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BOYD ORR MEMORIAL LECTURE

Milk and the newborn animal

By ELSIE M. WIDDOWSON, *Department of Medicine, Level* 5, *Addenbrooke's Hospital, Hills Road, Cambridge CB2 2QQ*

Five years ago, a symposium on milk—its present and future role in nutrition—was held at the Hannah Research Institute and during the course of it Angus Thomson gave the Fourth Boyd Orr Lecture on 'Problems and Politics in Nutritional Surveillance' (Thomson, 1978). He spoke from first-hand experience of working with Orr, which I cannot do; I did not even know him personally although I heard him speak on a number of occasions. It was Orr who organized the conference held at the Royal Institution in 1941, which was the beginning of our Nutrition Society, and he was our first President (Copping, 1978).

Now we have another symposium on milk, 'Milk Composition and its Manipulation', and another Boyd Orr Lecture. As far as I know, Orr was never concerned with milk and the newborn animal although the importance of milk to the neonate must have been obvious to him. What was not so obvious in the 1920s was the value of cow's milk for older children. At that time, as now, there was great over-production of milk and the problem was one of what to do with the surplus, particularly unwanted skimmed milk, for the butter industry took care of much of the cream. Orr, who was fully aware of the poverty and malnutrition of children in the slums of Glasgow and other large cities, had the idea that some of the surplus milk could be well used in improving the nutrition of these children. He obtained a grant of £5000 from the Empire Marketing Board to enable him to look into this (Kay, 1972). Corry Mann (1926) had already completed his study at a Dr Barnado's home in which he showed that children grew more rapidly in weight and height when they received 1 pint of milk per day, in addition to their normal rations, than when they received isoenergetic supplements of butter, sugar or margarine. In 1928 the results of Orr's first study at schools in seven Scottish towns and cities and in Belfast were published (Orr, 1928). Some of the children received $\frac{3}{4}$ to $1\frac{1}{4}$ pints, according to their age, of whole milk on each of the five school days per week, others had the same amount of separated milk and a third

group had biscuits equivalent in energy value to the separated milk. This was continued for seven months and it was found that the children having both kinds of milk grew a little faster in height and weight than those having the biscuits or no supplement. The children drinking the milk gained, on average, 0·21 inches and 0·52 lbs per month compared with 0·17 inches and 0·42 lbs for those not having milk. These are small differences, and in those days no statistical analyses were made. This did not matter to Orr, however, who, convinced by his own results, those of the 1928 study and those of other studies in the 1930s all purporting to show the high nutritive value of milk for school children, also convinced the authorities. It was as a result of these studies that the 'milk in schools' scheme was introduced which continued for about 40 years. This reminds me of another great man, Sir Frederick Gowland Hopkins, who made some experiments in 1906, also indicating the special value of milk, this time for rats fed on a synthetic diet. His paper (Hopkins, 1912) like that of Orr (1928) would not have stood up to criticism by present day editors of the *British Journal of Nutrition* and, in fact, nobody could repeat his experiment because the treatment of the rats was incorrectly described (Widdowson, 1983). However, it was this rather unconvincing experiment that led Hopkins to postulate that milk contained substances essential for the growth and health of the animals over and above the protein, fat, carbohydrate and minerals contained in the basal diet. We all know what tremendous nutritional consequences have stemmed from that far-sighted conclusion. It is interesting that Orr found it difficult to accept the existence of accessory food factors—he thought the remedying of mineral deficiencies would explain Hopkins' results. Consequently, approximately 16 years after Hopkins had first stated that, 'No animal can live upon a mixture of pure protein, fat and carbohydrate, and even when the necessary inorganic material is carefully supplied the animal still cannot flourish' (Hopkins, 1906), and after much more evidence had accumulated, Hopkins paid a special visit to Aberdeen in 1922 to try to convince Orr of the truth of the existence of these substances. He evidently succeeded and, in return, conceded that the incorporation of balanced supplements of minerals in the food given to farm animals was also very important (Kay, 1972).

Although cow's milk is undoubtedly a nutritious food for older children, particularly those living on a poor and inadequate diet, it is not an absolute necessity and, indeed, man is the only species known to be able to digest milk completely after weaning although, even in the human species, digestion of lactose sometimes fails. For young infants and animals, however, milk is essential, and they all depend on this one food for their survival.

