role in transferring immune factors to the infant (Aggett 2010, Pelto *et al.* 2010, Van Esterik *et al.* 2010). Continued breastfeed into the third year of life would have been vital for ensuring that infants still benefited from the immune properties of breastmilk.

The wide variation observed in both the age of initiation and cessation of weaning in human societies suggests that plasticity in the timing of weaning is an apomorphic (derived) trait of the human species (Kennedy 2005, Sellen 2007). This plasticity would have been adaptive, since it would enable lactation strategies to be varied according to the ecological context in which a child was being weaned (Sellen 2007, 2009). Weaning could thus be ad-



vanced or delayed to take advantage of periods of high resource availability and low infection risk, or in accordance with the physical development of an individual child.

### 3.2.2 Human Milk Composition

Milks are complex liquids and contain all the macro- and micronutrients required to sustain infant growth and development. In addition they contain a number of bioactive components that have functions beyond the nutritional. These include immune factors, hormones, growth factors, lipids and saccharides that help to protect the infant from pathogenic organisms and promote the development of the infant's own immune system and gut microbiota (Donovan 2006, Ebringer *et al.* 2008, Rautava and Walker 2009, Walker 2010, Martin and Sela 2013). The composition of milk is dynamic, and changes according to the age of the child, the time of day, and during each feed (Riordan and Wambach 2010, pp. 117–161, Khan *et al.* 2013). Furthermore, milk composition alters in order to maximise a mother's reproductive potential: a recent study has found that economically sufficient mothers produce milk with higher fat concentrations if their child is male rather than female, whereas amongst poor mothers milk fat concentrations are higher for daughters than sons (Fujita *et al.* 2012). This accords with predictions arising from the fact that male reproductive success is more variable than that of females, since females devote more time and resources to each offspring and thus have greater limits on the frequency with which they can reproduce. Under affluent conditions a mother is more likely to maximise her reproductive success by investing in her sons to make them better able to compete for mates. Under poor conditions, meanwhile, a mother is more likely to maximise her reproductive success by investing in her daughters, who can then mate with males of higher status, than in sons who are unlikely to be able to adequately compete for mates (Fujita *et al.* 2012).

*Table 1: Comparison of the gross composition of the milks of great apes and ruminant species (Primate data (except human) from Hinde and Milligan 2011, Ruminant and human data from the USDA nutrient database (USDA ARS 9)) .*

Species	Fat (%)	Protein (%)	Carbohydrate (%)	Water (%)
Human	4.4	1.0	6.9	87.5
Orangutan	2.2	0.7	7.4	88.1
Mountain Gorilla	1.8	1.9	6.6	89.0
Bonobo	1.1	1.0	8.2	89.6
Chimpanzee	2.2	0.9	7.4	88.2
Cow	3.7	3.3	4.7	87.7
Goat	4.1	3.6	4.5	87.0
Sheep	7.0	6.0	5.4	80.7

A comparison of the gross composition of human breastmilk compared to the milks of a number of domestic dairy species and other great apes is shown in Table 1. Although human breastmilk has one of the highest carbohydrate contents and lowest protein contents of any mammal, its gross composition is not unusual in comparison to the milks of other primates (Sellen 2009). The milks of humans and rhesus macaques (*Macaca mulatta*) are unusual in that the protein within them is dominated by whey (soluble) proteins rather than caseins (insoluble proteins) (Kunz and Lönnerdal 1993). The whey-to-casein ratio of human milk decreases during the course of lactation. The protein in human colostrum (the milk formed during the first five days post-partum) is around 80% whey, but this falls to around 60% in mature milk (after 14 days) and around 50% in late lactation (Kunz and Lönnerdal 1992, Lönnerdal 2003). By way of contrast, the protein in ruminant milks is around 70-80% casein (Gurr 1981, Park *et al.* 2007). A number of whey proteins are unique to milk, including the principle breastmilk protein,  $\alpha$ -Lactalbumin (McClellan *et al.* 2008).  $\alpha$ -Lactalbumin is a rich source of essential amino acids, and may also have a beneficial impact on the gut microbiota, stimulate immune function, and improve mineral absorption (Lönnerdal and Lien 2003). Other human whey proteins play important roles in protecting the infant from infection, promoting the development of the infant's immune defences and gut microbiota, in mineral transport, and stimulate mucosal growth (Walzem *et al.* 2002, Lönnerdal 2003, McClellan *et al.* 2008, Le Huërou-Luron *et al.* 2010).

There are also important differences in the digestibility of casein-rich versus whey-rich milks. The casein proteins clot in the acid environment of the stomach, whereas the whey proteins empty rapidly into the small intestine as intact proteins (Walzem *et al.* 2002, Khan *et al.* 2013). The high casein content of ruminant milks therefore causes a firm curd to form in the stomach that traps milk fat globules within it, and so leads to a slow release of amino acids, peptides, and fat to sustain the young animal between sucklings (McClellan *et al.* 2008). This firm curd is difficult for human infants, who suckle frequently, to digest, and the low casein:whey ratio of human milk protein produces a softer curd that can be more rapidly digested (McClellan *et al.* 2008).

The principle carbohydrate in milk is the milk-sugar lactose, a disaccharide that is uniquely synthesised in the mammary gland. Lactose provides around 40% of the energy in mature milk (Hinde and Milligan 2011: Table 2), and promotes the absorption of calcium in the small intestine (McClellan *et al.* 2008). Some lactose also makes it through to the large intestine intact, where it benefits the growth of beneficial bacteria (Mountzouris *et al.* 2007, McClellan *et al.* 2008). In addition, human milk carbohydrate contains an unusually high quantity and diversity of oligosaccharides (Bode 2009), which are polymers made up of two to ten simple sugars. These are not digested, but benefit the infant in other ways. Human milk oligosaccharides

are best known for their prebiotic effects: they are metabolised by and so promote the growth of beneficial gut bacteria. They also help prevent infection by pathogenic bacteria by inhibiting them from adhering to the intestinal epithelial cell surface, and possibly by modifying the sites on the intestinal cell surface that pathogenic bacteria attach to (Bode 2009, Martin and Sela 2013).

Fat is the most variable component of breastmilk. Milk fat concentrations are higher during the day and evening than at night and in the morning, and they also increase during the course of each feed (Kent *et al.* 2006, Khan *et al.* 2013). The milk produced during the first year of an infant's life has a lower fat concentration than that produced thereafter (Mandel *et al.* 2005). Milk fat is primarily an energy source; approximately half of all the energy in breastmilk is derived from the fat component (Thompson and Kharb 2007). It is also an important source of fatty acids, including long-chain polyunsaturated fatty acids important for brain development (Anderson *et al.* 1999, Guxens *et al.* 2011). Free fatty acids and monoacylglycerols released from milk triacylglycerols in the stomach also have various antimicrobial properties (Ebringer *et al.* 2008). In addition, milk lipid is an indispensable source of fat-soluble vitamins (Jelliffe and Jelliffe 1978, Thompson and Kharb 2007).

Colostrum, the milk produced immediately post-partum, is particularly geared towards supporting the immature neonatal immune system as the infant makes the transition from the relatively sterile uterine environment to the microbe-rich external environment (McClellan *et al.* 2008). It contains greater amounts of immune factors and antimicrobial proteins than mature milk, and thus has a higher total protein content (Hester *et al.* 2012). In addition it contains greater quantities of oligosaccharides than later milk (Engfer *et al.* 2000). In contrast to protein, the lipid and carbohydrate content of colostrum is lower than that of mature milk (Hester *et al.* 2012). A summary of the changing composition of human breastmilk during the first six weeks of life can be found in table Table 2.

*Table 2: The changing composition of human milk during the first six weeks of life (data from Hester et al. 2012).*

	<b>Colostrum (1-5 days)</b>		<b>Transitional Milk (6-14 days)</b>		<b>Mature Milk (15 days to 6 weeks)</b>	
	<i>Mean±SE</i>	<i>Range</i>	<i>Mean±SE</i>	<i>Range</i>	<i>Mean±SE</i>	<i>Range</i>
Lipid (g/100ml)	2.2±0.2	1.0-3.0	3.0±0.1	2.5-3.8	3.8±0.1	2.8-4.9
Carbohydrates (g/100ml)	5.6±0.6	2.6-7.6	5.9±0.4	4.1-6.8	6.7±0.2	5.0-8.3
Protein (g/100ml)	2.5±0.2	1.4-6.5	1.7±0.1	1.3-2.5	1.3±0.1	0.8-2.1
Energy (kcal/100ml)	53.6±2.5		57.7±4.2		65.2±1.1	
Volume (ml/day)	21.5±4.2		495.3±33.4		673.6±29.0	

### 3.2.3 Supplementary Foods

As an infant grows the ability of breastmilk to meet all its nutritional requirements diminishes, until eventually the nutritional demands of infant growth begin to outstrip that which breastmilk can supply. There then develops a “weanling’s dilemma” between the inevitable risk of growth faltering if exclusive breastfeeding continues, and the infection risk from introducing complementary foods to supplement nutritional intake (Fig. 2) (Rowland *et al.* 1978). Breastmilk combined with endogenous nutrient stores can meet all nutrient requirements for the first six months of life, with the possible exception of iron and vitamins A, B6 and D under certain circumstances (Butte *et al.* 2002, Kramer and Kakuma 2012). Supplementing the diet after the age of six months is also associated with a significantly reduced risk of gastrointes-



*Figure 2: Perhaps the greatest risk associated with supplementary feeding is that of consuming foods contaminated with infectious pathogens. Traditional feeding vessels, with narrow hard-to-clean spouts and rough surfaces, often provided ideal environments for microbial growth. Top Left: A late Neolithic feeding vessel from an infant grave, Tours-sur-Marne, France, © Wellcome Library, London. Bottom Left: A Roman feeding bottle in the shape of a swan, © Science Museum, London. Right: An infant feeding horn from Råneå in Norrbotten County, northern Sweden, © Nordiska Museet, Stockholm.*

tinal disease and respiratory disease, and six months thus appears to be the age at which the risks of not supplementing the diet outweigh the risks of doing so for most children (Kramer and Kakuma 2012).

Iron demands are extremely high during infancy, and iron deficiency during this time can have long-term effects on development (Lozoff *et al.* 2000). Breastmilk is a poor source of iron, but the majority of infants are born with sufficient iron reserves to sustain growth for the first six months of life (Butte *et al.* 2002). In cases where the maternal diet is poor in iron, infant endogenous reserves may be smaller and thus exhausted sooner (Kramer and Kakuma 2012). Iron is thus likely to be the first nutrient that requires supplementation of the breastmilk diet, and it is essential that complementary foods are iron-rich since they need to provide more than ninety percent of an infant's iron needs during the complementary feeding period (Agostoni *et al.* 2008).

During the second half of the first year breastmilk also becomes deficient in other micronutrients and overall energy content; at 9-11 months of age complementary foods need to supply 86% of an infant's zinc requirements, 81% of phosphorous, 76% of magnesium, 73% of sodium, and 72% of calcium (Dewey 2001). An infant's gastric capacity is however still small at this age, and so complementary foods must be nutrient dense (Dewey 2003). The inclusion of animal foods in the diet is essential for meeting all micronutrient requirements between 6 and 18 months of age (Dagnelie and Van Staveren 1994, Dewey 2003, Agostoni *et al.* 2008). This does not include dairy products, however. Goat's and cow's milk products are poor sources of iron, and cow's milk can also increase gastrointestinal blood (and thus iron) losses in infants under one year of age (Ziegler 2011). Goat's milk is also a poor source of vitamin B12 and folate, and its consumption by infants can lead to megaloblastic anaemia, electrolyte imbalances, and metabolic acidosis (Baur and Allen 2005, Ziegler *et al.* 2005, Basnet *et al.* 2010). Cow's milk is thus not recommended either as a breastmilk replacement or a supplementary food during the first year of life, and only in modest amounts thereafter (Ziegler 2011).



## 4 Infant Feeding in Cultural Perspective

“Taste...is an incorporated principle of classification which governs all forms of incorporation, choosing and modifying everything that the body ingests and digests and assimilates, physiologically and psychologically”

Pierre Bourdieu (1984, p. 190)

As with all other aspects of the human diet, infant feeding practices are deeply enmeshed in a set of cultural beliefs, attitudes, and fashions. Indeed, the nature of infant feeding, with low-repeatability (each child being weaned only once) and uncertain long-term outcomes that are far removed in time from the event itself, means that knowledge about it is suited to being transmitted by social learning rather than obtained through individual trial and error (Hadley *et al.* 2010). Cultural norms rather than optimal health outcomes thus set the standard from which infant feeding practices deviate (Hadley *et al.* 2010, Amir 2011). As a result, infant feeding practices may differ substantially from what would be predicted if they were governed purely by the need to provide an infant with sufficient nutrition in a given environment (Sellen 2007). Different populations living in the same ecological context, or indeed different subgroups of the same population, may therefore have differing beliefs about breastfeeding and weaning and employ vastly different infant feeding practices. This chapter will give an overview of some of the ways in which breastfeeding and weaning have been conceptualised in different cultures and the ways in which these have varied historically.

### 4.1 The Social Context of Nursing

It is relatively unusual for an infant to be breastfed by a woman other than its mother in industrialised societies today. Wet-nursing and cross-nursing (shared nursing of infants) are however widely attested in other cultures. The Cuna of Panama will for instance breastfeed each other's infants when the mother is not available to do so (Jelliffe *et al.* 1961). During the Edo period in Japan (17<sup>th</sup> to mid-19<sup>th</sup> centuries) the children of those who could afford it were nursed by their own mothers for around two years and then wet-nursed until the age of six or seven (Segawa 2008). Throughout much of European

For copyright reasons, there is no image in the digital edition

*Figure 3: The pressure to live up to social ideals is perhaps one of the most powerful determinants of human infant feeding practices. The disinterest of the mother in this satirical cartoon by James Gilray, published in 1796, implies that for many upper class women the primary motive for breastfeeding was to conform to the new fashion for maternal nursing, rather than any genuine desire to or belief in its benefits. Note the idealized nursing image on the wall behind. © Trustees of the British Museum*

history the offspring of the wealthy were sent out to wet-nurse from birth, and wet-nursing became a significant social institution that was highly professionalised (Fildes 1986, pp. 98–133). This began to change across much of Europe during the eighteenth century when books on nursing and child-care aimed specifically at women rather than the medical profession, such as Cadogan's "Essay upon nursing" (1748), inspired a change in fashion from wet-nursing to maternal breastfeeding (Fildes 1986, Matthews Grieco 1991). Social pressures on infant feeding thus changed from it being considered



unseemly for upper-class women to breastfeed, to it increasingly being considered a neglect of moral duty not to do so (Fig. 3).

In many cultures suckling is considered to create kinship or kin-like relations between the nurse and nursling. Three forms of kinship are defined under Islamic law, that by blood, marriage, and milk (Khatib-Chahidi 1992). Milk kinship is associated with similar marriage prohibitions to blood kinship; two people suckled by the same woman may not marry, and nor may they marry that woman or her blood or milk relatives (Khatib-Chahidi 1992, El-Khuffash and Unger 2012). Milk kinship does not directly imitate blood kinship, however; milk parents have no duty of guardianship over their milk-children, and milk kin do not inherit from each other (Khatib-Chahidi 1992). This is in contrast to infant fosterage practices in premodern southeast Europe. Historic accounts from the state of Abkhazia on the eastern shores of the Black Sea detail how milk-kinship was considered equal to that of blood, and fostered wards owed a life-long duty of protection to their milk-kin (Parkes 2004). This came to be extended symbolically, such that token-suckling and breast-biting were used to reconcile blood-feuds, create allegiances, and create impediments to marriage (Parkes 2004). Similar uses of milk-kinship to create ties and reconcile feuds are reported across a variety of different cultures (see Khatib-Chahidi 1992).

## 4.2 The Properties of Breastmilk

*"Were not I thine only nurse,  
I would say thou hadst suck'd wisdom from thy teat."*

The Nurse, *Romeo and Juliet*, Act I scene III

Breastmilk is widely considered to be an extremely powerful substance that is imbued with properties beyond the nutritional. According to Greek mythology the Milky Way was formed from breastmilk spilled by Hera as she pulled away from the suckling Heracles. The belief of Juliet's nurse that an infant's character and abilities were shaped by those of the woman from which it suckled was widely held historically. The Greek Physician Soranus of Ephesus was of the opinion that "by nature the nursling becomes similar to the nurse and accordingly grows sullen if the nurse is ill-tempered" (Soranus of Ephesus and Temkin 1991), and the 17<sup>th</sup> century French obstetrician Guillemeau believed that physical traits of the nurse could be passed to the child, and accordingly decreed that neither the nurse nor any of her ancestors should ever have been "stained or spotted, in body or mind" (Matthews Grieco 1991). In pre-revolutionary Russia breastmilk was viewed as the source of human sinful nature, and in the region of western Belarus infants who died without having consumed it were believed to bypass purga-

tory and go straight to heaven (Gerbeda-Wilson and Powers 2012). The Nso of Cameroon, meanwhile, consider breastmilk to have medicinal properties (Yovsi and Keller 2003), and in early modern England and America it was regarded as a beneficial food for the sick, both adults and children (Salmon 1994).

Perhaps due to its unusual appearance compared to mature milk, beliefs that the colostrum is not good milk and should not be given to infants are widespread (Fildes 1986, Matthews Grieco 1991, Yovsi and Keller 2003, Laroia and Sharma 2006, Shaikh and Ahmed 2006). The Roman physician Soranus was of this opinion, arguing that maternal milk was unwholesome for infants during the first twenty days post-partum, although not all contemporary physicians shared his view (Fildes 1986, pp. 26–27). These beliefs mean that the first milk is discarded, and infants may be given other foods or even just water for the first couple of days post-partum (Laroia and Sharma 2006, Shaikh and Ahmed 2006, Gerbeda-Wilson and Powers 2012). In both Hindu and Islamic culture these pre-lacteal feeds are important rituals that are usually performed by a respected family member (Laroia and Sharma 2006, Shaikh and Ahmed 2006). In pre-revolutionary Russia the first milk feed was given only after socialisation rituals had been performed for the infant and purification rituals for the mother, and the infant was first given a chew of grated beetroots that was believed to avoid a child being fussy and to prevent hernia (Gerbeda-Wilson and Powers 2012). The loss of the anti-infective properties of colostrum and the increased pathogen risk from feeding a neonate other foods mean that these practices are thought to increase infant morbidity, particularly in non-industrialised populations (Holman and Grimes 2003).

Once a woman's mature milk has come in, a variety of conditions may still be considered to turn it “bad” and so cause a cessation of breastfeeding. A belief from Classical times that persisted until medieval times in Europe was that the milk was related to the menstrual blood, and medical illustrations from the 16<sup>th</sup> Century even illustrate the “*vasa mensualis*” via which it was believed that the menses were directed to the breast during pregnancy and lactation (Fildes 1986, fig. 6.3). Menstruation was thus believed to reduce the quality and even corrupt the milk (Fildes 1986, pp. 179–182). Taboos against sexual intercourse during lactation are also widespread (Saucier 1972), and have been suggested as an explanation for the greater use of artificial feeding and wet-nursing historically in Catholic regions than Protestant regions of Europe (Van Poppel *et al.* 2002, Thorvaldsen 2008). Pregnancy is also widely regarded to either reduce the quality of or pollute the breastmilk (Matthews Grieco 1991, Eidelman 2006).

For copyright reasons, there is no image in the digital edition

*Figure 4: The origins of animal milks in infant feeding? Christian Bernhard Rode, 18<sup>th</sup> Century. © Trustees of the British Museum*

### 4.3 Artificial Feeding With Animal Milks

Gods and demi-gods raised on animal milk feature widely in European mythology. Amongst others the Nordic primordial frost giant Ymir was suckled by the cow Auðumbla, the Greek God Zeus was believed to have been raised on milk from the goat Amalthea, Telephus the son of Hercules was nursed by a doe, the Lydian King Croesus and Persian King Xerxes by mares, the Trojan Paris by a bear, and most famously the twin founders of Rome, Romulus and Remus, were nursed by a wolf (Radbill 1976). Being nursed by animals was presumably supposed to emphasise the other-worldly nature of these individuals and the origin of their powers. The characteristics derived from animal milks have not always been considered to be positive however. A 14<sup>th</sup> century Tuscan moralist Paulo de Certaldo was concerned that a child's cognitive development would be shaped by the animal whose milk they drank, and warned that that "the child nourished on animal milk does not have perfect wits like one fed on women's milk, but always looks stupid and vacant and not right in the head" (Matthews Grieco 1991). Medical authors thus typically only recommended animal milks for infant feeding in the event that breastfeeding was not possible (Fildes 1986, pp. 299–306).

Prior to the domestication of animals it would presumably not have been possible for animal milks to be used in human infant feeding, however ethnographic evidence suggests that the idea of doing so may not have required much of a cognitive leap. Hunter-gatherer women have been observed feed-

ing young abandoned animals their own breastmilk on a number of occasions (Radbill 1976, Bird-David 2008), and once possible using animal milks to feed human infants in need may well have been a natural extension of an already-extant idea. Media reports of an eighteen month old Cambodian boy imitating a calf and suckling directly from the family cow after he had been suddenly weaned when his parents left the country to find work (Samrang *et al.* 2011), show that once domestic animals were present the initiative to use their milk in infant feeding could even have come from children themselves rather than adults (Fig. 4).

## 4.4 The Introduction of Non-Milk Foods

Vast variation is exhibited between cultures in both the timing of the introduction of non-milk foods and the types of foods given. The first introduction of solid foods (aside from pre-lacteal feeds) may also be a rite of passage, such as the Hindu ceremony of Anna Prashan, in which an infant is fed its first solid food of rice mixed with curds, butter and ghee whilst the child's father speaks a mantra asking that the foods will not cause sickness (Laroia and Sharma 2006).

