Medical History, 1993, **37:** 225-249.

"HUMANIZING" MILK: THE FORMULATION OF ARTIFICIAL FEEDS FOR INFANTS (1850–1910)

by

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INTRODUCTION

By the middle of the nineteenth century, rates of infant mortality and morbidity in the industrial towns of Britain were a cause of increasing official concern. An article entitled 'The murder of the innocents' in the *Lancet* of 3 April 1858, encapsulated the problem and its perceived solution. Mortality rates among young children in London, Manchester, Leeds and Birmingham were reported as 40.2 to 55.4 per cent, double the rate in country districts. It was among the urban poor that mortality was highest; and poor diet was generally considered the main culprit.

> Meat, potatoes, often gin; scanty nourishment drawn from breasts whose secretive power cannot eliminate milk from a half-starved frame, and the unwholesome diluted milk of unhealthy badly-fed cows; such is the nourishment afforded to thousands of children on this day of an enlightened age, in this capital city of a civilized country where we 'count the gray barbarian lower than the Christian child!'.[1]

The article's anonymous author was dismissive of the role of wet nurses ("the mother who cannot or will not suckle her own offspring has no right to endanger the life of the child of another"), but confident that the solution lay in ensuring supplies of pure cows' milk and sound advice on its use in infant feeding. An "association of ladies" in Brighton had shown the way: "poor mothers are supplied gratuitously with feeding bottles, and with each one are given sensible counsels and warnings as to child-feeding which cannot fail to impress".[2]

The social context of such deprivation was not described, perhaps because its familiarity rendered any explanation superfluous. There can be little doubt, however, that infant mortality was highly correlated with working mothers' early return to employment following confinement, the consequent abandonment of breastfeeding and its substitution by far less suitable practices. For example, in evidence given to the 1833 Factory Commission, it was reported that some married cotton operatives returned to work as soon

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The study was supported by a Royal Society History of Science research grant. I am grateful to the librarians at the Wellcome Institute for the History of Medicine, The Royal Society of Medicine, and the Agricultural and Food Research Council Institute for Food Research, Reading, for their assistance and use of facilities; to Dr W. H. Brock, Prof. W. F. Bynum and two anonymous referees for helpful comments on the draft manuscript; and to Messrs L. M. Silvester and C. Royle for preparing the figures.

[1] Anonymous (Medical Annotations), 'The murder of the innocents', *Lancet*, 1858, **i**: 345–6.
[2] Ibid.

as nine days after confinement, and most within a fortnight.[3] In Lancashire, the usual practice was for a mother to leave her baby in the care of a "nurse" throughout the working day, delivering it on the way to the mill at, perhaps, 5.30 a.m. and collecting it in the evening. The fact that these women often took in several babies at a time, combined their child-minding role with that of local washerwoman, and, when absent from the house, frequently deputed the task of infant care to a pre-adolescent girl, can hardly have ensured an acceptable standard of childcare. While some mothers took milk for the baby to the nurse daily, most left her to purchase it out of her weekly payment. The temptation to economize on this expensive item must have been difficult to resist, and more often than not infants were fed a pap made of bread and water sweetened with sugar, or other farinaceous foods, such as oatmeal and sago.[4]

It is clear that pressures of economic necessity on working women were largely responsible for the abandonment of breastfeeding; but it was widely believed that women at the other end of the social scale were similarly affected, although from a different cause. According to Spargo, "for some subtle reason this function of maternity [lactation] is being atrophied in modern woman; and the higher their civilisation, the less able they are to suckle their infants".[5] It is thus not surprising that medical science should have been harnessed to the task of providing a suitable substitute for breastmilk. The chemists and medical scientists of the day accepted the challenge with apparent relish, even though, with hindsight, their understanding of the issues was seriously flawed.

The history of infant feeding has been surveyed by several authors.[6] For the most part, these accounts concentrate on socio-economic aspects. The major studies of Fildes[7] and Apple[8] deal with infant feeding up to 1800, and with the period 1890–1950 in the USA, respectively. By contrast, this paper examines the way in which developments in the chemical analysis of milk, and in nutritional and biochemical theory, influenced the formulation of artificial feeds for infants; and draws, in the main, on medical and scientific literature up to 1910. Reference sources cited are chiefly textbooks, monographs and review articles, as well as mothercare manuals written by paediatricians; the perspective is essentially Anglocentric. While such publications frequently made reference to research findings, they acted as filters and buffers to change, and are thus likely to have reflected the progressive development of medical scientific opinion. However, the extent to which these scientific ideas were put into practice remains largely unknown.

COMPOSITIONAL ANALYSIS OF MILK

The superiority of breastfeeding over other forms of infant feeding has been stressed repeatedly by medical practitioners throughout recorded history; despite this, attempts to

[3] M. Hewitt, *Wives and mothers in Victorian industry*, London, Rockliffe, 1958, pp. 126–7.

[4] Ibid., pp. 137–8.

[5] J. Spargo, *The common sense of the milk question*, New York, Macmillan, 1910, p. 17.

[6] Among the most useful are: D. Forsyth, 'The history of infant feeding from Elizabethan times', *Proc. roy. Soc. Med.*, 1910, **4**: 110–41; I. G. Wickes, 'A history of infant feeding', *Archs dis. Childh.*, 1953, **28**: 151–8, 232–40, 332–40, 416–22, 495–502; T. E. Cone, *Two hundred years of infant feeding in America*, Columbus, Ross Laboratories, 1976; V. A. Fildes, *Breasts, bottles and babies*, Edinburgh University Press, 1985; R. D. Apple, *Mothers and medicine: a social history of infant feeding 1890–1950*, Madison, University of Wisconsin Press, 1987.