In 1961 Sir Kenneth Blaxter reviewed the subject of lactation and growth of the young (Blaxter, 1961). I do not propose to go over the ground he covered but rather to discuss observations that have been made about milk and the newborn animal during the past 20 years, and to deal particularly with the events taking place during the first few days after birth when the digestive tract has to take over the function on which the whole well-being of an individual depends. Much is known about the way in which the digestive tract grows and develops before birth

from the great deal of detailed morphological work which has been done on the development of the digestive tract of the human fetus (Trier & Moxey, 1979). However, these studies stop before the stage in which I am particularly interested, that is the response of the gastrointestinal tract to its first real test, when it has to deal with the colostrum that reaches it, sometimes within minutes after the animal is born. The intestine functions in a small way before birth in that it absorbs water and dissolved substances from the swallowed amniotic fluid, and this may be important to its development. Colostrum and milk, however, are very different from amniotic fluid, containing as they do nutrients never before encountered—milk proteins, fat and lactose, all of which require considerably more processing than water.

The development of the digestive tract in response to the first feeding

In order to study the development of the digestive tract in response to the first feed after birth, I chose piglets as experimental animals. Their intestines are easier to handle than those of newborn rats, and pigs, having large litters, can have their young divided among several experimental groups. The stage of development at birth is somewhat similar to that of man, although the rate of growth is much faster, and piglets begin to feed directly after birth; in fact the first piglets are often feeding before the last has been born. We used thirty-eight piglets from eight litters, all weighing over 1 kg at birth, and the members of each litter were divided into four groups. One or two members of each litter were killed at birth before taking any milk. A second group of one or two piglets were removed before they had fed, and were given 20 ml of water by stomach tube every 4 h for 24 h. This meant spending the night with the piglets, but we were quite used to that. The remaining piglets of the litter were put back with the sow after they had been weighed and allowed to suckle normally. One or two were killed after 24 h, along with those that had received only water, and the remainder were killed after 10 d. Table 1 shows the mean weights of the animals in the four groups, at birth and at the time of killing (Widdowson *et al.* 1976). The mean weights were satisfactorily similar at birth. The suckled piglets gained over 100 g in weight during the first 24 h; those unfed but receiving water lost a little. However, the gain per 24 h was considerably greater between days 2 and 9 (279 g) than it was during the first 24 h (107 g).

Table 1. *Body-weights of pigs (g)*

(Each group contained from eight to thirteen animals)

When killed . . .	At birth	24 h unfed	24 h suckled	10 d suckled
Wt at birth, unfed	1215	1242	1249	1221
Wt after death, corrected for GI contents	1204	1142	1345	3828
Wt gain per 24 h	—	—	107	279

GI, gastrointestinal.

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Table 2. *Weights of separate parts of digestive tract (g)*

When killed . . .	At birth	24 h unfed	24 h suckled	10 d suckled
Stomach				
Wt	4·75	4·76	6·09	16·2
Wt gain per 24 h	—	—	1·34	1·11
Duodenum				
Wt	0·85	0·76	1·20	4·03
Wt gain per 24 h	—	—	0·36	0·31
Jejunum				
Wt	13·1	12·4	22·3	52·1
Wt gain per 24 h	—	—	9·2	3·3
Ileum				
Wt	13·7	10·9	21·0	56·6
Wt gain per 24 h	—	—	7·3	4·0
Large intestine				
Wt	6·0	5·7	8·6	203
Wt gain per 24 h	—	—	2·6	2·5

When the animals had been killed, the whole digestive tract was dissected out, the length of the small intestine measured and the whole gut carefully emptied. Table 2 shows the weights of the separate parts of the digestive tract. The stomach increased in weight by 28% during the first 24 h and 23% per 24 h over the next 9 d. By day 10 the stomach weighed 3·5 times its weight at birth. The duodenum also grew very rapidly, gaining 42% of its weight at birth during the first 24 h. It continued to grow quickly, more rapidly than the stomach, and gained 36% of its weight at birth per d during the following 9 d; its weight at day 10 was approximately five times its weight at birth. The jejunum grew even more rapidly, particularly during the first 24 h when it increased in weight by 70%, the rate of growth then slowing down to 25% of the weight at birth for each 24 h so that the weight at day 10 was approximately four times the weight at birth. The response of the ileum to the first food was similar to that of the jejunum, a very rapid gain in weight during the first 24 h followed by a slower gain for the next 9 d so that, like the jejunum, the weight at day 10 was four times the weight at birth. The large intestine also grew rapidly but at a steady rate over the first 10 d. All parts of the intestine grew in length as well as in weight. Table 3 shows the mean values for the jejunum, which added 22% to its length in 24 h, and for the ileum which increased in length by 24%.