A survey of infant feeding practices in non-industrial populations reveals that the first introduction of non-breastmilk liquids is often around the time of birth, and rarely after the age of six months (Sellen 2001). The timing of the introduction of solids is more varied, peaking at around six months but occurring at any time from birth to early in the second year (Sellen 2001). Comparison of the infant feeding practices of groups with agricultural, pastoralist, and hunter-gatherer economies reveals that the latter typically introduce both liquids and solids earlier than the two former, but also continue to breastfeed slightly longer (Sellen and Smay 2001). There is however a wide-variation between groups with similar economies.

Perhaps unsurprisingly, populations with food-producing economies are significantly more likely to use animal milks and crop-derived carbohydrate-rich foods in supplementary feeding than hunter-gatherer populations (Sellen and Smay 2001). The total range of foods used by agriculturalists, pastoralists and hunter-gatherers is however similar. In many cultures the foods used in supplementary feeding are specially sourced and produced. Amongst the Kazakhs the fat from under a horse's mane and over its sternum, and that from a camel's hump, are prized foods for infant feeding, as is ram's tail cooked in milk (Levine 1998). Amongst the Alaskan Yu'pik and Inupiat premasticated fish livers and fish liver oils were traditionally given to infants, as was a mixture of moose or caribou tallow and seal train oil known as "baby agatuk" (Heller and Scott 1967). Weanlings of the Ache culture of eastern Paraguay meanwhile eat foods including armadillo fat and insect

larvae (Konnor 2005). Weaning foods can thus be diverse, and whilst usually derived from the same resources as the adult diet they rarely replicate it.

## 4.5 The End of Suckling

*'Tis since the earthquake now eleven years,  
And she was weaned – I never shall forget it –,  
Of all the days of the year, upon that day:  
For I had then laid wormwood to my dug,  
Sitting in the sun under the dove-house wall;  
[...]  
When it did taste wormwood on the nipple,  
Of my dug and felt it bitter, pretty fool,  
To see it tetchy and fall out with the dug!*  
The Nurse, *Romeo and Juliet*, Act I Scene III

Weaning is not just a biological transition, but a social and emotional one too. In many cultures the end of breastfeeding marks the end of infancy and the beginning of childhood, which may be characterised by greater independence and interaction with carers other than the mother. The age at which it is considered appropriate to wean a child varies dramatically within and between cultures, and different ages may be considered appropriate for different individuals, as in ancient Rome where some physicians apparently recommended that females be weaned six months later than males (Fildes 1986, pp. 26–36). The biblical example of Abraham “throwing a great feast” on the day that his son Isaac was weaned (Genesis 21:8) shows that this transition was considered a socially important one, and was marked by ceremony. In pre-revolutionary Russia weaning would be marked with a ritual in which a mother gave her child bread and salt over her shoulder whilst telling the child not to “count on a tit”: the ritual marked the end of a worry-free life (Gerbeda-Wilson and Powers 2012). A child returning to the breast was greatly feared, since this was supposed to make a child stupid and meant that the child had abandoned society. In Ukraine and Belarus children who returned to the breast were even considered to possess the evil-eye (Gerbeda-Wilson and Powers 2012).

The different beliefs about and attitudes to the cessation of breastfeeding are well illustrated by the contrasting weaning practices employed by Bofi foragers and farmers of central Africa (Fouts 2004, Fouts *et al.* 2005). The Bofi farmers believe that allowing infants to breastfeed beyond the age of two years makes them inactive and lazy. There are also practical considerations, however, since once they are weaned mothers will no longer need to carry their heavy toddlers with them to the fields and can instead leave them in the village in the care of older siblings. Infants are thus coerced into ceasing to suckle at some point between the ages of eighteen months and two

years by invoking fear or disgust of the breast. Other examples of such techniques are reported both historically (Fildes 1986, pp. 377–380) and ethnographically (Shostak 1981, Fouts 2004). In the case of the Bofi farmers the breast is made to appear wounded, by bandaging it and/or painting the nipple with red nail varnish, and the wounded state of the breast is reinforced for the infant by gentle teasing and taunting. Perhaps unsurprisingly the withdrawal of nursing is associated with increased fretfulness and crying, and during the week or so a child is considered to be “being weaned” it is given special indulgences, such as a specially-prepared sweetened rice gruel that their older siblings are prohibited from eating. Rice is recognised as a special food, since it is not available locally and must be purchased in larger villages. For the Bofi farmers, therefore, the end of breastfeeding can be described as a liminal stage during which the infant is afforded a special status whilst they make the transition from infant to child.

The attitude of Bofi foragers to the cessation of breastfeeding differs markedly to that of Bofi farmers, despite the fact that each group is aware of the practices of the other. Bofi foragers believe that infants should decide for themselves when to cease nursing, and infants are allowed to nurse at will (although mothers may increasingly leave their children behind in camp for periods of time as they get older, thereby reducing the opportunities for nursing). Bofi foragers believe that if a child is forced to stop breastfeeding it will become sick and may die, and as a result they wean later and at a wider variety of ages than the Bofi farmers. Infant-led weaning has been recorded less frequently than coerced weaning, but has been reported for some other hunting and foraging populations (Heller and Scott 1967, Bird-David 2008). The majority of Bofi forager infants cease nursing during their mother’s next pregnancy: mothers reported that their infants were put-off either by the sight of their pregnant stomach and the movements of the unborn child, or by a decline in the quality and taste of the milk produced during pregnancy. In other populations infants continue nursing during and after their mother’s pregnancies, however, so this deterrent to suckling is clearly not universal (Jelliffe *et al.* 1961, Moscone and Moore 1993, Gerbede-Wilson and Powers 2012). If a further pregnancy does not occur a child may continue to nurse for many years.

For both forager and farmer children the end of weaning marks a social transition, with both groups of children being less dependent on the mother and spending more time in the company of other caregivers once weaning is completed. The reduction of maternal care is associated with a drop in the amount of time for which children are held by their mothers, however amongst forager children some of the loss of maternal holding is compensated for by being held more by fathers, grandmothers, and aunts, whereas farmer children are rarely held at all once weaning is completed (Fouts 2004, Fouts *et al.* 2005). For Bofi foragers therefore the end of weaning marks a less abrupt change in the child’s social relations than it does for the farmers,

and is unsurprisingly not associated with an increase in fussing and crying as it is amongst the foragers (Fouts 2004, Fouts *et al.* 2005).

The end of weaning is thus a transition that can be child-led or forced by the mother, that may occur at culturally prescribed ages or be more flexible in its timing, may be associated with special foods and rituals, and may to a greater or lesser degree be associated with a change in social status from being an infant to being a child.





## 5 Assessment of Weaning in Prehistoric Populations

### 5.1 Inferential Approaches

Prior to the development of chemical techniques, assessment of the age at weaning in prehistoric populations was only possible by inference from skeletal indicators of childhood stress presumed to have arisen in response to morbidity during the weaning process. Goodman and Armelagos (1989) for instance attributed a reduction in the peak age of occurrence of enamel hypoplasia (a deficiency in the thickness of tooth enamel that occurs when secretion of the enamel matrix is disrupted in response to physiological stress (Goodman and Rose 1990)), to an earlier age of weaning in conjunction with increasing intensification of agriculture at the Dickson Mounds Site, Illinois. These approaches are obviously limited, not least because there are dozens of potential causes of enamel hypoplasia, not all of them resulting from systemic disease (Cutress and Suckling 1982). There are many reasons aside from weaning why children might be at increased risk of morbidity at particular ages, such as changes in activity patterns and social interaction. Furthermore, the morbidity risk associated with weaning depends on the manner in which it is done, for instance the nutritional quality and sterility of the non-breastmilk diet, and the pathogen risk of the environment in which it takes place. The development of direct techniques for independently establishing the duration of breastfeeding has thus not only enabled the age at weaning to be established with more accuracy, but also makes it possible to draw inferences about the contribution of the weaning process to childhood morbidity rates in different prehistoric contexts.

### 5.2 Biomolecular Approaches to the Study of Weaning

#### 5.2.1 The Skeletal Tissues

All palaeodietary studies based on the analysis of the chemical composition of preserved body tissues rely on the principle that “you are what you eat”; the constituent atoms and molecules of the body tissues are derived from the diet and their chemical composition is thus related to it. The tissues most

commonly preserved in archaeological contexts and employed for the studies in this thesis are bone and teeth. The bones and teeth form in different ways, which means that the material within them is derived from the diet consumed at different periods during an individual's lifetime.

### 5.2.1.1 Bone

Bone is a composite material that consists of an organic matrix surrounded by a mineral "packing" (ICRP 2002). The mineral component consists mostly of a microcrystalline structurally-imperfect analogue of hydroxyapatite,  $\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$ , although other minerals such as carbonate are also present (Lowenstam and Weiner 1989, pp. 151–152, Burton 2007). Some 85-90% of the organic matrix consists of type I collagen (Lowenstam and Weiner 1989, pp. 152–153), which in total constitutes 22% of compact bone by weight and 36% by volume (Collins *et al.* 2002). The remainder of the organic material is made up of non-collagenous proteins.

Bone is a metabolically active tissue that undergoes constant modelling and remodelling (Robling *et al.* 2006). The rate of this process is faster in trabecular (spongy) bone than in cortical (compact) bone (ICRP 2002), and changes in response to a number of factors including activity levels, diet, ethnicity, menopausal status, growth, the time of day and season of the year, and in particular with age (Seibel 2005). Bone turnover declines with increasing age, such that the cortical bone of adults contains material formed many decades previously (ICRP 2002, Hedges *et al.* 2007). During adolescence femoral cortical bone remodels at rates of 10-30% each year, and at a much faster rate in males than females (Hedges *et al.* 2007). Remodelling rates in earlier childhood are not well-studied, but estimates of around 300% per year at birth have been given, falling to around 100% at the end of the first year and 50% by age five (ICRP 1995).

*Table 3: Growth rates of health human infants during the first five years of life. Based on the 50<sup>th</sup> percentile in the WHO child growth standards (2006)*

Age	Height (% increase on previous year )		Weight (% increase on previous year)	
	Boys	Girls	Boys	Girls
1	52	51	190	178
2	16	17	27	29
3	9	10	17	21
4	7	8	14	16
5	6	7	12	13

In addition to remodelling, the bones of infants and children are growing rapidly which means that the proportion of new material within them is increased still further. Healthy infants increase their height by 50% and nearly triple their birth weights during the course of the first year (Table 3, WHO Multicentre Growth Reference Study Group 2006). Equilibration of bone composition to dietary changes is thus very rapid in infancy, and gradually declines as both growth and remodelling rates drop during childhood. At death, the composition of an individual's bone is hence dependent on the diet over a period of months, years, or decades previously, depending on the age of the individual.

### 5.2.1.2 Teeth

The teeth are composed of a dentine core, and the tooth crown has an enamel coating (Fig. 5). The root of the tooth is coated with cementum, a calcified substance that helps support the tooth in its socket. As with bone, dentine takes the form of a mineralised organic mesh consisting mostly of collagen and hydroxyapatite (Märten *et al.* 2010). Enamel on the other hand is a heavily mineralised crystalline structure that is almost devoid of organic material once mature (Hillson 1996, pp. 148–149). Enamel and dentine are both laid down in a series of angled layers, beginning in the cusp of the crown (Hillson 1996, pp. 118–125). Enamel protein matrix and predentine then continue to be deposited in sequential layers until the tooth crown is complete, after which just predentine is secreted in sharply angled layers to form the tooth root. The enamel matrix and predentine then proceed to gradually mineralise, with the organic enamel matrix being broken down in the process (Hillson 1996, pp. 148–197).

In contrast to bone the teeth are inert and do not remodel once formed, with the exception of small amounts of secondary dentine deposited inside the pulp chamber and reparative tertiary dentine. The chemical composition of the dentine and enamel layers thus continues to reflect that of the diet at the time they were deposited and mineralised. The formation of the deciduous teeth begins *in utero* and ends around three years of age (Lunt and Law 1974), whereas that of the permanent teeth begins around the time of birth and ends with the completion of the third permanent molar in late adolescence or the early twenties (Moorrees *et al.* 1963, Smith 1991). An archive

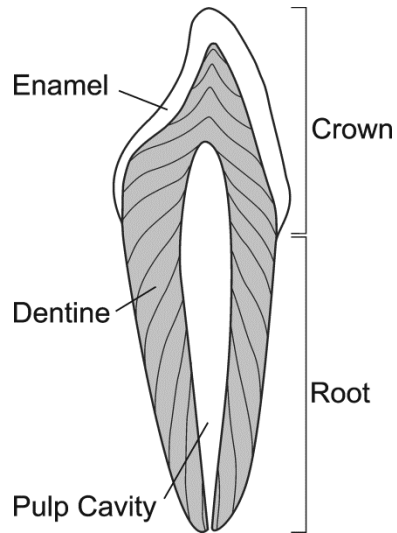


Figure 5: The structure of a tooth, with a schematic illustration of the pattern of dentine layering.

of the changing diet during childhood is thus retained within the mouths of adult individuals.

### 5.2.2 Strontium:Calcium Ratios

In 1984 Sillen and Smith published the first study of ancient weaning practices based on the chemical composition of skeletal material. Their study utilised the fact that the ratio of strontium (Sr) to calcium (Ca) is much lower in milk than in other foods to track the introduction of supplementary foods to the diet in a Middle-Eastern Byzantine population (Sillen and Smith 1984). Strontium substitutes for calcium in the skeleton, and the Sr:Ca ratio of infant bones is thus expected to increase as non-milk supplementary foods are introduced to the diet. Sillen and Smith (1984) observed an increase in the Sr:Ca ratio of infant bones with increasing age, with a peak between eighteen months and three years. This concurs with historical evidence that weaning was usually completed between two and three years (1984).

Despite being the longest established method, concerns over diagenesis mean that Sr:Ca ratios have only infrequently been used in the study of the prehistoric infant diet (Hühne-Osterloh and Grupe 1989, Katzenberg *et al.* 1996, Schurr 1998, Mays 2003). The porous nature of bone means that mineral exchange with the soil can easily occur (Burton 2007), and stable isotope analysis of the more diagenesis-resistant bone collagen has been preferred instead. Nevertheless, Mays has argued that where diagenesis can be shown to be minimal, Sr:Ca ratios may be a useful complement to stable isotope techniques because of their ability to identify the introduction of low-protein supplementary foods to the diet, rather than the removal of breastmilk protein as is tracked by nitrogen stable isotopes (2003).

Most recently, micro-analytical approaches have been used to analyse the changing Sr:Ca ratios of successively deposited layers of tooth enamel in single individuals. Enamel is extremely resistant to diagenesis, owing to a dense crystalline structure that is almost devoid of the pores and organic material that leave bone mineral vulnerable to contamination (Burton 2007). By using laser ablation techniques it has thus been possible to analyse the Sr:Ca ratio at dozens of points along single tooth crowns, and thereby to trace the onset of nursing after birth and the weaning process in single individuals (Humphrey *et al.* 2008a, Humphrey *et al.* 2008b). There are however probably limits to the time resolution that can be achieved with such methods, owing to the gradual maturation of tooth enamel (Balasse 2003, Passey *et al.* 2005, Lee-Thorp 2008).

### 5.2.3 Stable Isotope Ratios as Palaeodietary Indicators

Isotopes are atoms of an element that differ from one another in the number of neutrons in the atom nucleus. Some isotopes, such as Carbon-14, are un-

stable and subject to radioactive decay; others however are stable, meaning that the ratio of one stable isotope to another remains constant over time. The different isotopes of an element have more or less identical chemical properties, however the mass difference means that they have different kinetic properties and so participate in reactions at different rates. The products of a reaction, provided it does not go to completion, are thus likely to have different ratios of one stable isotope to another than the reactants, a process termed fractionation. Physical processes such as evaporation can also cause isotope fractionation, with the vapour typically being isotopically lighter than the remaining liquid. The ratio of one stable isotope to another is measured to the nearest thousand and reported using the delta notation according to the formula:

$$\delta_Z = \left( \frac{R_{\text{sample}} - R_{\text{standard}}}{R_{\text{standard}}} \right) \times 1000$$

where Z is the element in question, R the ratio of the heavier to lighter isotope, and x the atomic mass of the heavier isotope being analysed.

### 5.2.3.1 Nitrogen

Nitrogen has two stable isotopes,  $^{14}\text{N}$  and  $^{15}\text{N}$ . The origin of all dietary nitrogen is ultimately atmospheric  $\text{N}_2$ , which has a uniform abundance of  $^{15}\text{N}$  and so is used as the standard against which nitrogen isotope ratios are measured (Ehleringer and Rundel 1989). Nitrogen primarily enters the food web when bacteria living freely in the soil or in symbiosis with plants fix atmospheric nitrogen ( $\text{N}_2$ ) into compounds that can be taken up by plants (Dawson *et al.* 2002). Subsequent denitrification processes usually result in soil and plant  $^{15}\text{N}$  values that are higher than that of atmospheric  $\text{N}_2$ , however plants that are able to access atmospheric  $\text{N}_2$  through symbioses with  $\text{N}_2$ -fixing bacteria have  $^{15}\text{N}$  nearer to 0 (Peterson and Fry 1987, Ehleringer and Rundel 1989, Ambrose 1991).

Nitrogen in the animal diet is almost exclusively in the form of protein and its constituent amino acids (Schoeller 1999). Nitrogen stable isotope analysis of skeletal tissues must, therefore, be conducted on the collagenous proteins in bone and dentine rather than the mineral. Animals preferentially excrete the lighter isotope of nitrogen,  $^{14}\text{N}$ , via urea (Steele and Daniel 1978, Deschner *et al.* 2012), and as a result the  $^{15}\text{N}$  of an animal's body and its milk is enriched in  $^{15}\text{N}$  relative to its diet (Jenkins *et al.* 2001, Cheng *et al.* 2011). The  $^{15}\text{N}$  of animal body tissues thus increases with each level of the food chain (DeNiro and Epstein 1981, Minagawa and Wada 1984, Schoeninger and DeNiro 1984). The magnitude of this increase is often cited as being around +3-4 (Sealy 2001, Katzenberg 2008), however it is variable and differs both within and between species for reasons that are poorly understood (McCutchan *et al.* 2003, Hedges and Reynard 2007, Caut *et al.* 2009). Recent empirical evidence suggests that for humans the fractionation between diet and collagen may be as high as +6 (O'Connell *et al.* 2012).

Causes of within-species variation include growth (Lidén and Angerbjörn 1999, Warinner and Tuross 2010), pregnancy (Fuller *et al.* 2004), disease (Katzenberg and Lovell 1999, Loudon *et al.* 2007), water stress (Ambrose 1991), nutritional stress (Hobson and Clark 1992), and dietary protein intake (Sponheimer *et al.* 2003, Robbins *et al.* 2005).

In 1989 the first study of infant feeding practices using nitrogen stable isotope ratios was published (Fogel *et al.* 1989). At birth the  $\delta^{15}\text{N}$  of infant body tissues is slightly higher (c.1 ‰) than that of maternal tissues (De Luca *et al.* 2012). Since maternal milk is enriched in  $^{15}\text{N}$  compared to the maternal diet the  $^{15}\text{N}$  of new infant tissues formed after the onset of breastfeeding will be a trophic level higher than that of the mother's tissues (Fogel *et al.* 1989, Fuller *et al.* 2006a). The limited modern data available suggest that the tissues of exclusively breastfeeding infants are around 2.5 ‰ higher than the equivalent tissues in the mother (Fogel *et al.* 1989, Hobson *et al.* 2000, Fuller *et al.* 2006a). Once weaning is initiated and sources of non-breastmilk protein are introduced to the diet the  $^{15}\text{N}$  of infant tissues will begin to fall, until breastfeeding ceases and the infant is consuming the post-weaning diet (Fig. 6).

### 5.2.3.2 Carbon

The two main systematic differences in the carbon stable isotope composition of the food web are between marine and terrestrial food chains and between  $\text{C}_3$ - and  $\text{C}_4$ -photosynthesising plants. The  $\text{C}_4$  (Hatch-Slack) photosynthesis pathway, which is used by some drought-adapted grasses, discriminates less against  $^{13}\text{C}$  than the more common  $\text{C}_3$  pathway (Smith and Epstein 1971, Peterson and Fry 1987). The  $^{13}\text{C}$  of  $\text{C}_4$  photosynthesising plants is thus higher than that of  $\text{C}_3$  photosynthesising plants. The very first use of stable isotopes in palaeodietary studies was to track the introduction of a  $\text{C}_4$  photosynthesising crop, maize, into the temperate  $\text{C}_3$  environment of north-east America (Vogel and van der Merwe 1977). The second major difference in the  $^{13}\text{C}$  of the biosphere, that between marine and terrestrial food webs, was first utilised in palaeodietary studies by Tauber (1981) to demonstrate the apparent abandonment of marine-based dietary resources after the introduction of agriculture in Denmark. The difference between marine and terrestrial  $^{13}\text{C}$  arises because marine plants derive most of their carbon from dissolved bicarbonate, which has a higher  $^{13}\text{C}$  than atmospheric  $\text{CO}_2$ , and marine food webs thus also have higher  $^{13}\text{C}$  than terrestrial  $\text{C}_3$  food webs (Smith and Epstein 1971).