[7] Fildes, op. cit., see note 6 above.

[8] Apple, op. cit., see note 6 above.

devise breastmilk substitutes have an almost equally long history.[9] The strength of medical opinion has, however, influenced ideas on artificial feeding, so that the objective has been to modify animal milks in such a way that they correspond as closely as possible to the composition of human milk. Clearly, the starting point of such modification ("humanizing"[10]) of milk was, and still is, accurate chemical analysis of the milks of women and of suitable domesticated animals.

According to Cone, J. F. Simon (1807–1843) of Berlin, "was the first to perform accurate milk analyses and his studies may be considered the first real landmark in the exact science of infant metabolism as a basis for rational infant nutrition".[11] This claim is highly questionable because when Simon published his *Animal chemistry* (1842), which incorporated the analyses of milk reported in his 1838 doctoral thesis *De lactis muliebris ratione chemica et physiologica*, he cited, and criticized, results of earlier workers which are now known to be far more accurate than his own.[12]

Simon's analysis of human milk, based on a large number of measurements, showed a protein content of 3.43 g/100 g of milk and a sugar content of 4.82 g/100 g milk,[13] figures which were not dissimilar to those of C. A. Meggenhofen (1826),[14] viz. 3.01 and 5.87 g/100 g, respectively. By contrast, A. Chevallier and O. Henri, and L'Héritier published data showing much lower protein concentrations (1.52 and 1.17 g/100 g, respectively) and higher sugar concentrations (6.50 and 7.40 g/100 g, respectively).[15] However, any suggestion that the differences were related to Franco-German rivalry seems questionable, in that, in 1853, Vernois and Becquerel published results[16] very similar to those of Simon.

The analytical techniques employed generally consisted of gravimetric assays involving evaporation of milk samples to dryness to determine water content; extraction of fats from the residue with ether; precipitation of proteins (often designated "casein", "albuminoids" or "proteids"); and precipitation of milk sugar (later designated "lactose").

Simon criticized Chevallier and Henri's results because "they obtained much too small a quantity of casein . . . (since this constituent is only imperfectly precipitated by acetic acid) . . . and too large a quantity of sugar, which was . . . made to include all the destructible components, with the exception of casein and fat." In Simon's own method, following fat extraction with boiling sulphuric acid, the resuspended residue, evaporated to the consistuency of a thin syrup, was treated with ten to twelve times its volume of alcohol, which precipitated the casein.[17] However, the claim that human milk contained similar amounts of sugar and protein (and, indeed, amounts similar to those in cows'

[9] Fildes, op. cit., note 6 above.

[10] "Humanized milk" was a term sometimes applied specifically to certain pasteurized, partially predigested milk preparations. More generally, it was used to describe various preparations of cows' milk which had been modified to simulate the composition of human breastmilk (see W. G. Thompson, *Practical dietetics*, New York, Appleton, 1903, p. 85). It is in the latter sense that the term is used in this paper.

[11] Cone, op. cit., note 6 above, p. 21.

[12] J. F. Simon, *Animal chemistry: with reference to the physiology and pathology of man* [published in German in 1842], transl. G. E. Day, London, Sydenham Society, 1846, vol. 2, pp. 42–60.

[13] Ibid.

[14] See A. Wynter-Blyth, *Foods: their composition and analysis*, London, Charles Griffin, 1896, pp. 255–6.

[15] Reported by Simon, op. cit., note 12 above.

[16] Vernois and A. Becquerel, 'Extrait d'un Mémoire sur la composition du lait', *Comptes rendus de l'Académie des Sciences, Paris*, 1853, **36**: 187–91.

[17] Simon, op. cit., note 12 above, pp. 44–53.

milk[18]) appears to have contradicted not only the reports from French laboratories but also the conventional wisdom: witness the entry under 'Milk' in the third edition of the *Encyclopaedia Britannica*: "The milks of women, mares and asses, agree very much in their qualities . . . containing much saccharine matter", and, later: "women's milk, in its healthy state, contains no coagulable, mucilaginous or cheesy principle in its composition: or it contains so little that it cannot admit of any sensible proof".[19]

The compositional analyses of Simon and other chemists were challenged in the 1880s by A. V. Meigs, in the United States. Arthur Vincent Meigs (1850–1912), of the Pennsylvania Children's Hospital, was the son of J. F. Meigs and grandson of C. D. Meigs, both prominent paediatricians who had proposed methods of modifying milk for infant feeding.[20] In a paper entitled 'Proof that human milk contains only about one per cent protein,'[21] Meigs attributed earlier results to methodological deficiencies. Mean data were given as 1.046 per cent for casein and 7.407 per cent for sugar, demonstrating Meigs' remarkable faith in the precision of his analytical methods. He claimed that his own analytical procedure had several advantages, viz. the technique for fat extraction was more accurate than that of extracting it from a solid residue; and the separation of casein and sugar by simply dissolving the sugar in water and allowing the casein to sediment obviated the necessity for filtration, a process he considered the source of much error.[22] Meigs believed the latter problem accounted for the erroneous results of Vernois and Becquerel.[23] Simon's procedure he dismissed as follows:

> The fallacy of this method is caused by the fact that the milk-sugar is entirely insoluble in absolute alcohol as it becomes dilute, and further, because, as Simon himself says, if a concentrated solution of milk-sugar in water is treated with alcohol, a precipitation of sugar is caused. This fact renders it impossible to know, if the method of Simon is pursued, when all the sugar is removed from the precipitated casein.[24]

There is certainly a strong case for explaining Simon's results in terms of poor methodology. But this seems most unlikely to account for subsequent reports. Indeed, the diplomacy Meigs adopted in attributing inaccurate analyses to methodological causes occasionally gave way to an almost explicit accusation of dishonesty, for example:

> The weight of testimony that cows' milk contains much more casein than human milk, is so great that it is astonishing how almost universally the analyses of human milk of

[18] For example see G. H. Lewes' revision of: J. F. W. Johnston, *The chemistry of common life*, vol. 1, Edinburgh and London, Blackwood, 1859, p. 133. However, it is interesting to note that markedly different compositions of cows' and human milk (derived from Henri and Chevallier, see note 15 above) are cited in J. F. W. Johnston, *Agricultural chemistry*, New York, Moore, 1859, p. 534, which was published after Johnston's death.

[19] Article on 'Milk', *Encyclopaedia Britannica*, 3rd ed., 1797, vol. 12, pp. 17–23.

[20] A. Levinson, *Pioneers of pediatrics*, New York, Froben, 1943, pp. 97–102.

[21] A. V. Meigs, 'Proof that human milk contains only about one per cent casein: with remarks on infant feeding', *Archs Pediat.*, 1884, **1**: 216–41.

[22] *Idem, Milk analysis and infant feeding*, Philadelphia, Blakiston, 1885, pp. 49–60.

[23] Vernois and Becquerel, op. cit., note 16 above.

[24] Meigs, op. cit., note 22 above.

> Vernois & Becquerel, and of those who have arrived at like conclusions, have been accepted and given credence, in despite of the fact that the evidence of the senses of every one who has examined into the matter is diametrically opposed to such an acceptance.[25]

There are, indeed, serious grounds for questioning the "methodological explanation". Thus, Meigs employed a table to illustrate the pronounced variation evident in thirteen published reports of casein and sugar in human milk;[26] but when the same data are arranged chronologically with others, as in Figure 1, the apparently random variation is revealed as a progressive change over time. Whereas before 1845 and after 1885 the values recorded for nutrient concentrations in milk were unrelated to the date of reporting, during that period, both the protein and sugar concentrations reported were clearly significantly correlated, negatively and positively, respectively, with the date. The values reported by Meigs are essentially the same as those which are currently accepted.

There would thus seem to be a strong case in support of the thesis that it was allegiance to Simonian norms, and/or the closely similar data of Vernois and Becquerel, which inhibited publication of representative data on human milk composition. It was generally accepted that milk composition is subject to wide variations;[27] and this may well have led to a judicious selectivity in the quotation of results. According to this claim, at first, only results conforming to Simon's results were reported; but with time, as casein and milk-sugar data seemed to be consistently lower and higher, respectively, chemists gained the confidence to cite figures which diverged more widely from these norms. The alternative explanation, that analytical technique deteriorated uniformly and rapidly in the 1840s and then showed a steady improvement over several decades, hardly seems plausible. In any case, results published for cows' milk composition have shown very little variation from the 1840s until the present day.[28]

Meigs might appear to have had a similarly influential role following 1885, inducing virtually complete conformity in published research data (Figure 1). But this is questionable in view of the sustained trends in reported data between 1845 and 1880 (Figure 1). The latter point is illustrated by comparison of data on milk composition quoted in the 1859 and 1880 editions of Johnston's popular work *The chemistry of common life*.[29] In the former, casein and sugar concentrations were cited as 3.9 per cent and 4.5 per cent, respectively (from Vernois and Becquerel[30]); in the latter, *before* Meigs' publication, the values cited were 1.3 per cent and 6.7 per cent, respectively.

SPECIES-SPECIFICITY OF MILK CONSTITUENTS

Attempts to humanize animal (chiefly cows') milk depend on knowledge of far more than simple quantitative differences in the major milk constituents: qualitative differences

[25] Ibid., p. 64.

[26] Ibid., p. 40.

[27] Simon, op. cit., note 12 above.

[28] "So far as I have been able to learn, there has at no time been any disagreement among chemists in regard to the components of cow's milk results for which for all practical purposes may be taken as identical, having been reached by all". A. V. Meigs, 'The artificial feeding of infants', *Archs Pediat.*, 1889, **6**: 832–48.

[29] J. F. W. Johnston, *The chemistry of common life*, revised by G. H. Lewes, op. cit., note 18 above, p. 133; new ed., revised by A. W. Church, 1880, p. 101.