Table 3. *Lengths of jejunum and ileum (m)*

When killed . . .	At birth	24 h unfed	24 h suckled	10 d suckled
Jejunum				
Length	1·74	1·75	2·13	3·20
Gain in length per 24 h	—	—	0·39	0·12
Ileum				
Length	1·74	1·79	2·15	3·05
Gain in length per 24 h	—	—	0·41	0·10

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Table 4. *Weight of jejunal mucosa and of protein contained in the jejunal mucosa*

When killed . . .	At birth	24 h unfed	24 h suckled	10 d suckled
Wt of mucosa (g)	7·6	6·6	14·2	16·1
Wt gain per 24 h (g)	—	—	6·6	0·2
Protein in mucosa (mg)	802	806	2197	1937
Protein gain per 24 h (mg)	—	—	1395	—

Thus, all parts of the digestive tract responded to food by growing much more rapidly than the body as a whole, and the growth of the jejunum and ileum are particularly remarkable. We separated the jejunal mucosa from the muscle and found that, although both parts grew, the mucosa gained weight more rapidly so that it doubled in 24 h (Table 4). We analysed the mucosa for nitrogen and found that this, and hence protein, more than doubled during this short period of time. The amount of DNA in the whole jejunal mucosa also increased from 46·4 mg at birth, to 65·2 mg after 24 h, but this increase was proportionally less than that of the protein.

We did not examine the intestine histologically, so I cannot say whether there was any increase in the number of villi or whether all the growth was brought about by the lengthening of villi already present at birth. We did, however, look at the secretion of mucus from the goblet cells (Stoddart & Widdowson, 1976). At birth the piglet has goblet cells in each part of its small intestine, some of which are ready to discharge and some of which are immature. The mature goblet cells discharged their mucin in response to food during the first 24 h and a new generation of cells developed. This process was much more active in the duodenum and ileum than it was in the jejunum, and it did not take place in piglets that were given water instead of colostrum.

The pancreas of the piglets increased in weight more rapidly than any other organ in response to colostrum. There was a rapid incorporation of protein but no significant change in DNA. The magnitude of the change in protein—an increase of over 60% in 24 h—suggests that it was the acini of the serous cells that were growing so fast in response to food, although the endocrine pancreas may also have participated. We made no measurements of the tryptic activity of pancreatic secretion during that time.

I first presented these results at a Ross Symposium in the USA in 1976 (Widdowson, 1976). Dr Heird from New York was there and he was inspired to make a similar study on another species—the dog—and he used beagle puppies. He found, as we had done, a rapid increase in weight of the intestinal mucosa of suckled puppies during the first 24 h and an increase in its contents of protein and DNA (Heird & Hansen, 1977). Drs Heird and Hansen fed some of their puppies on an artificial bitch milk, presumably based on cow's milk. These puppies gained as much body-weight as those that were suckled, but there was no appreciable growth of the intestinal mucosa. This led the authors to suggest that colostrum contains a growth factor specific for intestinal mucosa.

Klagsbrun (1978) and Tapper *et al.* (1979) have followed up this idea and have shown that human colostrum and, to a much smaller extent, later milk, contains a polypeptide which stimulates DNA synthesis and induces cell division in cells grown in culture. This substance is resistant to breakdown at pH 1 and therefore probably reaches the intestine intact where, the authors postulate, it exerts its activity. They believe that it exists in the colostrum of species other than man.

Aynsley-Green (1983) has further added to our knowledge about the development of the intestine by studying the endocrine responses to feeding in the human infant. He and his colleagues have evidence that the presence of colostrum or milk in the intestine triggers the release of peptide hormones from the gut, pancreas and pituitary gland which initiate developmental changes in the structure and function of the intestinal tract and in the exocrine and endocrine pancreas. Enteroglucagon appears to be the hormone concerned with the growth of the intestinal mucosa. Giving milk causes a rise in the concentration of this hormone in the blood whereas dextrose solution has no effect. Whether or not it is the polypeptide identified by Klagsbrun (1978) in colostrum that stimulates the hormone response described by Aynsley-Green (1983), we do not know. This seems to be an obvious line of research for animal physiologists to develop.

The immunoglobulins in colostrum

Colostrum has other important properties besides that of stimulating the growth of the intestinal mucosa. The greatest difference between colostrum and mature milk is found in protein, and the concentration of protein falls very rapidly (Fig. 1). Much of the protein in early colostrum is present as soluble whey proteins, of which the major part is immunoglobulins. In some species, for example man, immunoglobulin A (IgA) predominates; in others, for example the ruminants and

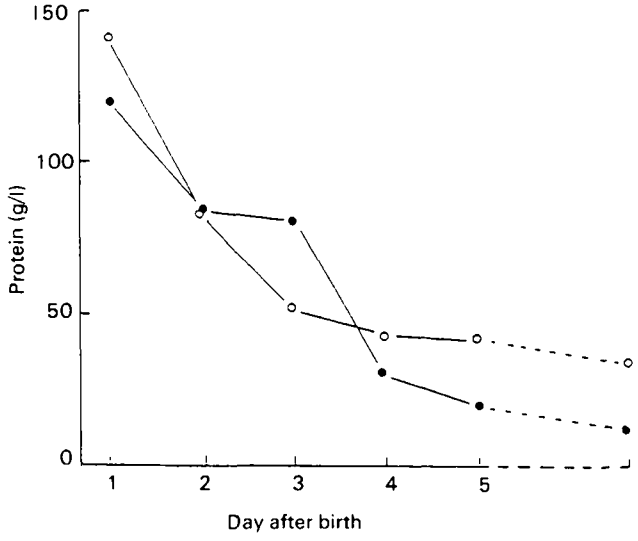

Fig. 1. Concentration of protein in colostrum and milk. (○), Cow; (●), human; (———), days 1–5 after birth; (– – – –), mature milk.