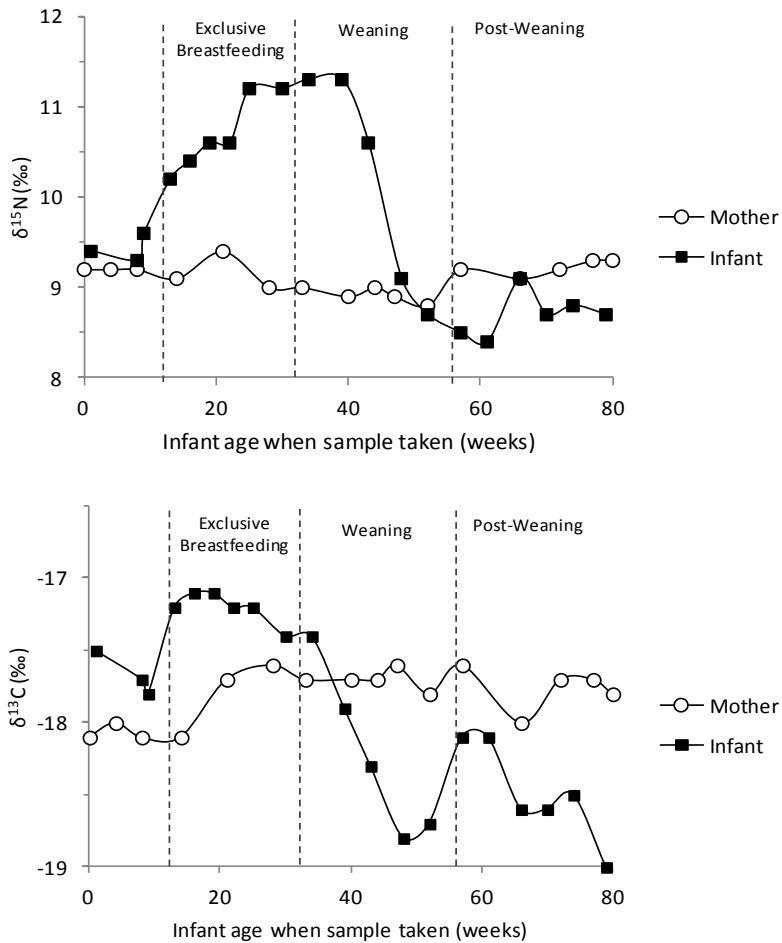


Figure 6: Patterns of change in  $\delta^{15}\text{N}$  (top) and  $\delta^{13}\text{C}$  (bottom) with breastfeeding and weaning in a modern mother infant pair. Redrawn from data in Fuller *et al.* 2006a. The samples are taken from fingernails, which take around 2-3 months to grow out from cuticle to tip in infants, and 4-6 months in adults. Note that  $\delta^{13}\text{C}$  drops rapidly when supplementary foods are introduced, whereas  $\delta^{15}\text{N}$  drops much more gradually. The decline in  $\delta^{13}\text{C}$  below the maternal value reflects the fact that the weaning diet (which was largely based on cereal products) differed to the maternal diet.

In contrast to nitrogen, carbon is found in all dietary fractions. The analysis of carbon stable isotope ratios can thus be conducted on both collagen and apatite, although the latter is less often used due to concerns that it is vulnerable to diagenesis. The carbon in collagen is preferentially routed from dietary protein, especially under high-protein diets (Ambrose and Norr 1993, Howland *et al.* 2003, Jim *et al.* 2004, 2006), whereas that in apatite is more

equally derived from all parts of the diet. The  $^{13}\text{C}$  of collagen is thus mostly a reflection of the source of dietary protein intake, whereas that of apatite also reflects carbohydrate and lipid intake.

Carbon stable isotopes also display slight trophic level increases of around 1-1.5 ‰, which have been observed between mothers and infants in one modern study of nursing infants (Fuller *et al.* 2006a). Since collagen  $^{13}\text{C}$  is at least to some extent influenced by dietary carbohydrate and lipid intake as well as protein, the  $^{13}\text{C}$  of infant tissues is more sensitive to the introduction of low-protein supplementary foods to the diet at the start of weaning than  $^{15}\text{N}$  is (Fig. 6). Carbon isotopes can also identify specialised weaning foods that are derived from different dietary sources to the maternal diet (Wright and Schwarcz 1999, Dupras *et al.* 2001, Williams *et al.* 2005, Clayton *et al.* 2006, Keenleyside *et al.* 2009, Choy *et al.* 2010).

#### 5.2.3.3 Oxygen

Oxygen stable isotopes are mostly used as indications of migration and climate rather than diet, however they have also occasionally been employed in the study of infant feeding (Dupras and Tocheri, 2007; Turner *et al.*, 2007; Williams *et al.*, 2005; Wright and Schwarcz, 1998, 1999). Water containing the light isotope of oxygen,  $\text{H}_2^{16}\text{O}$ , is preferentially lost through expiration, and the body water pool from which milk is formed thus has a higher  $^{18}\text{O}$  than water imbibed (Wright and Schwarcz 1998). The  $^{18}\text{O}$  of breastfeeding infants is therefore higher than that of their mothers. Whereas nitrogen stable isotope ratios track the changing protein composition of the diet and carbon the change in food sources, oxygen stable isotope ratios are indicative of the introduction of non-milk water sources to the diet.

#### 5.2.4 Approaches to the Study of Infant Feeding

The majority of stable isotopic studies of infant feeding have been based on the analysis of bone collagen from infants who died at different ages, and comparing the results to those from adult female bone collagen from the same site. This technique can give an impression of infant feeding norms within a population. There are a number of caveats and limitations to this approach, however. It requires that there is a reasonably strong cultural norm as to the duration and intensity of breastfeeding and a relatively homogenous adult female diet, since otherwise it can be impossible to discern the breastfeeding status of infants. Similarly, if the isotopic composition of supplementary foods or the post-weaning diet is different to that of the adult female diet, infants may appear as if they have ceased breastfeeding when they are in fact consuming a mixture of low-trophic level supplementary foods and breastmilk, or conversely as if they are still breastfeeding when they are in fact completely weaned and consuming a high trophic level post-weaning diet.



The gradual slowing of both growth and turnover means that the later in life dietary transitions take place the longer it takes for them to be reflected in the isotope composition of the bone. The lack of exact values for the rates of bone turnover and growth at different ages means that precise timings of infant dietary transitions cannot be established. Similarly, natural variations in growth and development rates mean that there is an inherent margin of error in assigning an age-at-death to skeletal individuals, one that increases with age and is greater when skeletal preservation is poor (Scheuer and Black 2000, pp. 4–17).

A further problem with studies based solely on bone collagen is that it means that the determination of the timing and mode of weaning is conducted on individuals who did not survive the process. It is thus possible that these individuals will not be representative of the usual infant feeding practices of a population.

An innovative approach taken recently to avoid the problem of intra-population variation in the infant and adult diet at different ages has been to use intra-longbone sampling (Waters-Rist *et al.* 2011). Long-bone growth takes place at the metaphyses, and as result the metaphyses of a bone contain more newly-formed material than the diaphysis. By comparing the stable isotope ratios of samples taken from the bone metaphyses to that from the diaphysis, Waters-Rist and colleagues have thus been able to gain an impression of the weaning status of single individuals from Neolithic hunter-fisher-gatherer groups from Siberia (2011).

A more common method of studying weaning at the individual level has been to analyse tooth dentine or enamel that formed at different ages during the lifetime of the same individual. Although there is still some variation in the timing of dental development between individuals, the inert nature of teeth means that imprecision about the duration of turnover is avoided. Since the teeth do not remodel this technique also makes it possible to study the infant diets of individuals who survived the weaning process.

Some researchers have conducted tooth-based analyses using whole tooth crowns from teeth that formed at different ages (Wright and Schwarcz 1999, Lidén *et al.* 2003, Dupras and Tocheri 2007), whereas others have analysed material that formed at different ages in the same tooth (Balasse 2002, Fuller *et al.* 2003, Rountrey *et al.* 2007, Eerkens *et al.* 2011). Improvements in the analytical capabilities of instrumentation mean that sample sizes have got ever smaller, and the recent study by Eerkens and colleagues (2011) demonstrated that it is possible to get up to ten spatially-discrete samples from a single permanent molar tooth. Although these samples are not chronologically discrete in terms of the timing of their formation, this analysis nevertheless allows for high-resolution studies of the changing infant and juvenile diet.

### 5.3 A Note About Representativity

A problem common to all analyses of skeletal assemblages is that of representation: skeletal assemblages are by definition not random samples of the living population, but rather have been selected by death. The two-year-olds in a skeletal assemblage, for example, are not a random sample of all two-year-olds in the living population, but only those that died at the age of two. This means that even if a sample is perfectly representative of all individuals in a population who died, it will still not be perfectly representative of all individuals who lived, but rather biased towards those who were at the greatest risk of dying at any particular age (Wood *et al.* 1992). Given that poor infant feeding practices increase the risk of death, information about infant feeding practices derived from skeletal remains will be biased towards those practices that were less successful. Furthermore, infants who were at greater risk of dying may have been fed differently, for instance sick children may be breastfed for longer than their healthy peers. As mentioned in the previous section, this problem is negated to a large extent by the use of dentine samples to study infant feeding practices in individuals who survived the process. Nevertheless, some bias may still remain since even amongst children who survived breastfeeding and weaning, those who received the best nutrition during infancy are liable to have been less frail and thus less likely to succumb to illness and death during later childhood.

There are also many reasons why the subadult individuals in a skeletal assemblage may not be truly representative of even the dead population. Subadult individuals are often underrepresented in the archaeological record, partly for taphonomic reasons and partly because they may be treated differently in death to adult individuals (Lewis 2007, pp. 20–37). Subadult bone is less mineralised and more porous than adult bone, and is thus more vulnerable to taphonomic processes in the burial environment (Guy *et al.* 1997). Furthermore, the small size and unfamiliarity with subadult skeletal elements means that subadult skeletal material is more likely to be missed by inexperienced excavators, particularly when poorly preserved (Lewis 2007, pp. 20–37). Whilst these problems reduce sample sizes, they should not lead to bias in the results of studies of the infant diet, since taphonomic processes will affect skeletal material equally, regardless of how infants were fed. Social factors leading to differential treatment of individuals in death may however bias the results. The burial of subadult individuals outside of the usual adult burial grounds, or in separate areas of a graveyard, has been reported for a number of archaeological populations (Lewis 2007, pp. 20–37), and age, along with vertical and horizontal social position, has been found to be one of the most common determinants of mortuary practices reported in ethnographic literature (Carr 1995). As detailed in Chapter 4, the introduction of non-breastmilk foods and the completion of weaning may both be regarded as rites of passage in a society that mark the transition from one age class to

another. It is plausible, therefore, that infant remains in a cemetery may be biased towards those who have already reached these milestones. Furthermore, since infant feeding practices may correlate with social class, differential treatment of different social classes in death may lead to a biased or incomplete impression of the infant feeding practices of a population.

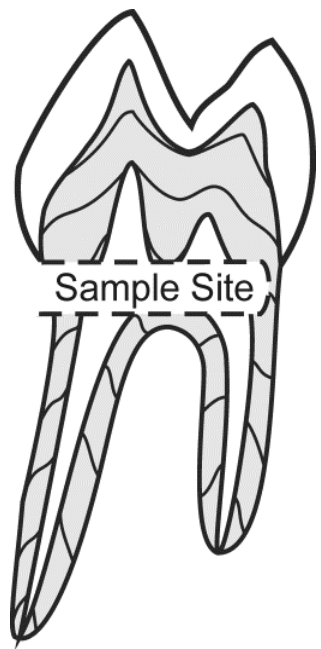
A final point concerns not the infants but the mothers: since it is rarely possible to identify mother-infant pairs, it is necessary to assume that the adult females in a population will be representative of nursing mothers. This may not be the case, however, since female diet may differ between reproductive and non-reproductive females, or between nursing and non-nursing females. The gradual turnover of adult bone means that this latter difference may be masked in the isotope data. Furthermore, as detailed in Chapter 4 it is not unusual for infants to be breastfed by women other than their mothers, and where infants were regularly breastfed by women outside of their communities, due to wet-nursing or fosterage arrangements, the diets of the nursing females may have differed substantially from those of females in the cemetery in which an infant was buried.

## 5.4 The Methods Used in this Study.

In the studies in this thesis a mixture of bone and dentine samples were used. This meant that samples were taken both from those who survived infancy, and those who died during it. One sample was taken from each tooth: for the permanent teeth samples were taken from the cervix of the tooth just beneath the tooth crown (Fig. 7), whereas the smaller size of deciduous teeth meant that for these it was also necessary to sample dentine from within the tooth crown. The sample formation times were estimated from information on tooth formation in Lunt and Law (1974) and Smith (1991). The deciduous tooth samples represent average diet over a period of some months to a year, whereas those from the permanent teeth represent diet over a period of around two years. For the permanent teeth the age at the end of formation was taken to be the time at which the tooth root was 25% complete, it should be noted that this is likely to be something of an over-estimation of the amount of dentine sampled. The time resolution of the samples is thus rather sharper than approaches in which the whole tooth crown is sampled.

By sampling the deciduous and permanent first and second molars plus the bone of individuals it was, where preservation permitted, possible to obtain four or even five samples representing diet at different points during a single individual's life. This sampling strategy is not as high-resolution as the micro-sampling approach of Eerkens and colleagues (2011), however it has the advantage that it is much less destructive to the skeletal material. Whereas the micro-sampling approach involves the destruction of the entire dentine portion of the tooth, the approach used here usually leaves the mor-

phological structure of the tooth intact. This leaves the dentition available for future research: an important consideration given the unique and non-renewable nature of archaeological material.



*Figure 7: Diagram of a molar showing the site at which samples were taken from the permanent dentition*

## 6 Results and Discussion: Neolithic Contributions to the Infant Diet

Three of the papers in this thesis report the results of stable isotopic studies of the infant feeding practices of prehistoric populations, and a fourth contains data pertaining to the infant diet (Figs. 8, & 9). Two of those papers, I and III, discuss the infant feeding practices of populations living on islands in the Baltic, but in different time periods (Neolithic vs. Iron Age) and with different economies (Hunter-Gatherer vs. Agricultural). The second (II) discusses the infant feeding practices of Neolithic and early Bronze Age communities with agricultural economies from Little Poland. In addition, the fourth paper (IV) also includes some data pertaining to the infant feeding practices of early Bronze Age individuals from the Wrocław region of Poland.

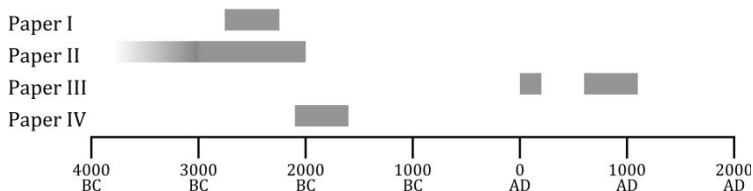
What all of these papers have in common is that they reveal variation in the way infants were fed, both within populations and between them (Fig. 10). The norm amongst Pitted Ware Culture hunter-gatherers living on the Baltic island of Gotland during the third millennium BC appears to have been to breastfeed infants into the third year of life. Supplementary feeding practices were more variable, however, and this is interpreted as probably being due to the seasonal nature of the diet at Ajvide. Comparison to other Pitted Ware Culture sites suggests that the broadly marine-based diet of the Pitted Ware Culture was adapted in different locations to suit either the local ecology or local traditions, and the data available suggests that this adaptability extended to the supplementary feeding of infants.

During the third millennium BC in the Little Poland region various farming communities were employing a diverse range of infant feeding practices. The data set is very diverse, reflecting a number of sites and different archaeological culture groups, and each site is represented by just a small number of individuals. It is thus difficult to draw definitive conclusions as to whether the differences in infant feeding practices observed between the sites and culture groups are representative of broader differences in practice, or are just artefacts of the small sample sizes. Nonetheless, it is apparent that in most cases breastmilk intake dropped more sharply between the first and second halves of the first year of life than it did at Ajvide. The exceptions to this are the infants buried at the sites of Koszyce and Kichary Nowe, where weaning appears to have been a more gradual process. At Koszyce it was also

observed that the diets of males and females differed from early in childhood. The finding that some of the Corded Ware individuals were more or less completely weaned by the age of six months is surprising, and deserves further investigation through the analysis of further Corded Ware Culture



Figure 8: Locations of the regions (large markers) and sites (small markers) examined in Papers I-IV



*Figure 9: The time periods analysed by the papers in this thesis*

Paper IV is primarily a comparison of the diets of children and adults in the early Bronze Age Únětice Culture in south-west Poland. For the vast majority of individuals diet changed very little during the lifetime, suggesting that eventual adult status was decided early in life and supporting the idea it may have been inherited. Information about the infant diet was also obtained from a small number of individuals, who all show different patterns of weaning. One shows a sharp drop in breastmilk intake between the first and second halves of the first year of life that is reminiscent of those common amongst the Corded Ware and Bell Beaker individuals in Paper II. In later childhood this individual seems to have consumed a diet very low in animal protein. Another individual was probably breastfed much less during the first six months of life, and was gradually weaned thereafter. A final individual was either breastfeeding more in both the first and fourth years of life, or was suckled by a woman who consumed more animal protein than the women who nursed the previous two individuals.

The data from the early Iron Age site of Bjärby on the Baltic island of Öland are in stark contrast to the previous three studies. Five individuals show evidence of having been breastfed during the first year of life. Two of these show a further drop in breastmilk consumption between the end of the first year and early in the fourth, suggesting that weaning occurred during the second year of life. Another individual appears to have been breastfed to a very similar pattern during the first year of life, but there is no data from later ages to assess the age at the end of breastfeeding. The drop in breastmilk intake between the first and second halves of the first year of life is not as great as it typically is in the previous studies, and with a total difference in  $^{15}\text{N}$  of just 2‰ it seems unlikely that these individuals were exclusively breastfed during the first six months. A fourth individual to show some evidence of having been breastfed was either consuming a similar quantity of breastmilk in the fourth year of life as the first, or more likely was weaned onto a very high trophic level diet similar to that consumed by an adult male in the population. The fifth individual is interpreted as having been weaned very rapidly towards the end of the first year of life.

Of the remaining three individuals for which there is intra-individual data, none shows any evidence of having been breastfed. Despite this, they survived until 3-7 years of age. This suggests that artificial feeding was relatively common in the community using the cemetery at Bjärby. With the

exception of one individual with an outlying marine-based diet there is no intra-individual data from the late Iron Age site of Triberga in the north of

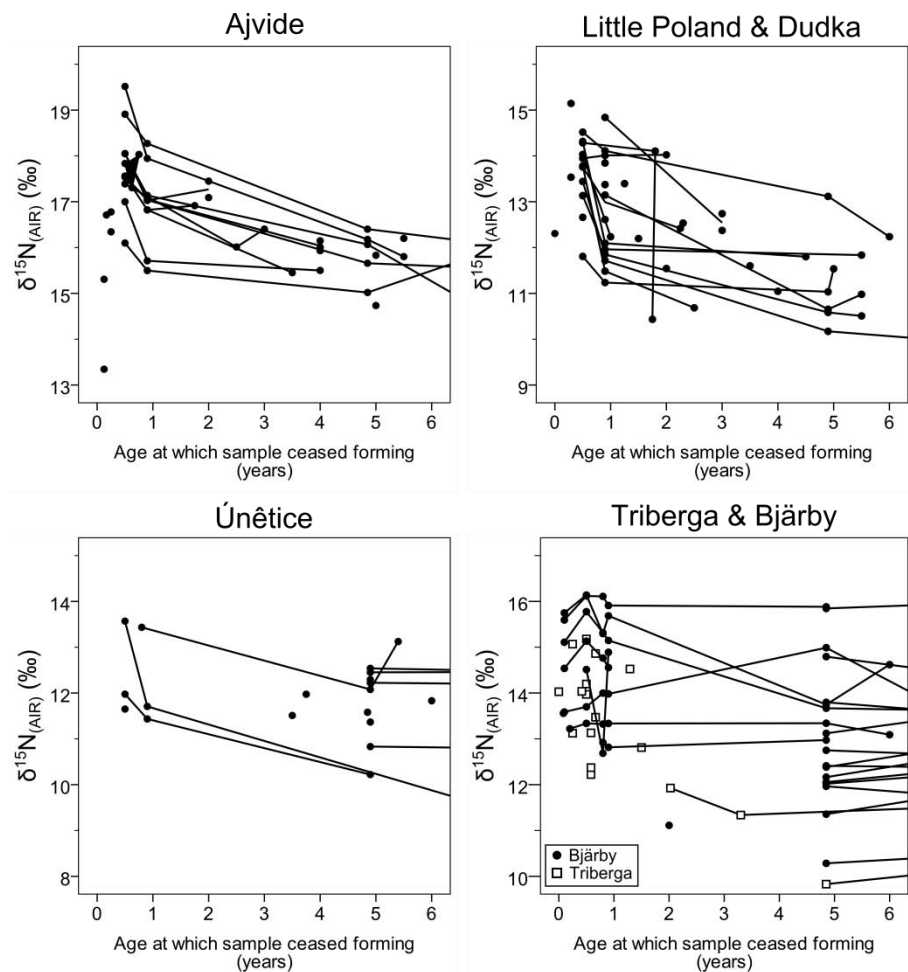


Figure 10: Comparison of the nitrogen isotope data pertaining to the diet prior to six years of age from Papers I-IV. Solid lines connect data points from the same individuals.

Öland, however the bone data are similarly dispersed to that from Bjärby. This implies that there was a similar diversity in breastfeeding practices to that at Bjärby, and that artificial feeding was being employed at Triberga too. Dating back until at least the fifteenth century there were regions of Europe, including parts of Sweden, in which breastfeeding was not the norm (Fildes 1986, p. 264). The data from this study thus suggest that the origins of the tradition of feeding infants artificially in these regions may be many centuries older.



## 6.1 The Results in Broader Context

Although infant feeding practices were found to differ between all of the populations analysed, the greatest difference was not between populations with hunter-gatherer and farming economies, nor between different geographic regions, but between the Ölandic Iron Age populations and everywhere else. How does this compare to broader evidence for prehistoric infant feeding practices? Stable isotopic studies of the infant diet have flourished over the past decade, and there is now a substantial body of literature describing the infant diet at different points over the past ten thousand years. The findings of these studies are summarised in Table 4. This table is necessarily somewhat crude and disguises a lot of variation: as with the papers in this thesis a number of studies have found that infant feeding practices were not homogenous. A number of the estimations were also based on very small numbers of infant individuals. Nevertheless the table gives an idea of how infant feeding practices varied between different times, places, and economic systems. Weaning has most commonly been found to be completed during the third year of life, which concurs with evidence for weaning practices in the ethnographic literature (Sellen 2001, Sellen and Smay 2001). There is also a wide range of variation, again reflecting the ethnographic data, with weaning being completed anywhere from the first year of life to around five years of age.