[30] Vernois and Becquerel, op. cit., note 16 above.

https://doi.org/10.1017/S0025727300058439 Published online by Cambridge University Press

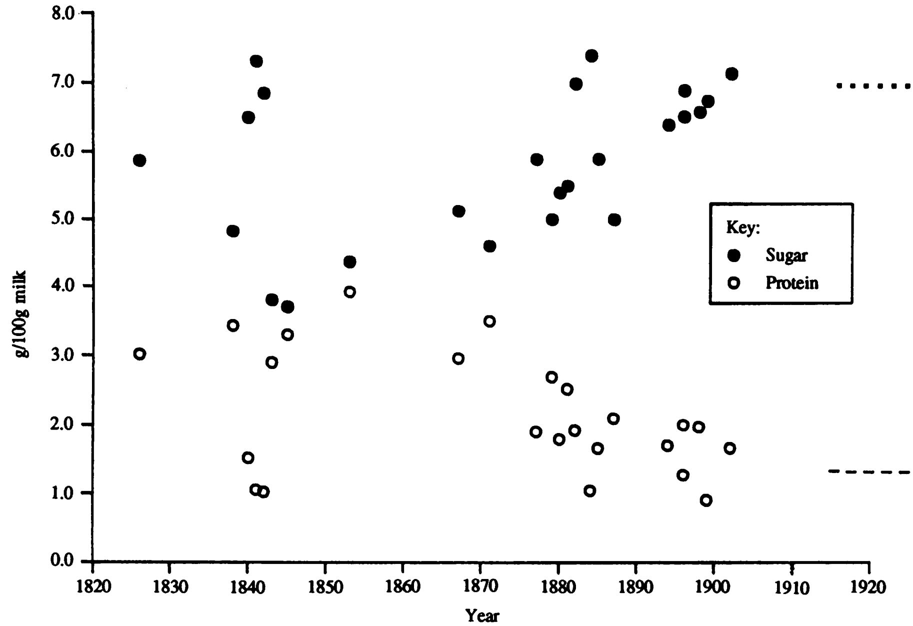

Figure 1: Reported values for milk protein and milk sugar in human milk, 1826–1902. Milk compositional data and sources of information are listed chronologically: [values reported are for milk protein and sugar, respectively, in g/100g]. Where necessary to establish all relevant information, more than one information source is quoted. Data included comprise all, and only, original reports for which reliable documentation has been obtained. Horizontal lines show currently accepted values for lactose (milk sugar) [▪▪▪▪▪▪] and milk protein [- - - - - -]; see note 123.

1826: Meggenhofen [3.01; 5.87] (cited by Wynter-Blyth, see note 14, p. 255).
1838: Simon [3.43; 4.82] (mean of values cited by Simon, see note 12).
1840: Chevallier and Henri [1.52; 6.50] (cited by Simon, see note 12).
1841: Quévenne [1.05; 7.31] (cited by Meigs, see note 22, pp. 40, 97).
1842: L'Héritier [1.02; 6.85] (cited by Halliburton in E. A. Schäfer (ed.), *Textbook of physiology*, Edinburgh, Pentland, 1898, p. 128).
1843: Haidlen [2.9; 3.8] (see note 104).
1845: Clemm [3.3; 3.7] (cited by Simon, see note 12, p. 51).
1853: Vernois and Becquerel [3.92; 4.36] (see note 16).
1867: Tidy [2.96; 5.13] (cited by Schäfer, op. cit., p. 127).
1871: Tidy [3.5; 4.6] (cited by Meigs, see note 22, pp. 40, 97).
1877: Christenn [1.9; 5.9] (cited by Schäfer, op. cit., p. 128).
1879: Frankland [2.7; 5.0] (cited by Halliburton, see note 55, p. 577; Rothschild, see note 121, second supplement, 1901, p. 83).
1880: Gerber [1.79; 5.4] (cited by Halliburton in Schäfer, op. cit., p. 128; Rothschild, see note 121, p. 421).
1881: Mendus de Leon [2.53; 5.5] (cited by Halliburton in Schäfer, op. cit., p. 128).
1882: Dolan and Wood [1.92; 7.0] (cited by Meigs, see note 22, pp. 40, 57).
1884: Meigs [1.04; 7.40] (see note 22, p. 34).
1885: Pfeiffer [1.66; 5.9] (cited by Halliburton in Schäfer, op. cit., p. 128; Rothschild, see note 121, p. 130).
1887: Munk and Uffelmann [2.1; 5.0] (cited by Lane-Claypon, see note 46, pp. 8, 28).
1894: Lehmann [1.7; 6.4] (cited by S. D. Morrison, *Human milk*, Farnham Royal, Commonwealth Agricultural Bureau, 1952, p. 89; Richmond, see note 42, p. 324).
1896: Camerer and Soldner [1.27; 6.52] (cited by Lane-Claypon, see note 46, pp. 27).
1896: Chittenden [2.0; 6.9] (cited by R. Hutchinson, *Food and the principles of dietetics*, London, Arnold, 1916, p. 462).
1898: Carter and Richmond [1.97; 6.59] (see Richmond, note 40, p. 324).
1899: Heubner [0.9; 6.75] (cited by Hutchinson, op. cit., p. 449).
1902: Schlossmann [1.66; 7.14] (cited by Lane-Claypon, see note 46, pp. 9, 29).

may be more important. A prime example is the differences between the proteins in bovine and human milk.

Liebig, in *Animal chemistry* (1842) claimed: "milk contains only one nitrogenous constituent, known under the name of caseine",[31] an assertion which implied the presence of a single protein in the milks of all species. Moreover, according to Liebig, casein was not confined to milk, for "the chief constituent of the seeds of the leguminosae agrees in all its properties and behaviour with the caseine of milk. Hence [is] derived the name . . . vegetable caseine".[32] Such an identity of vegetable and animal protein (and analogous relationships were thought to apply to albumin and fibrin), which in retrospect can be attributed to the imprecision of Liebig's analytical technique, formed the basis of his nutritional theory. The following encapsulates his views with respect to protein.