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the pig, immunoglobulin G (IgG) forms the largest part. This is linked with the permeability of the intestine to macromolecules at the time of birth. Before birth, the intestine of all species is permeable to macromolecules which are absorbed by pinocytosis. At the time of birth, the barrier to protein uptake in the intestine is not completely mature in any species studied, but it is more fully developed in some species than in others. In some species, for example man, the maternal IgG, which provides the newborn with passive systemic immunity, has been transferred to the fetus from the maternal circulation before birth, and the intestine of the full term, newborn infant is relatively impermeable to protein. In other species, for example ruminants, horse and pig, IgG is not transferred to the fetus before birth; the colostrum contains these antibodies and the intestine is permeable to them, so that they are absorbed and, within 2 or 3 d, their concentration in the serum of the neonate reaches adult levels. Then the intestinal tract 'closes', preventing further passage of proteins. Rodents are different again, receiving part of their passive immunity from intra-uterine transport of maternal antibodies and part from selective intestinal uptake of IgG after birth. This continues for 20 d, the interesting thing being that the process is selective—the IgG being absorbed but no other whey proteins such as albumen (Walker, 1979). Exactly what causes 'closure' is not known. Giving colostrum for a specific time for each species will cause it; so also will stress, and injection of cortisol into rats brings about premature closure (Kretchmer, 1983).

I mentioned that the major protein in human colostrum is immunoglobulin A and not G, as in these other species. The first colostrum to be secreted contains approximately 120 g IgA/l (McClelland *et al.* 1978). By day 5 this has fallen to 5 g/l and, in mature milk, the concentration of IgA is about 1 g/l. IgA acts in the intestine and limits the multiplication of bacterial and viral antigens within the digestive tract. At least three-quarters of the IgA in the colostrum is excreted as protein in the faeces. Human colostrum, and to a smaller extent later milk, contains other substances important for the infant; for example, lactoferrin which binds iron and makes it unavailable to *Escherichia coli* in the intestine and inhibits bacterial growth. Colostrum contains other nutrient-binder proteins, for example, vitamin B_{12} and folate for binding zinc, which are thought to act in a similar way to lactoferrin. These binder proteins are present in the colostrum of pigs and ruminants, and in these species also act in the gut, binding the micro-nutrients and thus making them unavailable to bacteria (Ford, 1974).

The question naturally arises of how both IgA and IgG, in colostrum, manage to escape digestion? I can find very little in the literature about this but several suggestions have been put forward (N. Kretchmer, personal communication). First, human colostrum has been reported to contain a trypsin inhibitor (Tapper *et al.* 1979). Second, the immunoglobulins are glycoproteins and the carbohydrate may form a protective shell around the protein molecule. The third and most likely possibility seems to be that, in these proteins, the amino acid sequence is such that the peptide bonds, at which pepsin, trypsin and chymotrypsin are able to act, are not present. Some proteins in colostrum must be broken down in the intestine and

Table 5. *Protein in organs and muscles of newborn piglets (mg)*

When killed . . .	At birth	24 h unfed	24 h suckled
Quadriceps muscle	863	840	1120
Gastrocnemius muscle	510	457	590
Kidneys	653	768	953
Liver	2702	2536	4161
Heart	959	991	1144
Lungs	1848	1765	2393
Spleen	135	122	163
Pancreas	141	161	230

the amino acids used for growth for, even during the first 24 h after birth, the internal organs and skeletal muscles of the suckled pigs grew, and the amount of protein in them increased (Widdowson & Crabb, 1976) (Table 5). This was true of all parts of the body studied, skeletal muscles, kidneys, liver, heart, lungs and spleen as well as the pancreas and intestinal muscle.