There have still only been a few isotopic studies of the weaning practices of hunter-gatherer populations, and the findings from these are often based on few individuals. Furthermore, many of the cases reported are from the same geographic regions, and might therefore have shared cultural practices. From the data that there is, however, it appears that the modal age at the end of weaning was later in prehistoric hunter-gatherer populations than it was in those with agricultural economies, and that post-medieval populations weaned earliest of all (Fig. 10). Comparison of the historic agricultural populations to the prehistoric ones found that the modal age at the completion of weaning was three years in both cases; however the prehistoric agricultural populations were more likely than the historic ones were to breastfeed for longer than this. Although the modal duration of breastfeeding was observed to be shorter in agricultural than in hunter-gatherer populations, the overall range of ages reported was similar. Unsurprisingly therefore, economy alone does not appear to be a sufficient explanation for the duration of breastfeeding in a population. Further research into the infant feeding practices of prehistoric hunter-gatherers is needed to support or refute this finding.

Table 4: The timing of weaning in archaeological populations, as reported in stable isotope studies

Location	Site(s)	Time Period	Introduction of supplementary foods	Cessation of breastfeeding	Method of Analysis	Material analysed	Notes	Reference
<b>Hunter-Gatherer Economies</b>								
Sweden	Ajvide	Middle Neolithic c.2750-2250 BC	<6mths	3-4yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone and dentine collagen		Paper I
Belgium	Meuse Basin	Mesolithic, 9300-8000 BC		<2yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone collagen	3 data points, all over three years	(Bocherens <i>et al.</i> 2007)
Siberia, Russia	Lokomotiv & Shamanka II	Early Neolithic, 8800–7000/6800 BP	2-3yrs	3.5-4yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone collagen	Intra-longbone analysis	(Waters-Rist <i>et al.</i> 2011)
Siberia, Russia	Ust'-Ida I	Late Neolithic, 7000/6800 – 5200 BP	<1yr	3yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone collagen	Intra-longbone analysis Only one individual under 2 years	(Waters-Rist <i>et al.</i> 2011)
South Africa	Matjes River Rock Shelter	Mid-Holocene, 7500-2000 BP	6mths-2yrs?	4yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone & dentine collagen		(Clayton <i>et al.</i> 2006)
Lower Ohio Valley, US	Indian Knoll	Late Archaic, 3500-1000BC	0.5-1yr	5yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone collagen		(Schurr and Powell 2005)
Lower Ohio Valley, US	Carlston Annis	Late Archaic 3500-1000BC	2yrs	5yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone collagen		(Schurr and Powell 2005)
California, US	Yukisma Mound	Ancestral Ohlone, 2200-250 BP	1.5-2yrs	3-3.5yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone collagen		(Gardner <i>et al.</i> 2011)
California, US	Marsh Creek	4300-3100 BP		3.6yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Dentine collagen		(Eerkens <i>et al.</i> 2011)

Location	Site(s)	Time Period	Introduction of supplementary foods	Cessation of breastfeed-ing	Method of Analysis	Material analysed	Notes	Reference
Tennessee Valley, US	Cherry, Eva, and Ledbetter	5500-2000 BC	18-20mths	c.2yrs?	$\delta^{15}\text{N}$	Bone collagen		(Fogel <i>et al.</i> 1989)
<b>Agricultural Economies</b>								
UK	Wetwang Slack	Iron Age, 4 <sup>th</sup> – 2 <sup>nd</sup> centuries BC	“Early”	<2.5	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone collagen		(Jay <i>et al.</i> 2008)
UK	Multiple, Dorchester region	Late Iron Age, 1 <sup>st</sup> century BC – 1 <sup>st</sup> century AD		<3yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone collagen	4 individuals <2yrs	(Redfern <i>et al.</i> 2012)
UK	Multiple, Dorchester region	Romano-British, mid-1 <sup>st</sup> -4 <sup>th</sup> century AD		<2yrs?	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone collagen	Just 2 individuals <2yrs	(Redfern <i>et al.</i> 2012)
UK	Queenford Farm	Late/Sub-Roman, 4 <sup>th</sup> -6 <sup>th</sup> centuries AD	<1yr?	3-4yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone collagen	Few Individuals <18mths	(Fuller <i>et al.</i> 2006b)
Orkney, UK	Newark Bay	Iron Age, Vi-king, Late Medieval, 500 bp -1200 bp		1.25+yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone collagen		(Richards <i>et al.</i> 2006)
UK	Raunds Furnells	Anglo-Saxon, AD 978-1040	1.75yrs	3yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone collagen		Haydock et al., accepted manuscript
UK	Wharram Percy	Medieval, 10 <sup>th</sup> -16 <sup>th</sup> Centuries AD		1.5-2yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$ , Sr/Ca	Bone & dentine collagen, Bone bioapatite		(Richards <i>et al.</i> 2002, Fuller <i>et al.</i> 2003, Mays 2003)

Location	Site(s)	Time Period	Introduction of supplementary foods	Cessation of breastfeeding	Method of Analysis	Material analysed	Notes	Reference
Sweden	Bjärby	Older Roman Iron Age, 1 <sup>st</sup> -2 <sup>nd</sup> centuries AD	0-6mths	1-4yrs+?	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone & dentine collagen	Very variable end of weaning, lack of samples representing 1-3yrs	Paper III
Sweden	Triberga	Younger Iron Age, 6 <sup>th</sup> -11 <sup>th</sup> centuries AD	0-6mths	18mths?	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone & dentine collagen		Paper III
Poland	Koszyce	Globular Amphorae, first half 3 <sup>rd</sup> M BC	c.6mths	c.3yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone & dentine collagen	Only 3 individuals, one weaned by 18mths	Paper II
Poland	<i>Multiple</i>	Corded Ware, c.2750-c.2350 BC	<6mths	6mths(?)	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone and dentine collagen		Paper II
Poland	Pełczyska	c.2400-c.2200BC	c.6mths	c.3yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone and dentine collagen	Only one individual older than 2yrs	Paper II
Poland	Kichary Nowe	Mierzanowice, 2200-1700 BC	c.6mths	3-5yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone and dentine collagen	Some infants weaned earlier	Paper II
Poland	<i>Multiple</i>	Únětice, 2100-1600 BC	c.6mths	<3yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone and dentine collagen	Few individuals, none aged 1-3 years	Paper IV
Germany	Wenigumstadt	Medieval AD 500-700	1yr	3yrs	$\delta^{15}\text{N}$	Bone collagen		(Dittmann and Grupe 2000)
Germany	Espenfeld	10 <sup>th</sup> -12 <sup>th</sup> Centuries AD		2+ yrs	Sr/Ca	Bone bioapatite	Use of animal milks?	(Grupe and Bach 1993)

Location	Site(s)	Time Period	Introduction of supplementary foods	Cessation of breastfeeding	Method of Analysis	Material analysed	Notes	Reference
Germany	Schleswig	Medieval 11 <sup>th</sup> -12 <sup>th</sup> Centuries AD	c.6mths	<2yrs	Sr/Ca	Bone bioapatite	Animal milk prior to 6mths?	(Hühne-Osterloh and Grupe 1989)
Belgium	Meuse Basin	Middle Neolithic, 4300-3000BC		<2yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone collagen		(Bocherens <i>et al.</i> 2007)
Belgium	Meuse Basin	Late Neolithic, 3300-1700 BC		<2.5-3yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone collagen		(Bocherens <i>et al.</i> 2007)
Italy	Isola Sacra	Roman 1 <sup>st</sup> -3 <sup>rd</sup> Century AD	<1yr	2-2.5yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone collagen		(Prowse <i>et al.</i> 2008)
Crete, Greece	Kastella	Byzantine, 11 <sup>th</sup> Century AD		2+yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone collagen	Just 2 individuals <2yrs	(Bourbou and Richards 2007)
Israel	Dor	AD 800-1300		2-3yrs	Sr/Ca	Bone bioapatite		(Sillen and Smith 1984)
Turkey	Cayönü Tepesi	Aceramic-Ceramic Neolithic, c.8500–6000 BC)	2yrs	3.5yrs	$\delta^{15}\text{N}$	Bone collagen		(Pearson <i>et al.</i> 2010)
Turkey	Aşikli Höyük	Aceramic Neolithic, c.8500-c.4500 BC	1yr	2yrs	$\delta^{15}\text{N}$	Bone collagen		(Pearson <i>et al.</i> 2010)
Turkey	Çatalhöyük	Early Neolithic, 8300-7400 BP		<1.5yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone collagen		(Richards <i>et al.</i> 2003a)
Egypt	Kellis 2, Dak-hleh Oasis	Roman Egypt c. AD 250	6mths+	3yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}/\delta^{18}\text{O}$	Bone & dentine collagen, enamel carbonate		(Dupras <i>et al.</i> 2001, Dupras and Tocheri 2007)

Location	Site(s)	Time Period	Introduction of supplementary foods	Cessation of breastfeeding	Method of Analysis	Material analysed	Notes	Reference
Tunisia	Leptiminus	Roman 3 <sup>rd</sup> -4 <sup>th</sup> Centuries AD	<2yrs	3yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone collagen		(Keenleyside <i>et al.</i> 2009)
Wadi Halfa, Sudan	5 cemeteries, Banks of Nile	Meroitic, X-group, Christian 350 BC-AD 1400		<6yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone collagen and muscle		(White and Schwarcz 1994)
Sudanese Nubia	Kulubnarti	Medieval, AD 550-800		3-4yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}/\delta^{18}\text{O}$	Bone collagen		(Turner <i>et al.</i> 2007)
South Korea	Yeanri	Iron Age (Gaya), AD 300-600	c.2yrs	c.4yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone collagen		(Choy <i>et al.</i> 2010)
Guatemala	Kaminaljuyu	Prehispanic	1-2yrs	4-5yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}/\delta^{18}\text{O}$	Dentine collagen & enamel carbonate		(Wright and Schwarcz 1998, 1999)
Belize	Marco Gonzalez	Postclassic Maya, 100 BC-AD 1350		2+yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}/\delta^{18}\text{O}$	Bone collagen & bioapatite		(Williams <i>et al.</i> 2005)
Belize	San Pedro	Postclassic Maya, AD 1450-1650		2+yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}/\delta^{18}\text{O}$	Bone collagen & bioapatite		(Williams <i>et al.</i> 2005)
Lower Ohio Valley, US	Tinsley Hill	Mississippian, AD1300-1450	0.5-1yr	5yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone collagen		(Schurr and Powell 2005)
Lower Ohio Valley, US	Angel	Mississippian, AD1300-1450	2yrs	5yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone collagen	Higher age than Schurr 1997 due to increased sample size.	(Schurr and Powell 2005)
South Dakota, US	Sully	Protohistoric, A.D. 1650-1700	18-20mths	c. 2yrs?	$\delta^{15}\text{N}$	Bone collagen		(Fogel <i>et al.</i> 1989)

Location	Site(s)	Time Period	Introduction of supplementary foods	Cessation of breastfeed-ing	Method of Analysis	Material analysed	Notes	Reference
Ontario, Canada	MacPherson	Protohistoric, AD 1530-1580		2-3yrs?	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone collagen		(Katzenberg <i>et al.</i> 1993)
<b>Post-Medieval</b>								
UK	Spitalfields	AD 1760- 1844		<1.25yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone collagen		(Nitsch <i>et al.</i> 2011)
UK	Lukin Street	AD 1845-1852	c.1yr (?)	c.2yrs	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone collagen		(Beaumont <i>et al.</i> 2013)
Ontario, Canada	Prospect Hill Methodist Cemetery, Newmarket	AD 1824-1879	1yr	1yr?	$\delta^{15}\text{N}/\delta^{13}\text{C}$	Bone collagen		(Katzenberg and Pfeiffer 1995)
Ontario, Canada	St Thomas', Belleville	AD 1821-1874	<5mths	14mths	$\delta^{15}\text{N}$	Bone collagen		(Herring <i>et al.</i> 1998)

In the vast majority of cases weaning in agricultural populations was completed between the ages of eighteen months and two years. With the exception of the Corded Ware individuals from Little Poland, there are no cases in which weaning was completed prior to the age of one year, and only two in which it is thought to have been completed prior to the age of eighteen months. This is in stark contrast to the few post-medieval sites that have been studied with regards to weaning age. In all four of these weaning is reported to have been completed by two years of age, and in three during the first few months of the second year. The four post-medieval sites to have been analysed consist of two London cemeteries dating to the eighteenth and nineteenth century, and two nineteenth century cemeteries from Ontario. It is perhaps not surprising that the individuals buried in these cemeteries used similar infant feeding practices, given the shared cultural history of the populations in Canada and the United Kingdom. Nevertheless, it has been noted elsewhere that breastfeeding duration in the British Isles appears to have decreased with increasing levels of urbanisation (Haydock *et al.* in press), and the question of whether urbanisation and/or industrialisation are associated with reduced breastfeeding duration on a global scale is worthy of further investigation.

Not all of the studies give an estimate of the timing of the introduction of supplementary foods, but where given these estimations are often much later than those observed in the ethnographic literature. In Sellen’s (2001) survey of the infant feeding practices of 113 non-industrial populations, all but one introduced solid foods by thirteen months of age. In the light of this, the ages of introduction of supplementary foods reported in the stable isotope studies

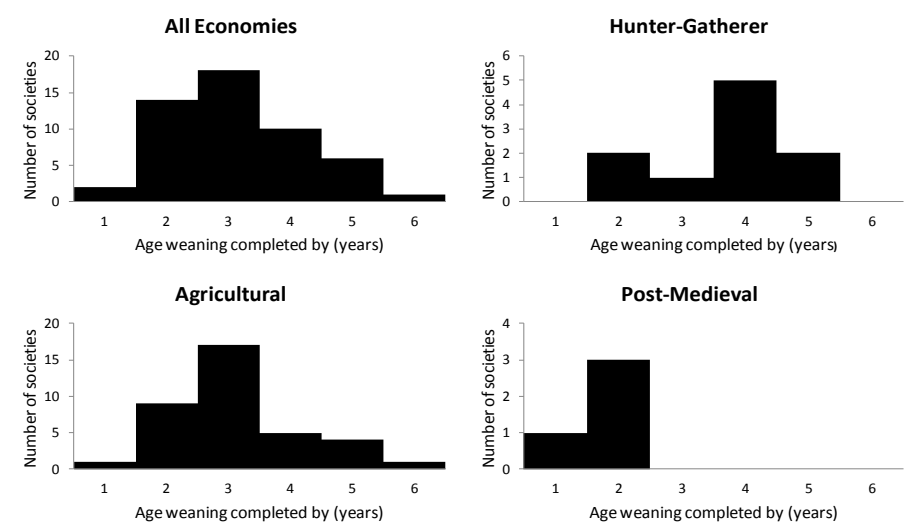


Figure 11: Reported ages at which breastfeeding was completed by in archaeological populations. Based on data in Table 4.



are surprising, and somewhat unconvincing. It seems more likely that the various limitations of the stable isotope technique, due to bone turnover and imprecise ageing methods, may mean that the timing of the introduction of supplementary foods is being consistently overestimated. Even in well-preserved skeletal material osteologically assigned ages are rarely more precise than three or four months, and since supplementary foods are often introduced whilst an infant is just a few months old, it is clear that inaccuracies in the estimation of the timing of their introduction will arise.

Furthermore, the time taken for bone to reflect the introduction of supplementary foods may overestimate the timing of their introduction more than is usually recognised. In an attempt to model the effect of weaning on nitrogen isotope ratios, Millard (2000) found that the peak in  $^{15}\text{N}$  could overestimate the timing of introduction of supplementary foods by as much as 6-9 months. This seems a remarkably long time considering the rapid rate of bone turnover in infancy, but some time-lag does seem plausible. If supplementation of the breastmilk diet occurs within the first few months, if not weeks, of life, it is plausible that it may begin before the  $^{15}\text{N}$  of bone has equilibrated to that of breastmilk (i.e. some collagen formed prenatally still remains). If the level of supplementation is initially low, the proportion of nitrogen being removed from the bone that was deposited prenatally may exceed the proportion of nitrogen being added that is derived from supplementary foods rather than breastmilk. If so, the  $^{15}\text{N}$  of newly formed collagen will be greater than that of collagen being removed, and the average  $^{15}\text{N}$  of whole bone collagen will continue to rise. A better understanding of nitrogen metabolism in the bone and of the rates of bone turnover in infancy are thus required in order to fully understand the effect of weaning on the  $^{15}\text{N}$  of infant bone collagen.

## 6.2 Agriculture, Fertility, and Infant Feeding

As discussed in chapter 2, one of the proposed mechanisms by which Neolithic population increase has been suggested to have come about is through the impact of a reduction on the duration of breastfeeding on a woman's fertility. Taken as a whole, the stable isotope data pertaining to the infant diet can be seen to support this hypothesis, since the modal age at the cessation of weaning is longer in the populations with extractive economies than those with agricultural economies. The vast range in breastfeeding duration in the agricultural populations demonstrates however that agriculture does not in and of itself cause a reduction in breastfeeding duration. There are relatively few studies of infant feeding practices in the early Neolithic, but in the few studies that have investigated infant feeding practices before and after the adoption of agriculture in a particular region, increased reliance on

agriculture has not been found to associate with an earlier cessation of breastfeeding (Schurr and Powell 2005, Bocherens *et al.* 2007).

A reduction in the duration of breastfeeding therefore remains a possible explanation for the population increase observed in association with the adoption of agriculture, but the current evidence does not provide particularly strong support for it. There are, however, numerous other possible explanations as to how an increase in fertility could have occurred. Recent evidence has demonstrated that, instead of being directly related to the frequency and duration of suckling via a mechanism of hormonal control as once thought (Konnor and Worthman 1980, Howie and McNeilly 1982), a woman's return to fertility post-partum is a function of her overall energy balance (Valeggia and Ellison, 2004, 2009). Ovulatory cycling has been found to resume when a woman has experienced a sustained period of positive energy balance (Valeggia and Ellison 2004). Lactation is a major energetic cost, requiring on average an extra 675kcal/day during the first six months post-partum and around 460kcal/day thereafter (Shetty 2011), and thus constitutes a substantial portion of a woman's overall energy balance. All other things being equal, women who breastfeed for longer will resume ovulation later. As noted in recent hypotheses about the causes of the demographic transition (Bocquet-Appel, 2008, 2009, 2011), changes in nutrition and activity patterns in conjunction with the introduction of agriculture are likely to have altered female energy intake and expenditure in other ways, meaning that a change in breastfeeding patterns is not necessary to explain increased fertility.

The determinants of female fertility do not however only act in adulthood, rather there is an increasing body of evidence to suggest that the conditions experienced in early life can shape a woman's reproductive potential. Even the conditions experienced *in utero* begin to shape female reproductive potential: first menstruation has for instance been found to occur up to 1.6 years earlier in girls of low birth weight than those of higher birth weights, suggesting that energetic investment is being directed towards reproduction rather than growth in individuals primed to expect poorer environmental conditions (Cooper *et al.* 1996, Ibáñez *et al.* 2000). Females born during the rainy season in Vietnam, when food supplies are low and infection rates high, have also been found to have a greater number of offspring in later life (Huber and Fieder 2009). The ovarian function of individuals with a low ponderal index (low weight-for-length) at birth has also been found to be more sensitive to changes in activity levels, suggesting that reproduction is also more carefully targeted to avoid periods of hardship in females who experienced poor conditions *in utero* (Jasienska *et al.* 2006).

The childhood environment has also been found to affect the timing of puberty, with better growth during childhood being associated with an earlier onset of menstruation in females (Cooper *et al.* 1996). These effects interact, such that individuals born into stressful environments but who then experi-

ence better conditions during childhood have high rates of precocious puberty, such as those observed in children adopted from developing to developed countries (Parent *et al.* 2003, Sloboda *et al.* 2011). In a study of migrants from the Sylhet region of Bangladesh, associated with good nutrition but poor sanitation and limited healthcare, to London, individuals who migrated prior to the age of nine were found to have an earlier age of menarche and higher ovarian hormonal function than those who migrated aged nine or older (Núñez-de la Mora *et al.* 2007). Amongst those who migrated under nine there was a negative correlation between age at migration and ovarian hormonal function in adulthood, whereas those who migrated after the age of nine had similar levels to individuals who remained in Bangladesh. It would thus appear that there is a developmental window during which the trajectory of reproductive maturation can be modulated according to environmental conditions (Núñez-de la Mora *et al.* 2007).

The environment during early life and childhood thus plays an important role in determining later fertility outcomes. Changes in the pathogen load of the environment and childhood nutrition with the adoption of agriculture could thus in and of themselves have brought about the Neolithic demographic transition, or more likely have played a role in causing it. The duration of breastfeeding and the timing of supplementation thus have the potential to affect fertility levels not just through its impact on the duration of post-partum infertility in the mother, but also by influencing the reproductive development of the child.

## 6.3 Animal Milks and the Infant Diet

*“The human species is the first mammal to eliminate lactation”* (Sellen 2006).

The final paper (V) in this thesis explores what the biological implications of introducing animal milks into the infant diet might have been in a prehistoric context. The article comes to the conclusion that substituting animal milks for human breastmilk would have had negative consequences for infant health. In particular it would have left infants more vulnerable to micronutrient deficiencies, particularly iron-deficiency and anaemia, and to diarrhoea from gastrointestinal infections. The earlier animal milks were introduced to the diet, the more severe the consequences would have been. The one situation in which supplementing the breastmilk diet with animal milk products at an early age might have been beneficial for infants would perhaps have been if maternal nutritional status was marginal and breastmilk fat content at the very low end of the human range. In this case the benefits of extra energy in the infant diet may have outweighed the risks of increased infection rates (cf. Gray 1998).