> How admirably simple, after we have acquired a knowledge of this relation between plants and animals, appears to us the process of formation of the animal body, the origin of its blood and its organs! The vegetable substances, which serve for the production of blood, contain already the chief constituent of blood, ready formed with all its elements.[33]

However, the implications of Liebig's assertion appeared to contradict long-standing beliefs about the nature of milk from different species. From at least the late eighteenth century, it had been appreciated that while cows' milk produced a tough mass of curd when coagulated, human milk yielded a much smaller amount of flocculent precipitate.[34] Consequently, a debate was initiated in the mid-nineteenth century over whether these differences in coagulability were due to real inter-species differences in the (molecular) nature of milk proteins, in the relative concentrations of milk proteins, or in the presence of other substances in milk.

Like the question of inter-species differences in concentrations, the debate over inter-species differences in the nature of milk protein was a protracted affair. Biedert (1874) was adamant that pure casein was physically and chemically distinct in human and cows' milk;[35] and over the subsequent decade this view was corroborated by several lines of evidence.[36] Meigs, however, remained sceptical, citing with approval the earlier claim of Lehmann that the jelly-like coagula of women's milk were more dependent on the alkaline state of the fluid than on any peculiarity in the protein.[37]

An important approach to explaining inter-species differences in the coagulability of milk was the attempt to characterize different milk proteins. After 1875, the existence of

[31] J. Liebig, *Animal chemistry*, 2nd ed., translated into English by W. Gregory, London, Taylor & Walton, 1843, p. 51.

[32] *Idem, Familiar letters on chemistry*, 4th ed., transl. J. Blyth, London, Walton & Maberly, 1859, p. 376.

[33] Ibid., p. 375.

[34] *Encyclopaedia Britannica*, op. cit., note 19 above.

[35] P. Biedert, 'Neue Untersuchungen und klinische Beobachtungen über Menschen- und Kuhmilch als Kindernahrungsmittel', *Archiv für pathologische Anatomie und Physiologie und für klinische Medizin*, 1874, **60**: 352–79.

[36] A. Sheridan Lea, *The chemical basis of the animal body*, London, Macmillan, 1892, pp. 23–4.

[37] Meigs, op. cit., note 22 above; C. G. Lehmann, *Physiological chemistry*, 2nd ed., transl. G. E. Day, 3 vols, London, Cavendish Society, 1851-54, vol. 1, p. 378.

several distinct milk albuminoids (proteins) was claimed, as a result of effects of treating milk with various reagents.[38] Initially, the claims were poorly founded, since the different precipitates obtained might merely have represented different degrees of precipitation of a single protein. The studies of Hammarsten were, however, to provide much firmer evidence for three proteins, namely casein, lactalbumin and lactoglobulin;[39] while Richmond, the leading British dairy chemist at the turn of the century, suggested that the presence of a fourth, Storch's mucoid, had also been established.[40] For example, casein was precipitated by saturating the solution with sodium chloride, magnesium sulphate and ammonium sulphate; while lactoglobulin was soluble in a saturated solution of sodium chloride, but precipitated by magnesium and ammonium sulphates.[41]

Thus, by the 1890s, the generic term "casein", signifying the totality of milk protein, had been supplanted by a more precise terminology, in which casein was but one of four proteins occurring in milk. This "new" casein was classed as a "nucleoalbumin", i.e. "a compound of nuclein and a proteid".[42] It has been pointed out that this claim led the eminent microscopist, Heidenhain, to report that the cells of the mammary gland possessed two nuclei, one of which underwent degradation (chromatolysis), the released nuclein combining with blood serum albumin to form casein.[43] Subsequent microscopical studies did not confirm this observation, which was thus a notable casualty of the "theory-dependence" of observation.

The new understanding of the nature of milk proteins was reflected by 1897 in quantitative comparisons of the different proteins in cows' and human milk. But while there was wide agreement that in cows' milk the casein concentration far exceeded that of albumin, reports of the "casein:albumin" ratio in human milk varied from 0.42 to 4.2.[44] Still (1909) quoted, without comment, values of 3.25 per cent casein and 0.75 per cent albumin in cows' milk; and 0.6 per cent and 1.4 per cent, respectively, in human milk,[45] but, well after the end of the period of this study, the precise percentages for human milk were a matter of considerable uncertainty.[46]

At the turn of the century, reports of the immunological properties of milk and colostrum were beginning to appear in research papers. Several authors suggested that whey (i.e. non-casein) proteins in milk were identical with proteins in blood, and that their absorption from the gut lumen *post partum* conferred immunity on the neonate.[47]

[38] W. Fleischmann, *The book of the dairy*, transl. C. M. Aikman and R. P. Wright, London, Blackie, 1896, pp. 16–19.

[39] O. Hammarsten, *A textbook of physiological chemistry*, 5th ed., transl. J. A. Mandel, New York, Wiley, 1904, pp. 440–4.

[40] H. D. Richmond, *Dairy chemistry*, London, Charles Griffin, 1899, p. 6.

[41] Ibid., pp. 24–5.

[42] Sheridan Lea, op. cit., note 36 above, p. 89.