Development of lipase (EC *3.1.1.3*) *and lactase*

Much work has been done on the development of other digestive enzymes. It has been known for many years that the activity of pancreatic lipase is low in the neonatal period, and how young infants could break down the large amounts of fat in colostrum and milk was puzzling to some of us. This was first studied in calves (Ramsey *et al.* 1956). Ruminants only need to digest fat for a short period of their lives for, after weaning, they eat very little fat. An active lipase—pregastric esterase—was found to be secreted by the glands lying beneath the tongue. Its activity was shown to be high in young calves, declining sharply when the animals were weaned and being greatly enhanced by sucking. In the early 1970s, Margit Hamosh, working at Georgetown University, extended the observation to other species and showed that, in both the newborn rat and human infant, lingual serous glands (von Ebner's glands) secrete a potent lipase that hydrolyses triglycerides to di- or monoglycerides, glycerol and free fatty acids (Hamosh, 1979). As in calves, sucking facilitates secretion and the enzyme is swallowed with the milk and acts in the stomach. It is independent of bile salts and has a low pH optimum. There is some secretion of the enzyme before birth, but activity rises very rapidly in response to food and this is undoubtedly the most important lipase in the neonatal period. There is yet another lipase, however, which seems peculiar to primates, including man (Freudenberg, 1953; Hall, 1983). It is contained in human milk, and bile salts are essential for its activity. Infant formulas do not contain this lipase.

As far as the carbohydrate fraction of milk is concerned, lactose is present to a greater or lesser extent in the milk of all species examined, except that of the sea-lion, and there is lactase activity in the small intestine of the newborn of all species examined, except that of the sea-lion (Kretchmer & Sunshine, 1967). Lactase activity falls very rapidly at weaning in all species except man and, even in some ethnic groups of the human species, lactase activity declines between 2 and

5 years of age. Caucasians, and other ethnic groups that have persistent lactase activity in their intestines continuing into adult life, are the exception rather than the rule and if, as Ugolev *et al.* (1979) have suggested, it is stress caused by separation from the mother that causes the suppression of lactase secretion in animals, it may be that we owe our ability to digest lactose to the continued care and protection given to us by our mothers throughout childhood. This, however, is only a flight of fancy, and the difference between human ethnic groups, who can and who cannot digest lactose after infancy, is generally supposed to be genetic in origin. In the guinea-pig, which starts being weaned as soon as it is born, intestinal lactase activity is highest before birth, falling from the time of birth. This brings me to my final point about enzymes. It has been reported that the activity of digestive enzymes tends to fall just after birth in a number of species. The conventional method of expression of enzymes measured in the intestinal mucosa is as so-called 'specific activity', that is, activity per unit weight protein. However, when mucosal protein is increasing as rapidly as it was in the piglets and puppies during the first 24 h after birth (see p. 91), this method of expression is quite misleading (Table 6). When lactase activity was expressed per mg protein, the value for the piglets fell from 347 to 208 units but, in fact, the total lactase activity of the jejunal mucosa rose from 240 to 443 units. Heird & Hansen (1977) made a similar observation on their puppies.

Table 6. *Effect of feeding on the activity of lactase* (EC *3.2.1.23*) *in the jejunal mucosa*

	Activity (units/g protein)	Total activity units
At birth	347	290
24 h unfed	301	246
24 h suckled	208	443
10 d suckled	146	287

The integration of food, growth and renal function in the neonatal period

In the 1950s we devoted a great deal of attention to the 'immaturity' of the kidneys of newborn infants and animals. Although the kidneys, like the digestive tract, function to a certain extent before birth, the maternal circulation is primarily responsible for the removal of waste products, as it is for the nutrition of the fetus. Directly after birth, the kidneys need to be able to take over the responsibility of maintaining the volume and composition of the body fluids. This they seem able to do provided that the food consists of colostrum and milk of their own species. Young babies and animals, however, have low urea clearances and glomerular filtration rates when compared with adults, whether comparisons are made on the basis of surface area or body-weight. An adult has to excrete in the urine almost as much nitrogen as he ingests in his food. A young baby or animal does not. This is illustrated in Table 7, which shows the N balances of young infants, piglets and puppies fed on their mother's milk soon after birth (McCance & Widdowson, 1956,

Table 7. *Nitrogen balances of newborn infants, piglets and puppies (mg/kg per 24 h)*

	Infants	Piglets	Puppies
N intake	397	3500	2500
N in faeces	67	negligible	negligible
N absorbed	330	3500	2500
N in urine	117	350	246
N retained	213	3150	2254

1958; Slater, 1961). First, note the much higher N intakes of piglets and puppies than of human infants per kg body-weight. This is in line with their more rapid growth. Second, note that 90% of the N in the food of the piglets and puppies were retained and only 10% required to be excreted by the kidneys. In the case of the human infants, the retention was 50% and urinary excretion was equivalent to 30% of the intake. The considerable faecal excretion of N by human infants is partly IgA. The immature kidneys are perfectly capable of excreting the necessary small amounts of N as urea and other breakdown products of N metabolism, and there is little or no rise in the blood urea. Some of the N retained by the piglet and puppy is, of course, IgG. We showed many years ago that the suckled newborn piglet absorbed 2·5 g globulin/kg body-weight during the first 24 h after birth, which would account for 400 mg or 13% of the total N retained (McCance & Widdowson, 1959).