Whilst less serious than the impact of replacing breastmilk with animal milk, the increased risk of iron-deficiency and anaemia means that the use of animal milks as supplementary foods is also expected to have had negative consequences for infant health, particularly if used in substantial quantities and/or during the first year of life. To this it can be added that the bioavailability of iron and zinc and calcium is poor in most cereals (Brown *et al.* 1998), and the use of cereal products alongside animal milks would only serve to compound the problem. Fermented dairy products, on the other hand, both facilitate the absorption of iron from other areas of the diet and contain probiotic bacteria, and could therefore have been beneficial to infant health if used in complementary feeding alongside other iron-rich foods. The consequences of iron deficiency are severe: iron deficiency during childhood causes growth stunting, reduces the ability of the body to fight infection and thereby increases morbidity and mortality rates, and impairs cognitive development (World Health Organization 2001). These effects are also long-lasting, and there is an increasing body of evidence suggesting that iron deficiency during childhood is associated with poorer cognitive performance and behavioural outcomes in adolescence and adulthood (Lozoff *et al.* 2000, Georgieff 2011). Infant feeding practices that increase or decrease the prevalence and severity of iron-deficiency thus have the power to affect not just infant morbidity and mortality rates, but also the productivity of an entire population.

Given that feeding infants raw animal milks is expected to have negatively affected infant health outcomes, why was it that their use in infant feeding became so widespread historically? The answer presumably lies in the fact that, although inferior to breastmilk, animal milks are nonetheless more similar to human milk than other foods. From the maternal point of view, therefore, they would have reduced the trade-off between the costs and benefits of weaning children earlier. Women would thus be more likely to wean their infants earlier in the face of pressures from work and activity patterns, further reproduction, the need to improve their own health status, or other physical and social pressures. Once artificial feeding was established as a cultural norm the increased rates of infant morbidity would also be perceived as normal, and the practice of artificial feeding would be liable to continue even in the absence of the original pressures that caused it.

In purloining animal milks for use in infant feeding, humans effectively outsourced the energetic cost of nursing, and in doing so eliminated the incentive to wean children off the milk diet. This means that, although infants may have lost the beneficial properties of breastmilk at earlier ages, they could have profited from the lower health benefits of animal milks (Haug *et al.* 2007, Ebringer *et al.* 2008, Kliem and Givens 2011) at least until the onset of lactase impersistence in mid-childhood (Sahi *et al.* 1983, Wang *et al.* 1998, Rasinperä *et al.* 2005). With the production of low-lactose dairy products and spread of lactase persistence dairy consumption could continue into

adulthood. In a sense, therefore, the human species has managed to eliminate both lactation and weaning.



## 7 Conclusions

At the start of this thesis a series of questions was raised. The first of these was whether prehistoric farming populations breastfed for less time than hunter-gatherers. From the data presented here it is apparent that in many cases they did, however this tendency was far from universal and many agricultural populations breastfed for just as long as hunter-gatherer ones did. It hence seems unlikely that there is any one feature of agricultural economies that exerts a strong reductive pressure on the duration of breastfeeding, but rather a variety of features that increased the likelihood of the trade-off between the costs and benefits of earlier weaning being perceived to be lower in any given situation. As discussed in Chapter 2 the potential candidates for these features are numerous, including changes in work patterns and social structures, maternal condition, disease risk and mortality rates, the possibility of artificial feeding using animal milks, and changes in cultural beliefs surrounding breastfeeding and weaning; and it is likely that the motivating feature or combination of features differed from population to population.

The second question was how the use of agricultural produce in infant feeding impacted upon infant health. This has primarily been explored with regards to animal milks, and the answer depends on how they were used. In so far as the use of animal milks may have promoted earlier weaning, or taken the place of iron-rich foods in complementary feeding, their impact on infant health can be presumed to have been negative. This would also hold true for cereal products. Fermented milk products meanwhile may have improved micronutrient status and helped mediate the infection risks of weaning if used alongside other iron-rich foods in complementary feeding and the post-weaning diet.

The third question was how differences in the duration of breastfeeding and weaning would have affected the health and fertility of prehistoric populations. This is explicitly addressed in Paper III, in which two cemetery populations with different demographic profiles, implying differential infant mortality rates, were compared. In contrast to what was expected, no difference in the duration of breastfeeding was observed between the two populations, but there was some indication that supplementary foods may have differed. This highlights the fact that the relationship between infant feeding practices and infant mortality is complex, being dependent on the disease risk of the environment and affected not just by the total duration of breastfeeding but also the foods used in complementary feeding, the timing of their

introduction, and practices such as pre-lacteal feeds that are currently still unobservable in archaeological material. The relationship between infant feeding and fertility is explored in Chapter 6, in which it is argued that higher fertility rates during the Neolithic may well have been related to changes in infant feeding practices, but that this could have been due to the influence of nutrition in early life on reproductive development rather than the impact of a reduction in breastfeeding on the duration of post-partum infertility.

Question four asked how infant feeding practices differed between different groups in a region and how they changed over time, whilst question five asked how they varied within populations. The question of change over time is addressed in Chapter 6, in which it is shown that the most dramatic change in the duration of breastfeeding may have occurred with industrialisation rather than with agriculture. Indeed, based on the isotopic evidence so far, it appears that prior to industrialisation it was very rare to completely wean infants before eighteen months of age, but common to do so thereafter.

Papers I, II and III all compared the breastfeeding and weaning practices of different groups within the same region as well as within individual populations. In Paper I it is argued that variation in the isotope composition of the weaning diet is likely to have been due to seasonal variation in the availability of different resources in a hunter-gatherer population. The differences between different Pitted Ware Culture groups living in different parts of the Baltic may also be attributable to differences in resource availability, but could also have been the result of different local traditions in infant feeding. In Paper II it is shown that there does appear to have been variation between different sites in the Little Poland region, but it is unclear whether the cause of this variation was due to cultural norms or local traditions. In Paper III meanwhile evidence from the adult diet was used to argue that differences in infant feeding practices between individuals at Bjärby was probably due to differences in social status. The similarity in the range of variation at both sites meanwhile was used to argue that the ideologies or social structures behind that variation may have been similar.

The final question addressed the childhood diet, and how it relates to eventual adult identity. Paper IV specifically addresses this in a study of Únětice individuals, and finds that for the majority of individuals diet varied very little throughout life, suggesting that adult identity was determined very early on in the life-course and was probably inherited. At the Globular Amphora site of Koszyce in Paper II animal protein intake appears to have increased during the lifetime and to have differed slightly between males and females. These differences were again established in early life, suggesting that gender differences were fixed and enacted through the diet from an early age. In Papers I, III and IV subadults with unusual diets were observed. The presence of a neonate with a “terrestrial” isotope signature at Ajvide suggests the presence of an adult with an unusual diet at the site, and possibly



contact with the Funnel Beaker Culture farmers. In Paper III an older subadult buried in a cemetery primarily reserved for young infants at Triberga was found to have consumed a much more marine-based diet in earlier childhood, suggesting that the location of this individual's burial location may have been due to it being a migrant or for some other reason considered to be an "outsider". A similar situation was observed in Paper IV, in which an individual buried in an isolated location and on the opposite side of the River Oder to most Únětice individuals was found to have undergone a dramatic dietary shift from apparently being breastfed by a female with a "normal" Únětice diet to consuming a more or less vegan diet prior to death. This again suggests that the unusual burial location may be related to a deviant social status in life.

What then have been the long-term consequences of the development of agriculture for infants? Whether or not the development of agriculture led to a revolution in infant feeding during the Neolithic itself remains something of an open question that will only be answered by increasing the number of studies of the infant feeding practices of Mesolithic hunter-gatherers and early farmers. It is clear, however, that the developments of that time have set in motion a sequence of events that have transformed the way that infants are fed. The relatively short durations of breastfeeding observed in industrialised populations today appear to be the result of a decline that began with the adoption of agriculture, and was possibly accelerated by industrialisation. In lieu of breastmilk infants are now provided with formula milks and fortified cereal products - modifications of foodstuffs made available by the advent of agriculture. Although the substitution of breastmilk with formula milks is still associated with poorer health outcomes and higher infant mortality rates, these products mean that in environments with good sanitation it is now possible to artificially feed an infant without severely compromising its welfare. Even as little as a century ago this was far from so, and although some infants who could not be breastfed would have been saved by the availability of animal milks, for numerous others their use would have left them at increased risk of stunting, sickness, and death. The legacy of the Neolithic for infant health can thus be seen in two ways, but it seems that until recently it was largely a negative one.



## 8 Sammanfattning

Denna avhandling behandlar hur jordbrukets införande påverkade olika sociala praktiker rörande amning och avvänjning. Den består av en s.k. kappa och fem artiklar, av vilka fyra behandlar amning och spädbarnskost baserat på analyser av stabila kol- och kväveisotoper på förhistoriskt skelettmaterial, och den femte artikeln diskuterar vilken potentiell effekt på sjukdom, ohälsa och dödlighet hos spädbarn som introduktionen av mjölk från andra djur kan ha haft under förhistorien.

Kappan sätter artiklarna i ett större arkeologiskt sammanhang. I de två inledande kapitlen redogörs för olika anledningar till att införandet av jordbruk kan förväntas ha förändrat hur spädbarn ammadess och avvänjdes. Jordbrukshushållning nådde sydöstra Europa under det sjunde årtusendet före vår tideräkning och spreds sedan över kontinenten. Jordbruket innebar inte bara nya sätt att skaffa mat, utan också att nya sorters mat blev tillgänglig – inklusive mjölk och cerealier, som är så vanligt förekommande i nutida spädbarnskost. Införandet av jordbruk medförde också förändrade aktivitetsmönster, som kan ha varit svårförenade med amning och därför ledde till en tidigare avvänjning. Bofasthet och nära kontakt med djur ökade risken för infektionssjukdomar, och det är därför tänkbart att kvinnor investerade energin i nya graviditeter snarare än i amning, för att kompensera för ökad spädbarnsdödlighet, och därmed avvänjde sina barn tidigare. Slutligen medförde spridningen av jordbruket över Europa massiva kulturella förändringar, där olika föreställningar om amning och avvänjning kan ha ingått.

Tredje kapitlet tar upp amning och avvänjning från ett evolutionärt och biologiskt perspektiv. Humanmjölk är komplex och dynamisk och innehåller förutom all näring ett barn behöver under det första halvåret även en rad olika immunologiskt aktiva komponenter som skyddar mot infektioner. Det medicinskt optimala amningsmönstret hos människan innebär sex månaders exklusiv amning följt av minst 18 månaders fortsatt amning med näringsriktig tilläggskost. Avvänjningsåldern hos människa är både ovanligt tidig – människan är den enda primaten som avvänjer sina barn innan de kan skaffa föda själva – och ovanligt plastisk (variabel). Denna plasticitet tros ha utvecklats för att möjliggöra flexibla amningsstrategier som varierar utifrån den specifika ekologiska miljön. Utöver detta är också förekomsten av speciellt tillredd och näringsrik föda som ges jämsides med fortsatt amning unik för människan, och tros ha utvecklats för att ge tillräcklig energi för

hjärnans tillväxt med bibehållandet av bröstmjölkens skyddande egenskaper. Att den kompletterande kosten är tillräckligt näringsrik för att upprätthålla barnets tillväxt är avgörande, eftersom tilläggskosten vid 9–11 månaders ålder behöver stå för merparten av barnets mineralbehov och utgöra en väsentlig del av energi- och proteinbehovet.

I fjärde kapitlet diskuteras amning och avvänjning från ett kulturellt perspektiv. Det finns en enorm variation i amnings- och avvänjningspraktiker och de är föremål för många olika föreställningar och ritualer. Beslutet att amma eller inte påverkas inte bara av ekologiska faktorer, utan också av moraliska normer och sociala påtryckningar. Föreställningar om att det skulle vara dåligt för det nyfödda barnet med råmjölk (kolostrum), den mjölk som produceras under de första dagarna efter förlossningen, är vanligt förekommande. Dessa föreställningar kan leda till praktiker som ökar spädbarnsdödligheten, såsom tillmatning eller att inte lägga barnet till bröstet förrän några timmar eller dagar efter förlossningen. Mogen bröstmjölk anses ofta ha magiska eller medicinska egenskaper, eller skapa släktskapsband mellan amma och det diande barnet. Många gånger tros ammans karaktärsdrag föras vidare till barnet genom mjölken, och barn som ges djurmjölk kan därför anses ha vissa krafter eller egenskaper, eller omvänt betraktas som mindre intelligent än jämnåriga som ammas. Tidpunkten för när tilläggskost introduceras och när amningen helt avslutas varierar utifrån det sociala sammanhanget, och båda tidpunkterna kan vara föremål för övergångsriter. I genomsnitt introducerar jägare och samlare tilläggskost tidigare än jordbrukare, men ammar längre. Även om typen av tilläggskost varierar enormt mellan olika populationer, har såväl jägare och samlare som jordbrukare tillgång till en lika stor repertoar av olika sorters födoämnen som de använder som kompletterande kost. Avslutningen av amningen kan tvingas fram vid en viss ålder, eller när mamman är gravid på nytt, eller också får barnet amma fritt så länge det önskar. Avslutad amning kopplas ofta till en social övergång, från beroende av mamman till större självständighet och interaktion med andra närstående.

I femte kapitlet ges en översikt över de metoder som används för att studera amning i förhistorien. Innan benkemiska metoder utvecklades, användes ofta generella indikatorer för ohälsa i skelettet som tecken på att avvänjningen skedde vid en viss ålder. Dessa metoder byggde dock på antagandet att avvänjning var kopplad till sjukdom, och att det saknades andra orsaker till indikatorer för ohälsa under tidig barndom. Att undersöka förhistoriska kostvanor genom kemiska analyser av skelettet ger möjligheter att studera amning och avvänjning med mera direkta metoder – antingen genom analys av kvoten strontium/kalcium, eller analys av de stabila kväve-, syre- eller kolisotoperna i ben och tänder. I synnerhet kväveisotopanalys ( $^{15}\text{N}$ ) har använts, där kvoten mellan den tyngre och den lättare isotopen av kväve ökar för varje steg i näringskedjan, och eftersom det ammade barnet är högre upp i näringskedjan än sin mamma, har det också mer av den tyngre

isotopen av kväve. Man kan således studera vid vilken ålder avvänjningen skedde genom kväveisotopanalyser av kollagen i ben från individer som dog vid olika åldrar. Det ger dock bara en uppfattning om avvänjningsåldern på populationsnivå, och dessutom från individer som dog under denna process. Till skillnad från benvävnad, som omsätts kontinuerligt under livstiden, avspeglar dentin (tandben) tiden när tanden bildades, dvs. i barndomen. Genom att analysera dentin från flera olika tänder som bildats vid olika åldrar, kan man därför uppskatta amningslängden på individnivå hos barn som överlevde processen. Det är också den metod som har tillämpats i denna avhandling.

I sjätte kapitlet presenteras översiktligt resultaten från de fem artiklarna och de placeras in i ett större sammanhang. I den första artikeln undersöks amningsmönster hos neolitiska marina jägare tillhörande gropkeramisk kultur från Ajvide på Gotland. Studien visar att amningslängden var relativt enhetligt, men att typen av tilläggskost kan ha varierat över året. I den andra artikeln undersöks amnings- och avvänjningsmönster under neolitikum och äldre bronsålder hos ett antal jordbrukande grupper i området Lillpolen i sydöstra Polen. Här varierade den totala amningslängden stort – från endast ett halvår upp till åtskilliga år. I den tredje artikeln görs en jämförelse av amningsmönster hos två järnålderspopulationer på Öland. Även här varierade amning och avvänjning stort, och det föreslås att social status kan ha påverkat hur barnen ammad och avvänjdes. Den fjärde artikeln behandlar främst kosten hos större barn tillhörande úněticekulturen under äldre bronsålder i sydvästra Polen, men presenterar också i begränsad omfattning data om amningsmönster, vilka varierade.

Resultaten från dessa fyra artiklar jämförs sedan med data från tidigare publicerade amningsstudier som bygger på analyser av stabila isotoper. Den vanligaste åldern då avvänjningen avslutas befinns då vara något lägre hos jordbrukare än hos jägare och samlare, men variationen är stor hos båda grupperna och har ungefär samma spännvidd. De fåtal studier som gjorts på amning och avvänjning hos populationer från tidigmodern tid visar på att avvänjningen ägde rum vid en mycket lägre ålder än hos nästan alla andra populationer från stenålder fram till medeltid. Urbaniseringen eller industrialiseringen kan således ha förkortat amningslängden i mycket högre utsträckning än övergången till jordbruksekonomi.

Även om det inte helt går att utesluta, saknas i nuläget belägg för idén om att förkortad amningslängd förklarar den neolitiska befolkningstillväxten. Därför diskuteras ett antal andra effekter på kvinnors fertilitet som införandet av jordbruk kan ha haft. En förändring av kvinnans energibalans, av andra orsaker än amning, kan ha lett till en minskning av perioden innan en kvinna kan bli gravid på nytt efter förlossningen. Vidare finns det alltmer som pekar på att näringsintag och exponering för infektioner tidigt i livet påverkar en individs senare reproduktiva förmåga.

Den sista artikeln jämför sammansättningen mellan humanmjölk och mjölk från idisslare utifrån lämpligheten som bröstmjölksersättning och/eller tilläggskost. Det framhålls att under förhistorien skulle mjölk från idisslare haft en negativ effekt på spädbarnets hälsa om den användes som hel eller delvis ersättning för bröstmjölk. Fermenterade mjölkprodukter, såsom exempelvis filmjölk och yoghurt, kan däremot ha haft en positiv inverkan på spädbarnshälsa om de användes jämsides med andra järnrika livsmedel. Att mjölk från idisslare trots detta är så vanlig i spädbarnskost beror sannolikt på att den ändå är en bättre ersättning än något annat naturligt förekommande livsmedel. Tillgången till mjölk kan därför ha gjort att det blev mindre skillnad för mamman mellan en tidig eller sen avvänjning, vilket i sin tur kan ha lett till en ökad benägenhet att byta ut bröstmjölken i de fall då det av någon anledning var gynnsamt för modern att sluta amma.

Avslutningsvis framhålls att det är klarlagt att införandet av jordbruk radikalt förändrade amnings- och avvänjningsmönstren, även om det är osäkert huruvida detta var en revolution som skedde under själva neolitikum eller senare. Nutida barn ammas vanligen relativt kort tid eller inte alls, och detta förefaller vara kulmen på en utveckling mot reducerad amningslängd som påbörjades i och med införandet av jordbruk och möjligen accelererade med urbaniseringen och industrialiseringen. Istället för att ammas, matas spädbarn då med en högprocessad form av komjölk som trots att den är underlägsen bröstmjölk förser spädbarnet med en relativt ideal form av näring. Detta är dock en sentida utveckling, och under större delen av vår historia har användandet av mjölk från idisslare istället för bröstmjölk lett till ökad förekomst av tillväxtstörningar, ohälsa och död. Sett utifrån spädbarnets hälsa är alltså det neolitiska arvet ett mynt med två sidor – det står dock klart att till för inte så länge sedan var det främst den negativa sidan som märktes.

Svensk översättning: Gunilla Eriksson

# References

- Aggett, P., 2010. Premastication. *Maternal & Child Nutrition*, 6 (1), 2–3.
- Agostoni, C., Decsi, T., Fewtrell, M., Goulet, O., Kolacek, S., Koletzko, B., Michaelsen, K.F., Moreno, L., Puntis, J., Rigo, J., Shamir, R., Szajewska, H., Turck, D., and Van Goudoever, J., 2008. Complementary feeding: a commentary by the ESPGHAN Committee on Nutrition. *Journal of Pediatric Gastroenterology and Nutrition*, 46 (1), 99–110.
- Ambrose, S.H., 1991. Effects of diet, climate and physiology on nitrogen isotope abundances in terrestrial food webs. *Journal of Archaeological Science*, 18 (3), 293–317.
- Ambrose, S.H. and Norr, L., 1993. Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In: J. Lambert and G. Grupe, eds. *Prehistoric Human Bone: Archaeology at the Molecular Level*. London: Spring Verlag, 1–37.
- Amir, L.H., 2011. Social theory and infant feeding. *International Breastfeeding Journal*, 6 (1), 7.
- Anderson, J.W., Johnstone, B.M., and Remley, D.T., 1999. Breast-feeding and cognitive development: a meta-analysis. *The American Journal of Clinical Nutrition*, 70 (4), 525–35.
- Armstrong, G.J., Brown, P.J., and Turner, B., 2005. Evolutionary, historical and political economic perspectives on health and disease. *Social Science & Medicine*, 61 (4), 755–65.
- Armstrong, G.J., Goodman, A.H., and Jacobs, K.H., 1991. The origins of agriculture: Population growth during a period of declining health. *Population and Environment*, 13 (1), 9–22.
- Badr, A., Müller, K., Schäfer-Pregl, R., El Rabey, H., Effgen, S., Ibrahim, H.H., Pozzi, C., Rohde, W., and Salamini, F., 2000. On the Origin and Domestication History of Barley (*Hordeum vulgare*). *Molecular Biology and Evolution*, 17 (4), 499–510.
- Balasse, M., 2002. Early Weaning of Neolithic Domestic Cattle (Bercy, France) Revealed by Intra-tooth Variation in Nitrogen Isotope Ratios. *Journal of Archaeological Science*, 29 (8), 853–859.
- Balasse, M., 2003. Potential biases in sampling design and interpretation of intra-tooth isotope analysis. *International Journal of Osteoarchaeology*, 13 (1-2), 3–10.
- Basnet, S., Schneider, M., Gazit, A., Mander, G., and Doctor, A., 2010. Fresh goat's milk for infants: myths and realities - a review. *Pediatrics*, 125 (4), e973–7.
- Baur, L.A. and Allen, J.R., 2005. Editorial Comment: Goat milk for infants: Yes or no? *Journal of Paediatrics and Child Health*, 41, 543.
- Beaumont, J., Geber, J., Powers, N., Wilson, A., Lee-thorp, J., and Montgomery, J., 2013. Victims and Survivors: Stable Isotopes Used to Identify Migrants From the Great Irish Famine to 19th Century London. *American Journal of Physical Anthropology*, 150 (1), 87–98.