[43] For a discussion of this question in two different contexts, see T. B. Mepham, 'The development of ideas on milk protein secretion', *Vlaams Diergeneeskundig Tijdschrift*, 1986, **55**: 228–38; and T. B. Mepham, 'Questions of validity in mammary physiology: methodology and ethics', *Proc. Nutr. Soc.*, 1989, **48**: 1–7.

[44] E. Cautley, *The natural and artificial methods of feeding infants*, London, J. & A. Churchill, 1897, p. 69.

[45] G. F. Still, *Common diseases and disorders of childhood*, London, Oxford University Press, 1909, p. 33.

[46] J. E. Lane-Claypon, *Milk and its hygienic relations*, London, Longmans, Green, 1916, p. 35.

[47] Ibid., pp. 37–42. This assertion was only partly true, as many whey proteins are now known to be milk specific.

However, such findings were mentioned in only very few paediatric textbooks and mothercare manuals of the period.[48]

Differences in the fat present in human and cows' milk received little attention. A. Bouchardat and T. A. Quévenne drew attention to the different sizes of fat globules in the two milks, as early as 1857, but few distinctions were noted during the nineteenth century.[49] Wynter-Blyth summarized the constitution of bovine milk fat as: "essentially an intimate mixture of the fatty acids—palmitic, stearic and oleic—not soluble in water, and also of certain soluble volatile fatty acids, of which butyric is the chief, and caproic, caprylic and capric acids minor constituents."[50] But in the same publication he claimed that women's milk had not been obtained in sufficient quantities for accurate investigation. This is a surprising statement in view of the extensive studies performed on milk proteins, but, certainly, few textbooks made any reference to fat in human milk. Holt (1897) stated only that it was not known to differ in any important respect from that in cows' milk.[51] Cautley claimed that the fat droplets in cows' milk were larger, but Hammarsten asserted the reverse.[52] It was only after 1910 that the significant compositional differences between human and bovine milk fats were appreciated.[53]

The concentration of salts in milk received rather more attention. Simon's analyses indicated that the total salt content of cows' milk was about three times that of breastmilk,[54] and the more extensive studies of G. von Bunge (1874) confirmed this observation and also showed that for individual minerals the disparity was even greater, e.g., five-fold for calcium and four-fold for sodium.[55]

MODIFICATION OF COWS' MILK BEFORE 1890

It would be reasonable to assume that in formulating artificial feeds for infants, paediatricians incorporated, as they became aware of them, new chemical discoveries on the differing compositions of cows' and human milk. However, this was by no means the only strategy employed. Certainly, before the 1850s, milk modification was frequently applied on a "trial and error" basis. Thus, Thomas Bull's (1848) prescription, which he was still advocating in 1862, appears to have had a largely pragmatic foundation:

> Cow's milk in the early weeks [i.e. of the infant's life] is objectionable from the large proportion of casein it contains. If however it is used, for the first ten days one third of cow's milk and two thirds of boiling water are the proportions, sweetening the mixture with a small quantity of loaf sugar, as it is rather deficient in this milk. Then for the next

[48] Among the few authors who referred to the immunological properties of milk were: J. S. Fowler, *Infant feeding*, London, Oxford University Press, 1909, pp. 9–10; and G. F. McCleary, *Infant mortality and infant milk depots*, London, P. S. King, 1905, pp. 34–6.

[49] Cited by Fleischmann, op. cit., note 38 above, p. 24.

[50] Wynter-Blyth, op. cit., note 14 above, p. 239.

[51] L. E. Holt, *The diseases of infancy and childhood*, New York, Appleton, 1897, p. 141.

[52] Cautley, op. cit., note 44 above, p. 137; Hammarsten, op. cit., note 39 above, p. 450.

[53] Apple, op. cit., note 6 above, p. 38.

[54] Simon, op. cit., note 12 above, p. 53.

[55] Bunge's results were reported by W. D. Halliburton, *A text-book of chemical physiology and pathology*, London, Longmans, Green, 1891, p. 587.

https://doi.org/10.1017/S0025727300058439 Published online by Cambridge University Press

four or five months, equal parts of milk and water, and at the expiration of this time, which brings us to about the sixth month, pure milk.[56]

Naphey's advice to mothers in 1870 was in the same vein:

For a child under three months of age, cows' milk should be used as the only food... When of ordinary richness, it is to be diluted with an equal quantity of water or thin barley-water... If green and acrid stools make their appearance, accompanied by emaciation and vomiting, the milk must be more diluted and given less frequently. If the symptoms of indigestion do not yield, milk containing an excess of cream should be used.[57]

Meigs was critical of this approach and urged adoption of the more rational practice of modelling artificial feeds on the genuine article—breastmilk.[58] Their subsequent development may be seen as a progression towards meeting that objective, albeit tempered with a good deal of pragmatism. Meigs recognized that clinical observations had resulted in milk modifications which were, incidentally, scientifically sound, but he felt progress was hampered by placing too much emphasis on them.