Food and growth during suckling, and the feeding of one species with the milk of another

We all know that the young of different species grow at very different rates and that the milks of different species are of very different compositions. Investigators have from time to time tried to relate the rate of growth to the composition of the milk. At the end of the last century, Bunge (1898) related the growth of the young to the percentage of protein in mother's milk. Powers (1933) reconsidered this idea and preferred to consider protein in terms of the percentage of energy it provided. Both these ideas are too simple, for the amount of milk taken as well as its composition must clearly be considered. In 1964 we made an attempt to include both milk composition and total milk intake (and hence the intake of protein and energy) in our calculations (McCance & Widdowson, 1964). We considered four species, rat, pig, calf and human, and we calculated the energy and protein intakes while the young of these four species were doubling their birth weights. Table 8 shows some of the results of our calculations. Irrespective of the composition of the milks, the energy and protein required to produce 1 g gain in weight was directly related to the rate of growth. This is because, the slower the growth, the greater the proportion of the energy intake which must be spent on maintenance. Since the protein is derived from the same food as the energy, their relationship is fixed and, in spite of the fact that human milk has only about one-eighth the percentage

Table 8. *Energy and protein intakes per g gain in weight while birth weight is doubling*

	Rat	Pig	Calf	Man
Time taken to double birth wt (d)	5	7	60	180
Energy intake per g wt gain:				
kJ	12·6	19·3	44·4	136·0
kcal	3·0	4·6	10·6	32·5
Protein intake per g wt gain (g)	0·15	0·28	0·48	0·54

protein of rat milk, the human infant takes in 3–4 times as much protein for each g weight gain. Payne & Wheeler (1968) used a more mathematical approach in their attempt to relate rate of growth to protein intake. They concluded that growth is a function of the total protein intake in the milk. I suggest, however, that no simple relationship will ever be found between milk composition (or even nutrient intake) and gain in weight, for two main reasons. First, it is characteristic of the suckling period that the proportion of fat in the body increases, the magnitude of the increase varying from species to species. More energy is required to lay down a given weight of fat than the same weight of lean. Second, there is a wide variation in maturity at birth between species and in the way of life of suckling animals. Some, often called altricial, are born in a relatively undeveloped, helpless state. They are usually born and reared in a nest and are entirely dependent on the mother for warmth, food and care, including disposal of urine and faeces. Mice, rats, kittens and puppies come into this category. At the other extreme are the precocious young of the guinea-pig and foal, for example, which can walk and run directly after birth and are responsible for their own thermal stability. Thus, when we consider postnatal development, each species has a different starting point, a different environment and a different way of life. The altricial young are usually born in large litters and they tend to feed from the mother almost continuously. There are exceptions, however, for rabbits feed only once in 24 h and tree shrews only once in 48 h. They have to take in sufficient food in a few minutes to last them until feeding time comes round again. The stomach enlarges rapidly—in the rabbit increasing in weight by 2·5 times in 3 d (Davies *et al.* 1964)—and it acts as a reservoir, gradually passing material through the pylorus into the small intestine. Most species fall between these extremes, feeding intermittently several times during each 24 h. The human infant and young of other primates, ruminants, pig and horse feed in this way. All these considerations have to be taken into account when we feed one species with the milk of another. It is clearly much more difficult technically to rear young animals that would normally feed continuously than those that naturally feed at intervals. Olav Oftedal, nutritionist at Washington Zoo, has given much thought to this and has emphasized the importance for young animals of reproducing the method of feeding as well as ensuring milk to be as similar in composition as possible to that of their mothers. We try to do this when we feed infants with formulas based on cow's milk to replace human milk. When it comes

to rearing the young of other species, however, information is sadly lacking. Of the 4300 species of mammals, the milks of only 176 have been analysed for protein, fat and carbohydrate and, of these analyses, the figures for only forty-eight species are considered to be reliable (Oftedal, 1980). Even with the limited information we have, however, it is evident that animals belonging to the same order generally have milks of similar composition. This is illustrated in Table 9. Rodents and carnivores have milks high in protein and containing moderately large amounts of fat and carbohydrate. The rabbit and tree shrew, not related zoologically, but feeding their young at long intervals, both have milks high in fat and energy; this may be related to the fact that their young have to get their food and energy in a very short time. The ruminants have less protein and fat in their milk and a little more carbohydrate. Equidae are characterized by producing a low-protein milk, high in carbohydrate with very little fat and a low energy value. The milk of primates is similar to that of equidae in protein and carbohydrate but contains more fat, while the milk of sea mammals is virtually devoid of lactose, is high in protein and contains a very high percentage of fat. This high percentage of fat may again be related to the fact that the young of mammals such as whales and dolphins, which feed at sea, have to get their meal in a few seconds so that they can surface for air. The young bottle-nose dolphin, for example, has to surface every 30 s. Young seals feed on the shore, but they lay down a great deal of fat during