- Bellwood, P., 2005. *First Farmers: The Origins of Agricultural Societies*. Oxford: Blackwell.
- Bellwood, P. and Oxenham, M., 2008. The Expansions of Farming Societies and the Role of the Neolithic Demographic Transition. In: J.-P. Bocquet-Appel and O. Bar-Yosef, eds. *The Neolithic Demographic Transition and its Consequences*. Dordrecht: Springer Science + Business Media B.V., 13–34.
- Bird-David, N., 2008. Feeding Nayaka Children and English Readers: A Bifocal Ethnography of Parental Feeding in “The Giving Environment”. *Anthropological Quarterly*, 81 (3), 523–550.
- Bocherens, H., Polet, C., and Toussaint, M., 2007. Palaeodiet of Mesolithic and Neolithic populations of Meuse Basin (Belgium): evidence from stable isotopes. *Journal of Archaeological Science*, 34 (1), 10–27.
- 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: J.-P. Bocquet-Appel and O. Bar-Yosef, eds. *The Neolithic Demographic Transition and its Consequences*. Dordrecht: Springer Science + Business Media B.V., 35–55.
- Bocquet-Appel, J.-P., 2009. The Demographic Impact of the Agricultural System in Human History. *Current Anthropology*, 50 (5), 657–660.
- Bocquet-Appel, J.-P., 2011. When the world’s population took off: the springboard of the Neolithic Demographic Transition. *Science*, 333 (6042), 560–1.
- Bocquet-Appel, J.-P. and Naji, S., 2006. Testing the Hypothesis of a Worldwide Neolithic Demographic Transition. Corroboration from American Cemeteries. *Current Anthropology*, 47 (2), 341–365.
- Bode, L., 2009. Human milk oligosaccharides: prebiotics and beyond. *Nutrition Reviews*, 67 Suppl 2, S183–91.
- Bollongino, R. and Burger, J., 2007. Neolithic cattle domestication as seen from ancient DNA. *Proceedings of the British Academy*, 144, 165–187.
- Bourbou, C. and Richards, M.P., 2007. The Middle Byzantine Menu: Palaeodietary Analysis: Information from isotopic analysis of humans and fauna from Kastella, Crete. *International Journal of Osteoarchaeology*, 17 (1), 63–72.
- Bourdieu, P., 1984. *Distinction: A social critique of the judgement of taste*. Cambridge, Massachusetts: Harvard University Press.
- Bramanti, B., Thomas, M.G., Haak, W., Unterlaender, M., Jores, P., Tambets, K., Antanaitis-Jacobs, I., Haidle, M.N., Jankauskas, R., Kind, C.-J., Lueth, F., Terberger, T., Hiller, J., Matsumura, S., Forster, P., and Burger, J., 2009. Genetic discontinuity between local hunter-gatherers and central Europe’s first farmers. *Science*, 326 (5949), 137–40.
- Brown, K., Dewey, K., and Allen, L.H., 1998. *Complementary feeding of young children in developing countries: A review of current knowledge*. Geneva: World Health Organization (WHO).
- Buikstra, J.E., Konigsberg, L.W., and 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., and 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), 3736–41.
- Burton, J., 2007. Bone Chemistry and Trace Element Analysis. In: M.A. Katzenberg and S.R. Saunders, eds. *Biological Anthropology of the Human Skeleton*. Hoboken: John Wiley and Sons, 443–460.



- Butte, N.F., Lopez-Alarcon, M.G., and Garza, C., 2002. *Nutrient adequacy of exclusive breastfeeding for the term infant during the first six months of life*. Geneva: World Health Organization (WHO).
- Cadogan, W., 1748. *An essay upon nursing: and the management of children, from their birth to three years of age. By a physician. In a letter to one of the governors of the Foundling Hospital. Published by order of the General Committee*. 2nd ed. London: Printed for J. Roberts.
- Carr, C., 1995. Mortuary Practices: Their social, philosophical-religious, circumstantial, and physical determinants. *Journal of Archaeological Method and Theory*, 2 (2), 105–200.
- Castilho, S.D. and Filho, A.D.A.B., 2010. The history of infant nutrition. *Jornal de Pediatria*, 86 (3), 179–188.
- Caut, S., Angulo, E., and Courchamp, F., 2009. Variation in discrimination factors ( $\Delta^{15}\text{N}$  and  $\Delta^{13}\text{C}$ ): the effect of diet isotopic values and applications for diet reconstruction. *Journal of Applied Ecology*, 46 (2), 443–453.
- Cheng, L., Kim, E.J., Merry, R.J., and Dewhurst, R.J., 2011. Nitrogen partitioning and isotopic fractionation in dairy cows consuming diets based on a range of contrasting forages. *Journal of Dairy Science*, 94 (4), 2031–41.
- Choy, K., Jeon, O.-R., Fuller, B.T., and Richards, M.P., 2010. Isotopic evidence of dietary variations and weaning practices in the Gaya cemetery at Yeanri, Gimhae, South Korea. *American Journal of Physical Anthropology*, 142 (1), 74–84.
- Clayton, F., Sealy, J.C., and Pfeiffer, S., 2006. Weaning age among foragers at Matjes river rock shelter, South Africa, from stable nitrogen and carbon isotope analyses. *American Journal of Physical Anthropology*, 129 (2), 311–7.
- Collins, M.J., Nielsen-Marsh, C.M., Hiller, J., Smith, C.I., Roberts, J.P., Prigodich, R.V., Wess, T.J., Csapo, J., Millard, A.R., and Turner-Walker, G., 2002. The survival of organic matter in bone: a review. *Archaeometry*, 44 (3), 383–394.
- Cooper, C., Kuh, D., Egger, P., Wadsworth, M., and Barker, D., 1996. Childhood growth and age at menarche. *British Journal of Obstetrics and Gynaecology*, 103 (8), 814–7.
- Copley, M.S., Berstan, R., Dudd, S.N., Docherty, G., Mukherjee, A.J., Straker, V., Payne, S., and Evershed, R.P., 2003. Direct chemical evidence for widespread dairying in prehistoric Britain. *Proceedings of the National Academy of Sciences of the United States of America*, 100 (4), 1524–9.
- Craig, O.E., Chapman, J., Heron, C., Willis, L.H., Taylor, G., Whittle, A., and Collins, M., 2005. Did the first farmers of central and eastern Europe produce dairy foods? *Antiquity*, 79, 882–894.
- Craig, O.E., Steele, V.J., Fischer, A., Hartz, S., Andersen, S.H., Donohoe, P., Glykou, A., Saul, H., Jones, D.M., Koch, E., and Heron, C.P., 2011. Ancient lipids reveal continuity in culinary practices across the transition to agriculture in Northern Europe. *Proceedings of the National Academy of Sciences of the United States of America*, 108 (44), 17910–5.
- Cutress, T.W. and Suckling, G.W., 1982 The Assessment of Non-Carious Defects of Enamel. *International Dental Journal* 32, 117–122
- Dagnelie, P.C. and Van Staveren, W.A., 1994. Macrobiotic nutrition and child health: results of a population based, mixed-longitudinalcohort study in The Netherlands. *American Journal of Clinical Nutrition*, 59, 1187S–96S.
- Dawson, T.E., Mambelli, S., Plamboeck, A.H., Templer, P.H., and Tu, K.P., 2002. Stable Isotopes in Plant Ecology. *Annual Review of Ecology and Systematics*, 33 (1), 507–559.

- DeNiro, M. and Epstein, S., 1981. Influence of diet on the distribution of nitrogen isotopes in animals. *Geochimica et Cosmochimica Acta*, 45, 341–351.
- Deschner, T., Fuller, B.T., Oelze, V.M., Boesch, C., Hublin, J.-J., Mundry, R., Richards, M.P., Ortmann, S., and Hohmann, G., 2012. Identification of energy consumption and nutritional stress by isotopic and elemental analysis of urine in bonobos (*Pan paniscus*). *Rapid Communications in Mass Spectrometry*, 26 (1), 69–77.
- Dettwyler, K.A., 1995. A Time to Wean: The Hominid Blueprint for the Natural Age of Weaning in Modern Human Populations. In: P. Stuart-Macadam and K.A. Dettwyler, eds. *Breastfeeding: Biocultural Perspectives*. New York: Aldine de Gruyter, 39–73.
- Dettwyler, K.A., 2004. When to wean: biological versus cultural perspectives. *Clinical Obstetrics and Gynecology*, 47 (3), 712–23.
- Dewey, K., 2001. Nutrition, growth, and complementary feeding of the breastfed infant. *Pediatric Clinics of North America*, 48 (1), 87–104.
- Dewey, K., 2003. *Guiding Principles for Complementary Feeding of the Breastfed Child*. Washington: Pan American Health Organization (PAHO) & World Health Organization (WHO).
- Dewey, K., 2005. *Guiding Principles for Feeding Non-Breastfed Children 6-24 Months of Age*. Geneva: World Health Organization (WHO).
- Dittmann, K. and Grupe, G., 2000. Biochemical and palaeopathological investigations on weaning and infant mortality in the early Middle Ages. *Anthropologischer Anzeiger*, 58 (4), 345–55.
- Donovan, S.M., 2006. Role of human milk components in gastrointestinal development: Current knowledge and future needs. *The Journal of Pediatrics*, 149 (5), S49–S61.
- Dupras, T.L., Schwarcz, H.P., and Fairgrieve, S.I., 2001. Infant feeding and weaning practices in Roman Egypt. *American Journal of Physical Anthropology*, 115 (3), 204–12.
- Dupras, T.L. and Tocheri, M.W., 2007. Reconstructing infant weaning histories at Roman period Kellis, Egypt using stable isotope analysis of dentition. *American Journal of Physical Anthropology*, 134 (1), 63–74.
- Ebringer, L., Ferencik, M., and Krajcovic, J., 2008. Beneficial health effects of milk and fermented dairy products - review. *Folia Microbiologica*, 53 (5), 378–94.
- Edwards, C.J., Bollongino, R., Scheu, A., Chamberlain, A., Tresset, A., Vigne, J.-D., Baird, J.F., Larson, G., Ho, S.Y.W., Heupink, T.H., Shapiro, B., Freeman, A.R., Thomas, M.G., Arbogast, R.-M., Arndt, B., Bartosiewicz, L., Benecke, N., Budja, M., Chaix, L., Choyke, A.M., Coqueugniot, E., Döhle, H.-J., Göldner, H., Hartz, S., Helmer, D., Herzig, B., Hongo, H., Mashkour, M., Ozdogan, M., Pucher, E., Roth, G., Schade-Lindig, S., Schmölcke, U., Schulting, R.J., Stephan, E., Uerpmann, H.-P., Vörös, I., Voytek, B., Bradley, D.G., and Burger, J., 2007. Mitochondrial DNA analysis shows a Near Eastern Neolithic origin for domestic cattle and no indication of domestication of European aurochs. *Proceedings of the Royal Society B: Biological Sciences*, 274 (1616), 1377–85.
- Eerkens, J.W., Berget, A., and Bartelink, E.J., 2011. Estimating Weaning and Early Childhood Diet from Serial Micro-samples of Dentin Collagen. *Journal of Archaeological Science*, 38 (11), 3101–3111.
- Ehleringer, J.R. and Rundel, P.W., 1989. Stable Isotopes: History, units, and instrumentation. In: P.W. Rundel, J.R. Ehleringer, and K.A. Nagy, eds. *Stable Isotopes in Ecological Research*. New York: Springer Verlag, 1–15.

- Eidelman, A.I., 2006. The Talmud and human lactation: the cultural basis for increased frequency and duration of breastfeeding among Orthodox Jewish women. *Breastfeeding Medicine*, 1 (1), 36–40.
- El-Khuffash, A. and Unger, S., 2012. The concept of milk kinship in Islam: issues raised when offering preterm infants of Muslim families donor human milk. *Journal of Human Lactation*, 28 (2), 125–7.
- Ellison, P.T., 2001. *On Fertile Ground. A natural history of human reproduction*. Cambridge, MA: Harvard University Press.
- Engfer, M.B., Stahl, B., Finke, B., Sawatzki, G., and Daniel, H., 2000. Human milk oligosaccharides are resistant to enzymatic hydrolysis in the upper gastrointestinal tract. *The American Journal of Clinical Nutrition*, 71 (6), 1589–96.
- Evershed, R.P., Payne, S., Sherratt, A.G., Copley, M.S., Coolidge, J., Urem-Kotsu, D., Kotsakis, K., Ozdoğan, M., Ozdoğan, A.E., Nieuwenhuysse, O., Akkermans, P.M.M.G., Bailey, D., Andeescu, R.-R., Campbell, S., Farid, S., Hodder, I., Yalman, N., Ozbaşaran, M., Biçakci, E., Garfinkel, Y., Levy, T., and Burton, M.M., 2008. Earliest date for milk use in the Near East and southeastern Europe linked to cattle herding. *Nature*, 455 (7212), 528–31.
- Fewtrell, M.S., Morgan, J.B., Duggan, C., Gunnlaugsson, G., Hibberd, P.L., Lucas, A., and Kleinman, R.E., 2007. Optimal duration of exclusive breastfeeding: what is the evidence to support current recommendations? *The American Journal of Clinical Nutrition*, 85 (2), 635S–638S.
- Fildes, V., 1986. *Breasts, Bottles and Babies: A history of infant feeding*. Edinburgh: Edinburgh University Press.
- Fogel, M.L., Tuross, N., and Owsley, D.W., 1989. Nitrogen isotope tracers of human lactation in modern and archaeological populations. *Annual Report of the Director, Geophysical Laboratory, Carnegie Institute of Washington*, 1988, 111–117.
- Fouts, H.N., 2004. Social and emotional contexts of weaning among Bofi farmers and foragers. *Ethnology*, 43 (1), 65–8.
- Fouts, H.N., Hewlett, B.S., and Lamb, M.E., 2005. Parent-Offspring Weaning Conflicts among the Bofi Farmers and Foragers of Central Africa. *Current Anthropology*, 46 (1), 29–50.
- Fujita, M., Roth, E., Lo, Y.-J., Hurst, C., Vollner, J., and Kendell, A., 2012. In poor families, mothers' milk is richer for daughters than sons: A test of Trivers-Willard hypothesis in agropastoral settlements in Northern Kenya. *American Journal of Physical Anthropology*, 149 (1), 52–9.
- Fuller, B.T., Fuller, J.L., Harris, D.A., and Hedges, R.E.M., 2006a. Detection of breastfeeding and weaning in modern human infants with carbon and nitrogen stable isotope ratios. *American Journal of Physical Anthropology*, 129 (2), 279–93.
- Fuller, B.T., Fuller, J.L., Sage, N.E., Harris, D.A., O'Connell, T.C., and Hedges, R.E.M., 2004. Nitrogen balance and  $^{15}\text{N}$ : why you're not what you eat during pregnancy. *Rapid Communications in Mass Spectrometry*, 18 (23), 2889–96.
- Fuller, B.T., Molleson, T.I., Harris, D.A., Gilmour, L.T., and Hedges, R.E.M., 2006b. Isotopic evidence for breastfeeding and possible adult dietary differences from Late/Sub-Roman Britain. *American Journal of Physical Anthropology*, 129 (1), 45–54.
- Fuller, B.T., Richards, M., and Mays, S., 2003. Stable carbon and nitrogen isotope variations in tooth dentine serial sections from Wharram Percy. *Journal of Archaeological Science*, 30 (12), 1673–1684.

- Garðarsdóttir, Ó., 2002. Saving the Child - Regional, cultural and social aspects of the infant mortality decline in Iceland, 1770-1920. Doctoral Thesis, Umeå University, Sweden.
- Gardner, K.S., Leventhal, A., Cambra, R., Bartelink, E.J., and Martinez, A., 2011. Mothers and Infants in the Prehistoric Santa Clara Valley: What Stable Isotopes Tell Us about Ancestral Ohlone Weaning Practices. *Proceedings of the Society for California Archaeology*, 25, 1–14.
- Garrison, F.H., 1923. *History of Pediatrics*. 5th ed. Philadelphia: Saunders.
- Gartner, L.M., Morton, J., Lawrence, R.A., Naylor, A.J., O'Hare, D., Schanler, R.J., and Eidelman, A.I., 2005. Breastfeeding and the use of human milk. *Pediatrics*, 115 (2), 496–506.
- Georgieff, M.K., 2011. Long-term brain and behavioral consequences of early iron deficiency. *Nutrition Reviews*, 69 Suppl 1, S43–8.
- Gerbault, P., Powell, A., and Thomas, M.G., 2012. Evaluating demographic models for goat domestication using mtDNA sequences. *Anthropozoologica*, 47 (2), 64–76.
- Gerbeda-Wilson, N. and Powers, N.G., 2012. Cultural practices and medical beliefs in pre-revolutionary Russia compared to modern textbook advice: did Russian women breastfeed the “wrong” way? *Breastfeeding Medicine*, 7 (6), 514–20.
- Ghosh, R., Mascie-Taylor, C.G.N., and Rosetta, L., 2006. Longitudinal Study of the Frequency and Duration of Breastfeeding in Rural Bangladeshi Women. *American Journal of Human Biology*, 18, 630–638.
- Gignoux, C.R., Henn, B.M., and Mountain, J.L., 2011. Rapid, global demographic expansions after the origins of agriculture. *Proceedings of the National Academy of Sciences of the United States of America*, 108 (15), 6044–9.
- Goodman, A.H. and Armelagos, G.J., 1989. Infant and childhood morbidity and mortality risks in archaeological populations. *World Archaeology*, 21 (2), 225–43.
- Goodman, A.H. and Rose, J.C., 1990. Assessment of systemic physiological perturbations from dental enamel hypoplasias and associated histological structures. *American Journal of Physical Anthropology*, 33 (S11), 59–110.
- Gray, S., 1998. Butterfat feeding in early infancy in african populations: New hypotheses. *American Journal of Human Biology*, 10 (2), 163–178.
- Gronenborn, D., 1999. A Variation on a Basic Theme: The Transition to Farming in Southern Central Europe. *Journal of World Prehistory*, 13 (2), 123–210.
- Grupe, G. and Bach, H., 1993. Life style, subsistence, and mortality in the Slavonic village at Espenfeld (Kr. Arnstadt, FRG). A trace element study. *Anthropologischer Anzeiger*, 51 (4), 317–332.
- Guerrero, E., Naji, S., and Bocquet-Appel, J.-P., 2008. The signal of the Neolithic demographic transition in the Levant. In: J.-P. Bocquet-Appel and O. Bar-Yosef, eds. *The Neolithic Demographic Transition and its Consequences*. Dordrecht: Springer Science + Business Media B.V., 57–80.
- 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), 519–54.
- Guxens, M., Mendez, M.A., Moltó-Puigmartí, C., Julvez, J., García-Esteban, R., Forns, J., Ferrer, M., Vrijheid, M., López-Sabater, M.C., and Sunyer, J., 2011. Breastfeeding, long-chain polyunsaturated fatty acids in colostrum, and infant mental development. *Pediatrics*, 128 (4), e880–9.
- Guy, H., Masset, C., and Baud, C.-A., 1997. Infant Taphonomy. *International Journal of Osteoarchaeology*, 7, 221–119.
- Haak, W., Balanovsky, O., Sanchez, J.J., Koshel, S., Zaporozhchenko, V., Adler, C.J., Der Sarkissian, C.S.I., Brandt, G., Schwarz, C., Nicklisch, N., Dresely, V.,

- Fritsch, B., Balanovska, E., Villems, R., Meller, H., Alt, K.W., and Cooper, A., 2010. Ancient DNA from European early neolithic farmers reveals their near eastern affinities. *PLoS biology*, 8 (11), e1000536.
- Hadley, C., Patil, C.L., and Gulas, C., 2010. Social Learning and Infant and Young Child Feeding Practices. *Current Anthropology*, 51 (4), 551–560.
- Haug, A., Høstmark, A.T., and Harstad, O.M., 2007. Bovine milk in human nutrition - a review. *Lipids in Health and Disease*, 6, 25.
- Haydock, H., Clarke, L., Craig-Atkins, E., Howcroft, R., and Buckberry, J., in press. Weaning at Anglo-Saxon Raunds: Implications for changing breastfeeding practice in Britain over two millennia. *American Journal of Physical Anthropology*, Accepted Manuscript.
- Hayssen, V., 1993. Empirical and Theoretical Constraints on the Evolution of Lactation. *Journal of Dairy Science*, 76, 3213–3233.
- Hedges, R. and Reynard, L., 2007. Nitrogen isotopes and the trophic level of humans in archaeology. *Journal of Archaeological Science*, 34 (8), 1240–1251.
- Hedges, R.E.M., Clement, J.G., Thomas, C.D.L., and O’Connell, T.C., 2007. Collagen turnover in the adult femoral mid-shaft: modeled from anthropogenic radiocarbon tracer measurements. *American Journal of Physical Anthropology*, 133 (2), 808–16.
- Heller, C.A. and Scott, E.M., 1967. *The Alaska Dietary Survey 1956-1961*. U.S. Department of Health, Education and Welfare, Public Health Service, Anchorage.
- Herring, D.A., Saunders, S.R., and Katzenberg, M.A., 1998. Investigating the weaning process in past populations. *American Journal of Physical Anthropology*, 105 (4), 425–39.
- Hester, S.N., Hustead, D.S., Mackey, A.D., Singhal, A., and Marriage, B.J., 2012. Is the macronutrient intake of formula-fed infants greater than breast-fed infants in early infancy? *Journal of Nutrition and Metabolism*, 2012, 891201.
- Heun, M., Schäfer-Pregl, R., Klawan, D., Castagna, R., Accerbi, M., Borghi, B., and Salamini, F., 1997. Site of Einkorn Wheat Domestication Identified by DNA Fingerprinting. *Science*, 278, 1312–1314.
- Hillson, S., 1996. *Dental Anthropology*. Cambridge: Cambridge University Press.
- Hinde, K. and German, J.B., 2012. Food in an evolutionary context: insights from mother’s milk. *Journal of the Science of Food and Agriculture*, 92 (11), 2219–23.
- Hinde, K. and Milligan, L.A., 2011. Primate milk: Proximate mechanisms and ultimate perspectives. *Evolutionary Anthropology: Issues, News, and Reviews*, 20 (1), 9–23.
- Hobson, K.A. and Clark, R.G., 1992. Assessing Avian Diets Using Stable Isotopes II: Factors Influencing Diet-Tissue Fractionation. *The Condor*, 94 (1), 189.
- Hobson, K.A., McLellan, B.N., and Woods, J.G., 2000. Using stable carbon ( $^{13}\text{C}$ ) and nitrogen ( $^{15}\text{N}$ ) isotopes to infer trophic relationships among black and grizzly bears in the upper Columbia River basin, British Columbia. *Canadian Journal of Zoology*, 78 (8), 1332–1339.
- Holman, D.J. and Grimes, M.A., 2003. Patterns for the initiation of breastfeeding in humans. *American Journal of Human Biology*, 15 (6), 765–80.
- Howarth, W.J., 1905. The influence of feeding on the mortality of infants. *The Lancet*, 166 (4273), 210–213.
- Howie, P.W. and McNeilly, A.S., 1982. Effect of breast-feeding patterns on human birth intervals. *Journal of Reproduction and Fertility*, 65 (2), 545–57.
- Howland, M.R., Corr, L.T., Young, S.M.M., Jones, V., Jim, S., van der Merwe, N.J., Mitchell, A.D., and Evershed, R.P., 2003. Expression of the dietary isotope sig-