All the facts show that the tendency has been constantly toward the truth, and the physicians have been learning empirically for what reasons cows' milk has failed as an infant food, and how the difficulties which its use entailed were to be overcome. The use of cream has been advised; cream and whey; diluted milk; diluted milk with milk sugar; cream, milk, lime-water, and arrow-root water; and finally comes Biedert's cream mixture, and he arrives more nearly at the true solution of the difficulty than any of the others, but still falls wide of the mark, from want of a precise knowledge of the composition of human milk, and of cows' milk and cream.[59]

Based on his own analyses of human and cows' milk, Meigs calculated that the desired composition of an artificial food could be produced by mixing: 5 cc of milk, 10 cc of cream, 10 cc of lime water, 15 cc of water and adding 2.2 g of milk sugar. Lime water served to produce an alkaline reaction in the mixture, the normal condition of human milk. Experience suggested that the mixture satisfied infants' needs better than any recommended previously, but Meigs, like virtually all other paediatricians, cautioned that: "no food has been found, or ever will be found, so good as the nourishment which a healthy mother is able to give her child".[60]

At about the same time in England, W. B. Cheadle at the Great Ormond Street Children's Hospital in London, bemoaning the absence from medical school curricula of any reference to artificial feeding, sought to place the subject on a "scientific basis". He identified six essential conditions to be observed in the diet of infants: (i) the food must

[56] T. Bull, *The maternal management of children*, 3rd ed., London, Longman, Brown, Green, and Longmans, 1848, pp. 45–6; T. Bull, *Hints to mothers*, 14th ed., London, Longman, Green, Longman & Roberts, 1862, p. 295.

[57] G. H. Naphey, *The physical life of woman*, Walthamstow, Mayhew, 1870, p. 230. See also A. Combe, *The management of infancy, physiological and moral*, 9th ed., revised J. Clark, Edinburgh, Maclachan and Stewart, 1860, pp. 147–54.

[58] Meigs, op. cit., note 22 above, p. 61.

[59] Ibid., p. 71.

[60] Ibid., p. 95.

contain the different "elements" [i.e. nutrients, such as proteins] in the same proportions as in human milk; (ii) it must possess the anti-scorbutic element; (iii) the total quantity fed in 24 hours must represent the nutritive value of one to three pints of human milk; (iv) "it must not be purely vegetable, but must contain a large proportion of animal matter"; (v) it must be suited to the digestive capabilities of the infant; (vi) "it must be fresh and sound, free from all taint of sourness or decomposition".[61]

There is little doubt that the compilation of this list was based on clinical experience, rather than derived from scientific theory. Indeed, by selecting the data on human milk composition cited by E. F. von Gorup-Besanez (1867) as the standard, Cheadle betrayed both a lack of knowledge of developments in chemistry over the previous twenty years and an uncritical acceptance of the precision of analytical technique, such that nutrient requirements were specified to an accuracy of 0.001 per cent. Gorup-Besanez, and A. Payen, whose data were also quoted by Cheadle, gave values for protein and sugar in human milk of about 3.5 per cent and 4 per cent, approximately three times and one half, respectively, the values reported by Meigs.

Despite these attempts to apply "scientific principles" in humanizing cows' milk, many babies reacted adversely to the modified milk. According to Cheadle:

> The real difficulty, however, does not lie in the inferior nutritive value of cows' milk and water, although this may retard development at first. It lies in the fact that cows' milk is much less digestible than human milk.[62]

To counter this problem he considered a range of other treatments, viz. (i) peptonized milk; (ii) addition of barley water; (iii) addition of lime water; (iv) addition of bicarbonate of soda; (v) condensed milk; and (vi) boiled cows' milk. Each might have merits for short-term use in particular cases, but he warned of the dangers of longer-term use. For example, peptonization, i.e. predigestion of protein by adding a substance marketed as *"extractum pancreatis"* (usually derived from pigs) "weakens the digestive power of the stomach, which becomes enfeebled by want of exercise of its proper function". Similarly, there were clear objections to excessive use of bicarbonate of soda, even though it yielded a flocculent casein curd, and to condensed milk, which he believed often caused infantile scurvy.[63]

Boiling the milk seemed the most satisfactory solution, since this produced light and digestible curds, and, equally important, it prevented souring. There were, Cheadle admitted, objections. For example, boiling caused some loss of nutritive value; it predisposed babies to constipation; and some babies simply did not like boiled milk. But he dismissed the first objection as insignificant, the second as "easily remedied by addition of a small quantity of carbonate of magnesia to the bottle" and the last as avoidable by using boiled milk "from the first . . . [for babies who] know no other take to it kindly enough".[64] The deciding factor in recommending boiling of milk was, however, the

[61] W. B. Cheadle, *Artificial feeding of infants*, London, Smith, Elder, 1889, pp. 33–5.

[62] Ibid., p. 47.

[63] Cheadle, together with Thomas Barlow, was responsible for describing the condition of "infantile scurvy" and attributing it to deficiency of an essential dietary factor. See J. C. Drummond and A. Wilbraham, *The Englishman's food: five centuries of English diet*, rev. ed., London, Cape, 1957, p. 377.

[64] Cheadle, op. cit., note 61 above, p. 55.

https://doi.org/10.1017/S0025727300058439 Published online by Cambridge University Press

protection it afforded against infection. This would seem to have been crucially important advice because in the nineteenth century milk supplies, particularly those to towns, were recognized as a major route of disease transmission (see below).