Table 9. *Composition of milk per kg fresh milk*

Order (suborder)	Species	Protein (g)	Fat (g)	Lactose (g)	Gross energy* (kJ)	Gross energy* (kcal)
Rodentia	Mouse	90	131	30	7699	1840
	Rat	81	88	38	5941	1420
Carnivora	Cat	106	108	37	7280	1740
	Dog	75	95	38	6067	1450
	Wolf	92	96	34	6443	1540
Lagomorpha	Rabbit	103	152	18	8619	2060
Insectivora	Tree shrew	85	170	20	8912	2130
Artiodactyla	Cow	32	37	46	2971	710
(*Ruminantia*)	Goat	29	38	47	2929	700
	Giraffe	40	38	49	3598	860
(*Suidae*)	Pig	56	83	50	5356	1280
	Peccary	54	35	65	3724	890
Perissodactyla	Horse	19	13	69	2092	500
	Donkey	19	6	61	1674	400
	Rhinoceros	14	2	66	1506	360
Cetacea	Dolphin	68	330	11	14560	3480
	Blue whale	109	423	13	19163	4580
Marine *carnivora*	Seal	102	494	1	21548	5150
Primates	Rhesus monkey	16	40	70	3096	740
	Baboon	15	46	77	3431	820
	Chimpanzee	12	37	70	2887	690
	Man	11	42	70	3054	730

*Factors used for calculating gross energy (kcal/g): protein 5·65, fat 9·25, lactose 3·95.

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suckling, and the high energy value of seal milk may be necessary for this. So far so good; but we know nothing about the mineral and vitamin make-ups of the majority of these milks and these may be as important as the energy-providing constituents. We found ourselves in difficulties once when, having insufficient supplies of sow's milk to feed by stomach tube to our newborn piglets, we gave them evaporated cow's milk (McCance & Widdowson, 1957). This contained more sodium than the piglet's kidneys could excrete with the amount of water available, and they all became oedematous. Moreover, there are peculiarities about milks of particular species which may or may not be important to them—for example, the fat in rabbit's milk is rich in medium-chain triglycerides (Glass *et al.* 1967), the main fatty acid in elephant milk is capric acid (McCullagh *et al.* 1969), and cat's milk contains relatively large amounts of the free amino acid, taurine (Rassin *et al.* 1978). Kittens and cats cannot synthesize taurine and they need it for the conjugation of bile acids since the acids cannot conjugate with glycine (Knopf *et al.* 1978). If taurine is deficient in the food, conjugation of bile salts has preference and, since taurine is also necessary for the development of the nervous tissue, retinal degeneration occurs and the animals become blind. Cow's milk is particularly low in taurine. Those trying to rear the young of animals on preparations based on cow's milk face these and many other problems which those involved in feeding the human infant have, generally speaking, solved. I think we can say with certainty that colostrum is of vital importance to those species that depend on it for their supply of IgG. Those that have received their IgG before birth benefit from IgA in colostrum, but it is not essential for their survival.

And so we come back to Lord Boyd Orr. He gave milk of another species to boys and girls who were far older than the natural age of milk consumption. Fortunately for him they were Caucasian children who still had lactase activity in their intestines; their kidneys were fully mature and able to excrete the N and minerals not required for the slow rate of growth at that time, and the nutrients in the milk must have made up for the lack of a nutrient in the children's diets. Orr made no suggestion as to what this may have been—I think it could have been calcium.

REFERENCES

Aynsley-Green, A. (1983). *Journal of Pediatric Gastroenterology and Nutrition* **2**, 418–427.
Blaxter, K. L. (1961). In *Milk: The Mammary Gland and its Secretion*, vol. 1, pp. 305–361 [S. K. Kon and A. T. Cowrie, editors]. New York: Academic Press.
Bunge, G. (1898). *Lehrbuch der Physiologischen Chemie*, 4th ed. Leipzig.
Copping, A. M. (1978). *Proceedings of the Nutrition Society* **37**, 105–139.
Corry Mann, H. C. (1926). *Diets for Boys During the School Age*. Special Report Series, Medical Research Council, no. 105. London: HM Stationery Office.
Davies, J. S., Widdowson, E. M. & McCance, R. A. (1964). *British Journal of Nutrition* **18**, 385–392.
Ford, J. E. (1974). *British Journal of Nutrition* **31**, 243–257.
Freudenberg, E. (1953). *Die Frauen-Milch Lipase*. Basel: Karger.
Glass, R. L., Troolin, H. A. & Jenness, R. (1967). *Comparative Biochemistry and Physiology* **22**, 415–425.
Hall, B. (1983). Lipid biochemistry of human milk. PhD Thesis, University of London.