- nal in the compound-specific  $^{13}\text{C}$  values of pig bone lipids and amino acids. *International Journal of Osteoarchaeology*, 13 (1-2), 54–65.
- Huber, S. and Fieder, M., 2009. Strong association between birth month and reproductive performance of Vietnamese women. *American Journal of Human Biology*, 21 (1), 25–35.
- Le Huërou-Luron, I., Blat, S., and 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.
- Huffman, S.L., 1984. Determinants of breastfeeding in developing countries: overview and policy implications. *Studies in Family Planning*, 15 (4), 170–83.
- Hühne-Osterloh, G. and Grupe, G., 1989. Causes of infant mortality in the Middle Ages revealed by chemical and palaeopathological analyses of skeletal remains. *Zeitschrift für Morphologie und Anthropologie*, 77 (3), 247–258.
- Humphrey, L.T., 2010. Weaning behaviour in human evolution. *Seminars in Cell & Developmental Biology*, 21 (4), 453–61.
- Humphrey, L.T., Dean, M.C., Jeffries, T.E., and Penn, M., 2008a. Unlocking evidence of early diet from tooth enamel. *Proceedings of the National Academy of Sciences of the United States of America*, 105 (19), 6834–9.
- Humphrey, L.T., Dirks, W., Dean, M.C., and Jeffries, T.E., 2008b. Tracking dietary transitions in weanling baboons (*Papio hamadryas anubis*) using strontium/calcium ratios in enamel. *Folia Primatologica*, 79 (4), 197–212.
- Ibáñez, L., Ferrer, A., Marcos, M.V., Hierro, F.R., and De Zegher, F., 2000. Early puberty: rapid progression and reduced final height in girls with low birth weight. *Pediatrics*, 106 (5), e72.
- ICRP, 1995. Basic Anatomical & Physiological Data for use in Radiological Protection - The Skeleton. ICRP Publication 70. *Annals of the ICRP*, 25 (2).
- ICRP, 2002. Basic Anatomical and Physiological Data for Use in Radiological Protection: Reference Values. ICRP Publication 89. *Annals of the ICRP*, 32 (3-4).
- Ingram, C.J.E., Mulcare, C.A., Itan, Y., Thomas, M.G., and Swallow, D.M., 2009. Lactose digestion and the evolutionary genetics of lactase persistence. *Human Genetics*, 124 (6), 579–91.
- Ip, S., Chung, M., Raman, G., Trikalinos, T.A., and Lau, J., 2009. A summary of the Agency for Healthcare Research and Quality's evidence report on breastfeeding in developed countries. *Breastfeeding Medicine*, 4 Suppl 1, S17–30.
- Isaksson, S. and Hallgren, F., 2012. Lipid residue analyses of Early Neolithic funnel-beaker pottery from Skogsmossen, eastern Central Sweden, and the earliest evidence of dairying in Sweden. *Journal of Archaeological Science*, 39 (12), 3600–3609.
- Isern, N. and Fort, J., 2012. Modelling the effect of Mesolithic populations on the slowdown of the Neolithic transition. *Journal of Archaeological Science*, 39 (12), 3671–3676.
- Itan, Y., Powell, A., Beaumont, M. a, Burger, J., and Thomas, M.G., 2009. The origins of lactase persistence in Europe. *PLoS computational biology*, 5 (8), e1000491.
- Jasienska, G., Thune, I., and Ellison, P.T., 2006. Fatness at birth predicts adult susceptibility to ovarian suppression: an empirical test of the Predictive Adaptive Response hypothesis. *Proceedings of the National Academy of Sciences of the United States of America*, 103 (34), 12759–62.
- Jay, M., Fuller, B.T., Richards, M.P., Knüsel, C.J., and King, S.S., 2008. Iron Age breastfeeding practices in Britain: isotopic evidence from Wetwang Slack, East Yorkshire. *American Journal of Physical Anthropology*, 136 (3), 327–37.

- Jelliffe, D.B., and Jelliffe, E.F.P., 1978. The volume and composition of human milk in poorly nourished communities. A review. *The American Journal of Clinical Nutrition*, 31, 492–515.
- Jelliffe, D.B., Jelliffe, E.F.P., García, L., and De Barrios, G., 1961. The children of the San Blas Indians of Panama: An ecologic field study of health and nutrition. *The Journal of Pediatrics*, 59 (2), 271–285.
- Jenkins, S.G., Partridge, S.T., Stephenson, T.R., Farley, S.D., and Robbins, C.T., 2001. Nitrogen and Carbon Isotope Fractionation between Mothers, Neonates, and Nursing Offspring. *Oecologia*, 129 (3), 336–341.
- Jim, S., Ambrose, S.H., and Evershed, R.P., 2004. Stable carbon isotopic evidence for differences in the dietary origin of bone cholesterol, collagen and apatite: implications for their use in palaeodietary reconstruction. *Geochimica et Cosmochimica Acta*, 68 (1), 61–72.
- Jim, S., Jones, V., Ambrose, S.H., and Evershed, R.P., 2006. Quantifying dietary macronutrient sources of carbon for bone collagen biosynthesis using natural abundance stable carbon isotope analysis. *British Journal of Nutrition*, 95 (06), 1055–1062.
- Kachel, A.F., Premo, L.S., and Hublin, J.-J., 2011. Modeling the effects of weaning age on length of female reproductive period: implications for the evolution of human life history. *American Journal of Human Biology*, 23 (4), 479–87.
- Katzenberg, M.A., 2008. Stable Isotope Analysis: A Tool for Studying Past Diet, Demography, and Life History. In: M.A. Katzenberg and S.R. Saunders, eds. *Biological Anthropology of the Human Skeleton*. Hoboken: Wiley, 413–442.
- Katzenberg, M.A., Herring, D.A., and Saunders, S.R., 1996. Weaning and infant mortality: Evaluating the skeletal evidence. *American Journal of Physical Anthropology*, 101 (S23), 177–199.
- Katzenberg, M.A. and Lovell, N.C., 1999. Stable isotope variation in pathological bone. *International Journal of Osteoarchaeology*, 9 (5), 316–324.
- Katzenberg, M.A. and Pfeiffer, S., 1995. Nitrogen isotope evidence of weaning age in a nineteenth century Canadian skeletal sample. In: A.L. Grauer, ed. *Bodies of Evidence: Reconstructing history through skeletal analysis*. New York: John Wiley and Sons, 221–235.
- Katzenberg, M.A., Saunders, S.R., and Fitzgerald, W.R., 1993. Age differences in stable carbon and nitrogen isotope ratios in a population of prehistoric maize horticulturists. *American Journal of Physical Anthropology*, 90 (3), 267–81.
- Keenleyside, A., Schwarcz, H.P., Stirling, L., and Ben Lazreg, N., 2009. Stable isotopic evidence for diet in a Roman and Late Roman population from Leptiminus, Tunisia. *Journal of Archaeological Science*, 36 (1), 51–63.
- 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), 123–45.
- Kent, J.C., Mitoulas, L.R., Cregan, M.D., Ramsay, D.T., Dorota, A., Hartmann, P.E., and Doherty, D.A., 2006. Volume and Frequency of Breastfeedings and Fat Content of Breast Milk Throughout the Day. *Pediatrics*, 117 (3), e387–95.
- Khan, S., Hepworth, A.R., Prime, D.K., Lai, C.T., Trengove, N.J., and Hartmann, P.E., 2013. Variation in Fat, Lactose, and Protein Composition in Breast Milk over 24 Hours: Associations with Infant Feeding Patterns. *Journal of Human Lactation*, 29 (1), 81–9.
- Khatib-Chahidi, J., 1992. Milk Kinship in Shi'ite Islamic Iran. In: V. Maher, ed. *The Anthropology of Breastfeeding*. Oxford: Berg, 109–132.
- Kliem, K.E. and Givens, D.I., 2011. Dairy products in the food chain: their impact on health. *Annual Review of Food Science and Technology*, 2, 21–36.

- Knott, C., 2001. Female reproductive ecology of the apes. In: P.T. Ellison, ed. *Reproductive Ecology and Human Evolution*. New Brunswick: Transaction, 429–463.
- Konnor, M., 2005. Hunter-gatherer infancy and childhood: The !Kung and others. In: B.S. Hewlett and M.E. Lamb, eds. *Hunter-Gatherer Childhoods*. New Brunswick: Transaction, 19–64.
- Konnor, M. and Worthman, C., 1980. Nursing frequency, gonadal function, and birth spacing among !Kung hunter-gatherers. *Science*, 207 (4432), 788–791.
- Kramer, M.S. and Kakuma, R., 2002. Optimal duration of exclusive breastfeeding. *Cochrane Database of Systematic Reviews (Online)*, (1), CD003517.
- Kramer, M.S. and Kakuma, R., 2012. Optimal duration of exclusive breastfeeding. *Cochrane Database of Systematic Reviews (Online)*, 8 (8), CD003517.
- Kunz, C. and Lönnerdal, B., 1992. Re-evaluation of the whey protein/casein ratio of human milk. *Acta Paediatrica*, 81 (2), 107–112.
- Kunz, C. and Lönnerdal, B., 1993. Protein composition of rhesus monkey milk: comparison to human milk. *Comparative Biochemistry and Physiology*, 104A (4), 793–797.
- Ladizinsky, G., 1999. Identification of the lentil's wild genetic stock. *Genetic Resources and Crop Evolution*, 46 (2), 115–118.
- Laroia, N. and Sharma, D., 2006. The Religious and Cultural Bases for Breastfeeding Practices Among the Hindus. *Breastfeeding Medicine*, 1 (2), 94–99.
- Lauer, J.A., Betrán, A.P., Barros, A.J., and de Onís, M., 2007. Deaths and years of life lost due to suboptimal breast-feeding among children in the developing world: a global ecological risk assessment. *Public Health Nutrition*, 9 (06), 673–685.
- Lee-Thorp, J.A., 2008. On isotopes and old bones. *Archaeometry*, 50 (6), 925–950.
- Lefèvre, C.M., Sharp, J. a, and Nicholas, K.R., 2010. Evolution of lactation: ancient origin and extreme adaptations of the lactation system. *Annual Review of Genomics and Human Genetics*, 11, 219–38.
- 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., and Rijnkels, M., 2009. The bovine lactation genome: insights into the evolution of mammalian milk. *Genome Biology*, 10 (4), R43.
- Leslie, P. and Winterhalder, B., 2002. Demographic consequences of unpredictability in fertility outcomes. *American Journal of Human Biology*, 14 (2), 168–83.
- Levine, M.A., 1998. Eating horses: the evolutionary significance of hippophagy, 72, 90–100.
- Lewis, M.E., 2007. *The Bioarchaeology of Children: Perspectives from biological and forensic anthropology*. Cambridge: Cambridge University Press.
- Lidén, K. and Angerbjörn, A., 1999. Dietary change and stable isotopes: a model of growth and dormancy in cave bears. *Proceedings of the Royal Society B: Biological Sciences*, 266 (1430), 1779–83.
- Lidén, K., Olsson, A., Eriksson, G., and Angerbjörn, A., 2003. Nitrogen isotope analysis of deciduous teeth: a tool for tracing weaning patterns. In: G. Eriksson. *Norm and Difference: Stone Age dietary practice in the Baltic region*. Doctoral Thesis, Archaeological Research Laboratory, Stockholm University, Sweden. Paper I.
- Lönnerdal, B., 2003. Nutritional and physiologic significance of human milk proteins. *The American Journal of Clinical Nutrition*, 77 (6), 1537S–1543S.
- Lönnerdal, B. and Lien, E.L., 2003. Nutritional and physiologic significance of alpha-lactalbumin in infants. *Nutrition Reviews*, 61 (9), 295–305.



- Loudon, J.E., Sponheimer, M., Sauther, M.L., and Cuozzo, F.P., 2007. Intraspecific Variation in Hair  $^{13}\text{C}$  and  $^{15}\text{N}$  Values of Ring-Tailed Lemurs (*Lemur catta*) With Known Individual Histories, Behavior, and Feeding Ecology. *American Journal of Physical Anthropology*, 133, 978–985.
- Lowenstam, H.A. and Weiner, S., 1989. *On Biomineralization*. Oxford: Oxford University Press.
- Lozoff, B., Jimenez, E., Hagen, J., Mollen, E., and Wolf, A.W., 2000. Poorer behavioral and developmental outcome more than 10 years after treatment for iron deficiency in infancy. *Pediatrics*, 105 (4), E51.
- De Luca, A., Boisseau, N., Tea, I., Louvet, I., Robins, R.J., Forhan, A., Charles, M.-A., and Hankard, R., 2012.  $^{15}\text{N}$  and  $^{13}\text{C}$  in hair from newborn infants and their mothers: a cohort study. *Pediatric Research*, 71 (5), 598–604.
- Lukacs, J.R., 2008. Fertility and Agriculture Accentuate Sex Differences in Dental Caries Rates. *Current Anthropology*, 49 (5), 901–914.
- Lunt, R.C. and Law, D.B., 1974. A review of the chronology of calcification of deciduous teeth. *The Journal of the American Dental Association*, 89 (3), 599–606.
- Malmer, M.P., 2002. *The Neolithic of South Sweden. TRB, GRK, and STR*. Stockholm: Almqvist & Wiksell.
- Mandel, D., Lubetzky, R., Dollberg, S., Barak, S., and Mimouni, F.B., 2005. Fat and energy contents of expressed human breast milk in prolonged lactation. *Pediatrics*, 116 (3), e432–5.
- Märten, A., Fratzl, P., Paris, O., and Zaslansky, P., 2010. On the mineral in collagen of human crown dentine. *Biomaterials*, 31 (20), 5479–90.
- Martin, M.A. and Sela, D.A., 2013. Infant Gut Microbiota: Developmental Influences and Health Outcomes. In: K.B.H. Clancy, K. Hinde, and J.N. Rutherford, eds. *Building Babies: Primate Development in Proximate and Ultimate Perspective*. New York: Springer, 233–256.
- Mattar, R., De Campos Mazo, D.F., and Carrilho, F.J., 2012. Lactose intolerance: diagnosis, genetic, and clinical factors. *Clinical and Experimental Gastroenterology*, 5, 113–21.
- Matthews Grieco, S., 1991. Breastfeeding, Wet Nursing and Infant Mortality in Europe 1400–1800. In: F. Arrigoni and J.R. Himes, eds. *Historical Perspectives on Breastfeeding*. Florence: UNICEF/Istituto degli Innocenti, 15–62.
- Mays, S., 2003. Bone strontium: calcium ratios and duration of breastfeeding in a Mediaeval skeletal population. *Journal of Archaeological Science*, 30 (6), 731–741.
- McClellan, H.L., Miller, S.J., and Hartmann, P.E., 2008. Evolution of lactation: nutrition v. protection with special reference to five mammalian species. *Nutrition Research Reviews*, 21 (2), 97–116.
- McCutchan, J.H., Lewis, W.M., Kendall, C., and McGrath, C.C., 2003. Variation in trophic shift for stable isotope ratios of carbon, nitrogen, and sulfur. *Oikos*, 102 (2), 378–390.
- Millard, A.R., 2000. A model for the effect of weaning on nitrogen isotope ratios in humans. In: G. Goodfriend, M. Collins, M. Fogel, S. Macke, and J. Wehmler, eds. *Perspectives in Amino Acid and Protein Geochemistry*. New York: Oxford University Press, 51–59.
- Minagawa, M. and Wada, E., 1984. Stepwise enrichment of  $^{15}\text{N}$  along food chains: Further evidence and the relation between  $^{15}\text{N}$  and animal age. *Geochimica et Cosmochimica Acta*, 48, 1135–1140.

- Molleson, T., Jones, K., and Jones, S., 1993. Dietary change and the effects of food preparation on microwear patterns in the Late Neolithic of abu Hureyra, northern Syria. *Journal of Human Evolution*, 24, 455–468.
- Moorrees, C.F., Fanning, E.A., and Hunt, E.E., 1963. Age Variation of Formation Stages for Ten Permanent Teeth. *Journal of Dental Research*, 42, 1490–502.
- Moscone, S.R. and Moore, M.J., 1993. Breastfeeding during pregnancy. *Journal of Human Lactation*, 9 (2), 83–88.
- Mountzouris, K.C., McCartney, A.L., and Gibson, G.R., 2007. Intestinal microflora of human infants and current trends for its nutritional modulation. *British Journal of Nutrition*, 87 (05), 405–420.
- Naderi, S., Rezaei, H.-R., Pompanon, F., Blum, M.G.B., Negrini, R., Naghash, H.-R., Balkiz, O., Mashkour, M., Gaggiotti, O.E., Ajmone-Marsan, P., Kence, A., Vigne, J.-D., and Taberlet, P., 2008. The goat domestication process inferred from large-scale mitochondrial DNA analysis of wild and domestic individuals. *Proceedings of the National Academy of Sciences of the United States of America*, 105 (46), 17659–64.
- Nerlove, S.B., 1974. Women's Workload and Infant Feeding Practices: A Relationship with Demographic Implications. *Ethnology*, 13 (2), 207–214.
- Nitsch, E.K., Humphrey, L.T., and Hedges, R.E.M., 2011. Using stable isotope analysis to examine the effect of economic change on breastfeeding practices in Spitalfields, London, UK. *American Journal of Physical Anthropology*, 146 (4), 619–628.
- Nommsen-Rivers, L.A., 2004. Does breastfeeding protect against infant mortality in the United States? *Journal of Human Lactation*, 20 (3), 357–8.
- Núñez-de la Mora, A., Chatterton, R.T., Choudhury, O.A., Napolitano, D.A., and Bentley, G.R., 2007. Childhood conditions influence adult progesterone levels. *PLoS Medicine*, 4 (5), e167.
- O'Connell, T.C., Kneale, C.J., Tasevska, N., and Kuhnle, G.G.C., 2012. The diet-body offset in human nitrogen isotopic values: A controlled dietary study. *American Journal of Physical Anthropology*, 149 (3), 426–34.
- Oftedal, O.T., 2002. The Mammary Gland and Its Origin During Synapsid Evolution. *Journal of Mammary Gland Biology and Neoplasia*, 7 (3), 225–252.
- Oftedal, O.T., 2012. The evolution of milk secretion and its ancient origins. *Animal*, 6 (3), 355–68.
- Ottoni, C., Girdland Flink, L., Evin, A., Geörg, C., De Cupere, B., Van Neer, W., Bartosiewicz, L., Linderholm, A., Barnett, R., Peters, J., Decorte, R., Waelkens, M., Vanderheyden, N., Ricaut, F.-X., Cakirlar, C., Cevik, O., Hoelzel, A.R., Mashkour, M., Mohaseb Karimlu, A.F., Sheikhi Seno, S., Daujat, J., Brock, F., Pinhasi, R., Hongo, H., Perez-Enciso, M., Rasmussen, M., Frantz, L., Megens, H.-J., Crooijmans, R., Groenen, M., Arbuckle, B., Benecke, N., Strand Vidarsdottir, U., Burger, J., Cucchi, T., Dobney, K., and Larson, G., 2013. Pig Domestication and Human-Mediated Dispersal in Western Eurasia Revealed through Ancient DNA and Geometric Morphometrics. *Molecular Biology and Evolution*, mss261v2 (Epub ahead of print).
- Parent, A.-S., Teilmann, G., Juul, A., Skakkebaek, N.E., Toppra, J., and Bourguignon, J.-P., 2003. The Timing of Normal Puberty and the Age Limits of Sexual Precocity: Variations around the World, Secular Trends, and Changes after Migration. *Endocrine Reviews*, 24 (5), 668–693.
- Park, Y., Juarez, M., Ramos, M., and Haenlein, G., 2007. Physico-chemical characteristics of goat and sheep milk. *Small Ruminant Research*, 68 (1-2), 88–113.
- Parkes, P., 2004. Fosterage, Kinship, and Legend: When Milk Was Thicker than Blood? *Comparative Studies in Society and History*, 46 (3), 587–615.

- Passey, B.H., Cerling, T.E., Schuster, G.T., Robinson, T.F., Roeder, B.L., and Krueger, S.K., 2005. Inverse methods for estimating primary input signals from time-averaged isotope profiles. *Geochimica et Cosmochimica Acta*, 69 (16), 4101–4116.
- Patterson, N., Moorjani, P., Luo, Y., Mallick, S., Rohland, N., Zhan, Y., Genschoreck, T., Webster, T., and Reich, D., 2012. Ancient admixture in human history. *Genetics*, 192 (3), 1065–93.
- Pearson, J.A., Hedges, R.E.M., Molleson, T.I., and Ozbek, M., 2010. Exploring the relationship between weaning and infant mortality: An isotope case study from Aşikli Höyük and Cayönü Tepesi. *American Journal of Physical Anthropology*, 143 (3), 448–457.
- Pedrosa, S., Uzun, M., Arranz, J.-J., Gutiérrez-Gil, B., San Primitivo, F., and Bayón, Y., 2005. Evidence of three maternal lineages in Near Eastern sheep supporting multiple domestication events. *Proceedings of the Royal Society B: Biological Sciences*, 272 (1577), 2211–7.
- Pelto, G.H., Zhang, Y., and Habicht, J.-P., 2010. Premastication: the second arm of infant and young child feeding for health and survival? *Maternal & Child Nutrition*, 6 (1), 4–18.
- Pérez-Losada, J. and Fort, J., 2010. Age-dependent mortality, fecundity and mobility effects on front speeds: theory and application to the Neolithic transition. *Journal of Statistical Mechanics: Theory and Experiment*, 2010 (11), P11006.
- Peterson, B.J. and Fry, B., 1987. Stable Isotopes in Ecosystem Studies. *Annual Review of Ecology and Systematics*, 18 (1), 293–320.
- Piperata, B.A. and Mattern, L.M.G., 2011. Longitudinal study of breastfeeding structure and women's work in the Brazilian Amazon. *American Journal of Physical Anthropology*, 144 (2), 226–37.
- Plantinga, T.S., Alonso, S., Izagirre, N., Hervella, M., Fregel, R., van der Meer, J.W.M., Netea, M.G., and de la Rúa, C., 2012. Low prevalence of lactase persistence in Neolithic South-West Europe. *European Journal of Human Genetic*, 20 (7), 778–82.
- Pond, C.M., 1977. The Significance of Lactation in the Evolution of Mammals. *Evolution*, 31 (1), 177–199.
- Power, M.L., Oftedal, O.T., and Tardif, S.D., 2002. Does the milk of Callitrichid monkeys differ from that of larger anthropoids? *American Journal of Primatology*, 56 (2), 117–27.
- Prowse, T.L., Saunders, S.R., Schwarcz, H.P., Garnsey, P., Macchiarelli, R., and Bondioli, L., 2008. Isotopic and dental evidence for infant and young child feeding practices in an imperial Roman skeletal sample. *American Journal of Physical Anthropology*, 137 (3), 294–308.
- Psouni, E., Janke, A., and Garwicz, M., 2012. Impact of carnivory on human development and evolution revealed by a new unifying model of weaning in mammals. *PloS One*, 7 (4), e32452.
- Radbill, S.X., 1976. The Role of Animals in Infant Feeding. In: W.D. Hand, ed. *American Folk Medicine*. Berkeley: University of California Press, 21–30.
- Rasinperä, H., Kuokkanen, M., Kolho, K.-L., Lindahl, H., Enattah, N.S., Savilahti, E., Orpana, A., and Järvelä, I., 2005. Transcriptional downregulation of the lactase (LCT) gene during childhood. *Gut*, 54 (11), 1660–1.
- Rautava, S. and Walker, W.A., 2009. Academy of Breastfeeding Medicine founder's lecture 2008: breastfeeding - an extrauterine link between mother and child. *Breastfeeding Medicine*, 4 (1), 3–10.

- Redfern, R.C., Millard, A.R., and Hamlin, C., 2012. A regional investigation of subadult dietary patterns and health in late Iron Age and Roman Dorset, England. *Journal of Archaeological Science*, 39 (5), 1249–1259.
- Reilly, J.J. and Wells, J.C.K., 2007. Duration of exclusive breast-feeding: introduction of complementary feeding may be necessary before 6 months of age. *British Journal of Nutrition*, 94 (06), 869.
- Richards, M., Fuller, B.T., and Molleson, T., 2006. Stable isotope palaeodietary study of humans and fauna from the multi-period (Iron Age, Viking and Late Medieval) site of Newark Bay, Orkney. *Journal of Archaeological Science*, 33 (1), 122–131.
- Richards, M.P. and Hedges, R.E.M., 1999. A Neolithic revolution? New evidence of diet in the British Neolithic. *Antiquity*, 73 (282), 891–897.
- Richards, M.P., Mays, S., and Fuller, B.T., 2002. Stable carbon and nitrogen isotope values of bone and teeth reflect weaning age at the Medieval Wharram Percy site, Yorkshire, UK. *American Journal of Physical Anthropology*, 119 (3), 205–10.
- Richards, M.P., Pearson, J.A., Molleson, T.I., Russell, N., and Martin, L., 2003a. Stable Isotope Evidence of Diet at Neolithic Çatalhöyük, Turkey. *Journal of Archaeological Science*, 30 (1), 67–76.
- Richards, M.P. and Schulting, R.J., 2006. Against the grain? A response to Milner et al. (2004). *Antiquity*, 80, 444–457.
- Richards, M.P., Schulting, R.J., and Hedges, R.E.M., 2003b. Sharp shift in diet at onset of Neolithic. *Nature*, 425, 366.
- Riordan, J. and Wambach, K., 2010. *Breastfeeding and Human Lactation*. Fourth. London: Jones and Bartlett.
- Robbins, C.T., Felicetti, L.A., and Sponheimer, M., 2005. The effect of dietary protein quality on nitrogen isotope discrimination in mammals and birds. *Oecologia*, 144 (4), 534–40.
- Robinson, S. and Fall, C., 2012. Infant nutrition and later health: a review of current evidence. *Nutrients*, 4 (8), 859–74.
- Robling, A.G., Castillo, A.B., and Turner, C.H., 2006. Biomechanical and molecular regulation of bone remodeling. *Annual Review of Biomedical Engineering*, 8, 455–98.
- Robson, S.L., Van Schaik, C.P., and Hawkes, K., 2006. The Derived Features of Human Life History. In: K. Hawkes and R.R. Paine, eds. *The Evolution of Human Life History*. Oxford: James Currey, 17–44.
- Rountrey, A., Fisher, D., Vartanyan, S., and Fox, D., 2007. Carbon and nitrogen isotope analyses of a juvenile woolly mammoth tusk: Evidence of weaning. *Quaternary International*, 169–170, 166–173.
- Rowland, M.G.M., Barrell, R.A.E., and Whitehead, R.G., 1978. The Weanling's Dilemma. *The Lancet*, 311 (8056), 136–138.
- Rowley-Conwy, P., 2004. How the West Was Lost: A Reconsideration of Agricultural Origins in Britain, Ireland, and Southern Scandinavia. *Current Anthropology*, 45 (S4), S83–S113.
- Rowley-Conwy, P., 2011. Westward Ho! The spread of agriculture from Central Europe to the Atlantic. *Current Anthropology*, 52 (S4), S431–S451.
- Sahi, T., Launiala, K., and Laitinen, H., 1983. Hypolactasia in a fixed cohort of young Finnish adults. A follow-up study. *Scandinavian Journal of Gastroenterology*, 18 (7), 865–70.
- Salmon, M., 1994. The Cultural Significance of Breastfeeding and Infant Care in Early Modern England and America. *Journal of Social History*, 28 (2), 247–269.

- Salque, M., Bogucki, P.I., Pyzel, J., Sobkowiak-Tabaka, I., Grygiel, R., Szmyt, M., and Evershed, R.P., 2013. Earliest evidence for cheese making in the sixth millennium BC in northern Europe. *Nature*, 493 (7433), 522–5.
- Samrang, P., Thul, P.C., and Szep, J., 12 September 2011. Baby suckles directly from cow for milk. *Reuters* [Online], Available from: <http://www.reuters.com/article/2011/09/12/us-boy-cow-idUSTRE78B4CG20110912> [Accessed 3 February 2013].
- Saucier, J.-F., 1972. Correlates of the Long Postpartum Taboo: A Cross-Cultural Study. *Current Anthropology*, 13 (2), 238–249.
- Scheuer, L. and Black, S., 2000. *Developmental Juvenile Osteology*. London: Elsevier.
- Schoeller, D., 1999. Isotope Fractionation: Why aren't we what we eat? *Journal of Archaeological Science*, 26 (6), 667–673.
- Schoeninger, M.J. and DeNiro, M.J., 1984. Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. *Geochimica et Cosmochimica Acta*, 48 (4), 625–639.
- Schurr, M.R., 1997. Stable Nitrogen Isotopes as Evidence for the Age of Weaning at the Angel Site: A Comparison of Isotopic and Demographic Measures of Weaning Age. *Journal of Archaeological Science*, 24 (10), 919–927.
- Schurr, M.R., 1998. Using stable nitrogen-isotopes to study weaning behaviour in past populations. *World Archaeology*, 30 (2), 327–342.
- Schurr, M.R. and Powell, M.L., 2005. The role of changing childhood diets in the prehistoric evolution of food production: An isotopic assessment. *American Journal of Physical Anthropology*, 126 (3), 278–94.
- Sealy, J.C., 2001. Body tissue chemistry and palaeodiet. In: D.R. Brothwell and A.M. Pollard, eds. *Handbook of Archaeological Sciences*. Chichester: Wiley, 269–279.
- Segawa, M., 2008. Buddhism and breastfeeding. *Breastfeeding Medicine*, 3 (2), 124–8.
- Seibel, M.J., 2005. Biochemical markers of bone turnover: part I: biochemistry and variability. *The Clinical Biochemist Reviews*, 26 (4), 97–122.
- Sellen, D.W., 2001. Comparison of Infant Feeding Patterns Reported for Nonindustrial Populations with Current Recommendations. *The Journal of Nutrition*, 131, 2707–2715.
- Sellen, D.W., 2006. Lactation, Complementary Feeding, and Human Life History. In: K. Hawkes and R.R. Paine, eds. *The Evolution of Human Life History*. Oxford: James Currey, 155–196.
- Sellen, D.W., 2007. Evolution of infant and young child feeding: implications for contemporary public health. *Annual Review of Nutrition*, 27, 123–48.
- Sellen, D.W., 2009. Evolution of human lactation and complementary feeding: Implications for understanding contemporary cross-cultural variation. In: G.R. Goldberg, ed. *Breastfeeding: early influences on later health*. 253–282.
- Sellen, D.W. and Smay, D.B., 2001. Relationship between subsistence and age at weaning in “preindustrial” societies. *Human Nature*, 12 (1), 47–87.
- Shaikh, U. and Ahmed, O., 2006. Islam and infant feeding. *Breastfeeding Medicine*, 1 (3), 164–7.
- Shennan, S., 2008. Population Processes and Their Consequences in Early Neolithic Central Europe. In: J.-P. Bocquet-Appel and O. Bar-Yosef, eds. *The Neolithic Demographic Transition and its Consequences*. Dordrecht: Springer Science + Business Media B.V., 315–329.
- Sherratt, A.G., 1981. The plough and pastoralism: Aspects of the secondary products revolution. In: I. Hodder, G. Isaac, and N. Hammond, eds. *Pattern of the Past*:

- Studies in honour of David Clarke*. Cambridge: Cambridge University Press, 261–305.
- Shetty, P., 2011. Energetic cost of gestation and lactation in humans. In: C.G.N. Mascie-Taylor and L. Rosetta, eds. *Reproduction and Adaptation. Topics in Human Reproductive Ecology*. Cambridge: Cambridge University Press, 98–111.
- Shostak, M., 1981. *Nisa: The Life and Words of a !Kung Woman*. Harvard University Press.
- Sillen, A. and Smith, P., 1984. Weaning patterns are reflected in strontium-calcium ratios of juvenile skeletons. *Journal of Archaeological Science*, 11 (3), 237–245.
- Skoglund, P., Malmström, H., Raghavan, M., Storå, J., Hall, P., Willerslev, E., Gilbert, M.T.P., Götherström, A., and Jakobsson, M., 2012. Origins and genetic legacy of Neolithic farmers and hunter-gatherers in Europe. *Science*, 336 (6080), 466–9.
- Sloboda, D.M., Hickey, M., and Hart, R., 2011. Reproduction in females: the role of the early life environment. *Human Reproduction Update*, 17 (2), 210–27.
- Smith, B.H., 1991. Standards of human tooth formation and dental age assessment. In: M.A. Kelley and C.S. Larsen, eds. *Advances in Dental Anthropology*. New York: Wiley-Liss, 143–168.
- Smith, B.N. and Epstein, S., 1971. Two categories of  $^{13}\text{C}/^{12}\text{C}$  ratios for higher plants. *Plant Physiology*, 47 (3), 380–4.
- Soranus of Ephesus and Temkin, O., 1991. *Soranus' Gynecology. Translated with an introduction by Oswei Temkin, with the assistance of Nicholson J. Eastman, Ludwig Edelstein and Alan F. Guttmacher*. Baltimore: John Hopkins University Press.
- Sponheimer, M., Robinson, T., Roeder, B., Passey, B., Ayliffe, L., Cerling, T., Dearing, M., and Ehleringer, J., 2003. An experimental study of nitrogen flux in llamas: is  $^{14}\text{N}$  preferentially excreted? *Journal of Archaeological Science*, 30 (12), 1649–1655.
- Steele, K.W. and Daniel, R.M., 1978. Fractionation of nitrogen isotopes by animals: a further complication to the use of variations in the natural abundance of  $^{15}\text{N}$  for tracer studies. *Journal of Agricultural Science*, 90, 7–9.
- Tauber, H., 1981.  $^{13}\text{C}$  evidence for dietary habits of prehistoric man in Denmark. *Nature*, 292 (5821), 332–333.
- Thomas, J., 2004. Current debates on the Mesolithic-Neolithic transition in Britain and Ireland. *Documenta Praehistorica*, XXXI, 113–130.
- Thompson, D.K. and Kharb, S., 2007. Aspects of Infant Food Formulation. *Comprehensive Reviews In Food Science And Food Safety*, 6, 79–102.
- Thorvaldsen, G., 2008. Was there a European breastfeeding pattern? *The History of the Family*, 13 (3), 283–295.
- Tresset, A. and Vigne, J.-D., 2011. Last hunter-gatherers and first farmers of Europe. *Comptes Rendus Biologies*, 334 (3), 182–9.
- Troy, C.S., MacHugh, D.E., Bailey, J.F., Magee, D.A., Loftus, R.T., Cunningham, P., Chamberlain, A.T., Sykes, B.C., and Bradley, D.G., 2001. Genetic evidence for Near-Eastern origins of European cattle. *Nature*, 410 (6832), 1088–91.
- Turner, B.L., Edwards, J.L., Quinn, E.A., Kingston, J.D., and Van Gerven, D.P., 2007. Age-related variation in isotopic indicators of diet at Medieval Kulubnarti, Sudanese Nubia. *International Journal of Osteoarchaeology*, 17 (1), 1–25.
- USDA ARS (U.S. Department of Agriculture, Agricultural Research Service), 2009. – *USDA National Nutrient Database for Standard Reference, Release 22. Nutri-*

- |     |       |          |      |            |      |   |
|-----|-------|----------|------|------------|------|---|
| ent | Data. | Nutrient | Data | Laboratory | Home | Page,   |
|     |       |          |      |            |      | <a href="http://www.ars.usda.gov/ba/bhnrc/nd">http://www.ars.usda.gov/ba/bhnrc/nd</a> |
- Valeggia, C. and Ellison, P.T., 2004. Lactational Amenorrhoea in Well-Nourished Toba Women of Formosa, Argentina. *Journal of Biosocial Science*, 36 (5), 573–595.
- Valeggia, C. and Ellison, P.T., 2009. Interactions between metabolic and reproductive functions in the resumption of postpartum fecundity. *American Journal of Human Biology*, 21 (4), 559–66.
- Van Esterik, P., Williams, A., Fewtrell, M.S., Tolboom, J.J.M., Lack, G., and Penagos, M., 2010. Commentaries on Premastication: the second arm of infant and young child feeding for health and survival? By Gretel Peltó, Yuanyuan Zhang & Jean-Pierre Habicht. *Maternal & Child Nutrition*, 6 (1), 19–26.
- Van Poppel, F., Schellekens, J., and Liefbroer, A.C., 2002. Religious differentials in infant and child mortality in Holland, 1855–1912. *Population Studies*, 56 (3), 277–89.
- Vigne, J., 2008. Zooarchaeological Aspects of the Neolithic Diet Transition in the Near East and Europe, and Their Putative Relationships. In: J.-P. Bocquet-Appel and O. Bar-Yosef, eds. *The Neolithic Demographic Transition and its Consequences*. Dordrecht: Springer Science + Business Media B.V., 179–205.
- Vogel, J.C. and van der Merwe, N.J., 1977. Evidence for Early Maize Cultivation in New York State. *American Antiquity*, 42 (2), 238–242.
- Vorbach, C., Capecchi, M.R., and Penninger, J.M., 2006. Evolution of the mammary gland from the innate immune system? *BioEssays* 28 (6), 606–16.
- Walker, A., 2010. Breast milk as the gold standard for protective nutrients. *The Journal of Pediatrics*, 156 (2 Suppl), S3–7.
- Walzem, R.L., Dillard, C.J., and 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.
- Wang, Y., Harvey, C.B., Hollox, E.J., Phillips, A.D., Poulter, M., Clay, P., Walker-Smith, J.A., and Swallow, D.M., 1998. The genetically programmed down-regulation of lactase in children. *Gastroenterology*, 114 (6), 1230–6.
- Warinner, C. and Tuross, N., 2010. Brief communication: tissue isotopic enrichment associated with growth depression in a pig: implications for archaeology and ecology. *American Journal of Physical Anthropology*, 141 (3), 486–93.
- Waters-Rist, A.L., Bazaliiskii, V.I., Weber, A.W., and Katzenberg, M.A., 2011. Infant and child diet in Neolithic hunter-fisher-gatherers from cis-baikal, Siberia: Intra-long bone stable nitrogen and carbon isotope ratios. *American Journal of Physical Anthropology*, 146 (2), 225–41.
- White, C.D. and Schwarcz, H.P., 1994. Temporal Trends in Stable Isotopes for Nubian Mummy Tissues. *American Journal of Physical Anthropology*, 93, 165–187.
- Whittle, A., 1996. *Europe in the Neolithic: The Creation of New Worlds*. Cambridge: Cambridge University Press.
- Williams, J.S., White, C.D., and Longstaffe, F.J., 2005. Trophic level and macronutrient shift effects associated with the weaning process in the Postclassic Maya. *American Journal of Physical Anthropology*, 128 (4), 781–90.
- Winterhalder, B. and Leslie, P., 2002. Risk-sensitive fertility The variance compensation hypothesis. *Evolution and Human Behavior*, 23 (1), 59–82.
- Wood, J.W., Milner, G.R., Harpending, H.C., and Weiss, K.M., 1992. The Osteological Paradox: Problems of Inferring Prehistoric Health from Skeletal Samples. *Current Anthropology*, 33 (4), 343–370.

- World Health Organization, 2001. *Iron Deficiency Anaemia: Assessment, Prevention, and Control. A guide for programme managers*. Geneva: World Health Organization (WHO).
- World Health Organization Multicentre Growth Reference Study Group, 2006. *WHO Child Growth Standards: Length/height-for-age, weight-for-age, weight-for-length, weight-for-height and body mass index-for-age: Methods and development*. Geneva: World health Organization (WHO).
- World Health Organization Task Force on Methods for the Natural Regulation of Fertility, 1998. The World Health Organization multinational study of breastfeeding and lactational amenorrhea. II. Factors associated with the length of amenorrhea. *Fertility and Sterility*, 70 (3), 461–471.
- World Health Organization and UNICEF, 2003. Global strategy for infant and young child feeding. *Forum of Nutrition*, 56, 236–8.
- Wright, L.E. and Schwarcz, H.P., 1998. Stable carbon and oxygen isotopes in human tooth enamel: identifying breastfeeding and weaning in prehistory. *American Journal of Physical Anthropology*, 106 (1), 1–18.
- Wright, L.E. and Schwarcz, H.P., 1999. Correspondence Between Stable Carbon, Oxygen and Nitrogen Isotopes in Human Tooth Enamel and Dentine: Infant Diets at Kaminaljuyú. *Journal of Archaeological Science*, 26 (9), 1159–1170.
- Yovsi, R.D. and Keller, H., 2003. Breastfeeding: An Adaptive Process. *Ethos*, 31 (2), 147–171.
- Zeder, M.A., 2008. Domestication and early agriculture in the Mediterranean Basin: Origins, diffusion, and impact. *Proceedings of the National Academy of Sciences of the United States of America*, 105 (33), 11597–604.
- Zeder, M.A., 2011. The Origins of Agriculture in the Near East. *Current Anthropology*, 52 (S4), S221–S235.
- Ziegler, D.S., Russell, S.J., Rozenberg, G., James, C.A., Trahair, T.N., and O'Brien, T.A., 2005. Goats' milk quackery. *Journal of Paediatrics and Child Health*, 41 (11), 569–71.
- Ziegler, E.E., 2011. Consumption of cow's milk as a cause of iron deficiency in infants and toddlers. *Nutrition Reviews*, 69 Suppl 1, S37–42.
- Zilhão, J., 2001. Radiocarbon evidence for maritime pioneer colonization at the origins of farming in west Mediterranean Europe. *Proceedings of the National Academy of Sciences of the United States of America*, 98 (24), 14180–5.
- Zvelebil, M. and Rowley-Conwy, P., 1984. Transition to farming in Northern Europe: A hunter-gatherer perspective. *Norwegian Archaeological Review*, 17 (2), 104–128.