Hamosh, M. (1979). In *Development of Mammalian Absorptive Processes*, pp. 69–92. Ciba Foundation Symposium 70 (NS). Amsterdam: Excerpta Medica.
Heird, W. C. & Hansen, I. H. (1977). *Pediatric Research* **11**, 406.
Hopkins, F. G. (1906). *Analyst* **31**, 395–404.
Hopkins, F. G. (1912). *Journal of Physiology* **44**, 425–460.
Kay, H. D. (1972). *Biographical Memoirs of Fellows of the Royal Society* **18**, 43–81.
Klagsbrun, M. (1978). *Proceedings of the National Academy of Sciences of the USA* **75**, 5057–5061.
Knopf, K., Sturman, J. A., Armstrong, M. & Hayes, K. C. (1978). *Journal of Nutrition* **108**, 773–778.
Kretchmer, N. (1983). In *Introduction of Food to Infants: Why, When, Which?* (In the Press.)
Kretchmer, N. & Sunshine, P. (1967). *Gastroenterology* **53**, 123–129.
McCance, R. A. & Widdowson, E. M. (1956). *Journal of Physiology* **133**, 373–384.
McCance, R. A. & Widdowson, E. M. (1957). *Acta Paediatrica* **46**, 337–353.
McCance, R. A. & Widdowson, E. M. (1958). *Journal of Physiology* **141**, 81–87.
McCance, R. A. & Widdowson, E. M. (1959). *Journal of Physiology* **145**, 547–550.
McCance, R. A. & Widdowson, E. M. (1964). In *Mammalian Protein Metabolism*, vol. 2, pp. 225–245 [H. N. Munro and J. B. Allison, editors]. New York: Academic Press.
McClelland, D. B. L., McGrath, J. & Samson, R. R. (1978). *Acta Paediatrica Scandinavica*, Supplement 271.
McCullagh, K. G., Lincoln, H. G. & Southgate, D. A. T. (1969). *Nature* **222**, 493–494.
Oftedal, O. (1980). In *The Nutrition of Captive Wild Animals*, pp. 67–83 [E. R. Maschgan, M. E. Allen and L. E. Fisher, editors]. First Annual Dr Scholl Nutrition Conference.
Orr, J. B. (1928). *Lancet* **i**, 202–203.
Payne, P. R. & Wheeler, E. F. (1968). *Proceedings of the Nutrition Society* **27**, 129–138.
Powers, G. F. (1933). *Journal of Pediatrics* **3**, 201–216.
Ramsey, H. A., Wise, G. H. & Tove, S. B. (1956). *Journal of Dairy Science* **39**, 1312–1322.
Rassin, D. K., Sturman, J. A. & Gaull, G. E. (1978). *Early Human Development* **2**, 1–13.
Slater, J. E. (1961). *British Journal of Nutrition* **15**, 83–97.
Stoddart, R. W. & Widdowson, E. M. (1976). *Biology of the Neonate* **29**, 18–27.
Tapper, D., Klagsbrun, M. & Neumann, J. (1979). *Journal of Pediatric Surgery* **14**, 803–807.
Thomson, A. M. (1978). *Proceedings of the Nutrition Society* **37**, 317–332.
Trier, J. S. & Moxey, P. C. (1979). In *Development of Mammalian Absorptive Processes*, pp. 3–20. Ciba Foundation Symposium 70 (NS). Amsterdam: Excerpta Medica.
Ugolev, A. M., De Laey, P., Iezuitova, N. N., Rakhimov, K. R., Timofeeva, N. M. & Stepanova, A. T. (1979). In *Development of Mammalian Absorptive Processes*, pp. 221–246. Ciba Foundation Symposium 70 (NS). Amsterdam: Excerpta Medica.
Walker, W. A. (1979). In *Development of Mammalian Absorptive Processes*, pp. 201–216. Ciba Foundation Symposium 70 (NS). Amsterdam: Excerpta Medica.
Widdowson, E. M. (1976). In *Gastrointestinal Development and Neonatal Nutrition*. Report of 72nd Ross Conference on Pediatric Research, pp. 14–19 [P. Sunshine, editor]. Columbus, Ohio: Ross Laboratories.
Widdowson, E. M. (1983). In *Nutrition in the 20th Century. Current Concepts in Nutrition* [M. Winick, editor]. New York: J. Wiley & Sons. (In the Press.)
Widdowson, E. M., Colombo, V. E. & Artavanis, C. A. (1976). *Biology of the Neonate* **28**, 272–281.
Widdowson, E. M. & Crabb, D. E. (1976). *Biology of the Neonate* **28**, 261–271.

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