THE "PERCENTAGE METHOD"

Following Meigs' advocacy of the need to adopt scientific principles in humanizing cows' milk, major developments were initiated in the United States of America. In her important social history of infant feeding, Apple has provided a detailed account of the evolution of the "percentage method", introduced by T. M. Rotch.[65] A principal motive for this development appears to have been the perceived need to re-assert the authority of the medical profession in the face of the growing popularity of proprietary infant feeds (discussed below), which mothers were able to buy and use without reference to medical advice. As Rotch put it:

> It would hardly seem necessary to suggest that the proper authority for establishing rules for substitute feeding should emanate from the medical profession, and not from non-medical capitalists.[66]

He and his fellow paediatricians thus embarked on a course which seemed to be aimed at proving that infant feeding was far too complicated to be left to amateurs. At the same time, and perhaps for the same reason, emphasis was placed on the variability of breastmilk. For example, the concentrations of its major constituents vary between women, with diet, with stage of lactation, and even during a single nursing period. In the light of such discoveries it seemed only a small step to suggest that breastfeeding was no guarantee that an infant was receiving optimal nourishment. It was this line of reasoning which led Rotch to advocate formulation of feeds which were uniquely suited to each baby's digestive capabilities and stage of development.

Rotch's percentage method was based on the theory that even very slight changes in the relative proportions of fat, protein and sugar in the feed mixture could have important effects on the infant's growth and development. He claimed that instructions for preparing feeds should be written as precisely as drug prescriptions, emphasizing the point by specifying nutrient concentrations to 0.01 per cent. Clearly, such precision was beyond the capabilities not only of kitchen equipment, but of most hospital laboratories as well. Consequently, in 1891, Rotch established the first milk modification laboratory (the Walker-Gordon Laboratory in Boston, Massachusetts), where doctors could send their prescriptions for artificial feeds, which were subsequently delivered directly to customers' homes daily. By 1907, Walker-Gordon laboratories had been established in twenty cities in North America.[67]

In England, humanized milk could be obtained from the milk laboratories of, among others, the Aylesbury Dairy Company, Welford and Sons, the Friern Manor Dairy Farm

[65] Apple, op. cit., note 6 above; T. H. Rotch, *Pediatrics: the hygienic and medical treatment of children*, Philadelphia, Lippincott, 1895.

[66] *Idem*, 'The general principles underlying all good methods of infant feeding', *Boston Med. and Surg. J*, 1893, **129**: 506.

[67] Apple, op. cit., note 6 above, p. 66.

Ltd (whose dairy herd grazed on what is now Peckham Rye, a public park in south London), as well as from branches of the Walker-Gordon Laboratory. The laboratory companies had direct control of the breeding and management of dairy cattle and of the handling of the milk.[68]

Their ability to modify the feeds was facilitated by the centrifugal cream separator, a machine which had been devised for use in butter manufacture,[69] but which also permitted substantial mechanization of the humanization process. Thus, in the process devised by G. Gaertner, equal quantities of milk and sterilized water were poured into a centrifugal separator, which was arranged so that the flow rates of the two outgoing streams (nominally, the "cream" and "skimmed milk" fractions) were equalized.[70] The resulting "Fettmilch" contained 1.5 per cent protein and 3.2 per cent fat; sugar was subsequently added to bring its final concentration to 6.0 per cent. In England, Gaertner's Fettmilch was sold by the Friern Manor Dairy Farm Ltd.

Centrifugal separation had an additional advantage in that it facilitated removal of foreign particulate matter, such as cow manure and hair, which was commonly present in milk. However, a fundamental defect of such preparations was that the "casein:whey protein" ratio in cows' milk persisted at all dilutions. The resulting high casein content was thought to be the cause of the not infrequent cases of indigestibility, and when this occurred, the most usual remedy was predigestion. This consisted of partial or total conversion of casein to more assimilable forms, such as peptones, by incubating the milk with peptogenic enzyme preparations. Cautley described four such procedures.[71] A more elaborate procedure (Frankland's method) involved the complete removal of casein from the milk. This was achieved by precipitation of casein by addition of rennet; straining off the whey; heating the whey to destroy the rennet; and adding cream and sugar to complete the compositional modification.[72]

In Britain, the percentage method was advocated by several leading paediatricians, but the formulations they recommended were usually simpler than those of Rotch. Eric Pritchard was, perhaps, the most enthusiastic supporter of the method:

> The physiological feeding of infants is, or should be, an exact science, and it is to Dr. Rotch that we owe the very ABC, the very terms and the symbology in which this science can be accurately expressed.[73]

Pritchard was opposed to laboratory milk, largely because its expense put it beyond the reach of all but the rich; and the central theme of his book, *The physiological feeding of infants,* was that cows' milk could be suitably and economically modified in the home. His prescriptions for the home-modification of milk were, however, liable to deter any but the

[68] These companies advertised in mothercare books, e.g. those of G. Carpenter, *Chavasse's advice to a mother*, 15th ed., London, Churchill, 1898; and E. Pritchard, *The physiological feeding of infants*, 2nd ed., London, Kimpton, 1904.

[69] Fleischmann, op. cit., note 38 above, pp. 119–53.

[70] Cautley, op. cit., note 44 above, p. 141.

[71] Ibid., pp. 235–8.

[72] I. Burney Yeo, *Food in health and disease*, rev. ed., London, Cassell, 1896, pp. 255–6.

[73] Pritchard, op. cit., note 68 above, p. 10. Another prominent English advocate of the "percentage method" was Ralph Vincent, of the Westminster Infants' Hospital: see R. Vincent, *Lectures on babies*, London, Baillière, Tindall & Cox, 1908, pp. 29–39.

most conscientious mothers: the principal table in the book contained instructions for preparing no fewer than 45 different modified milks, of varying fat, protein and sugar content. The prescriptions were based on the use of cream known to contain 16 per cent fat, and Pritchard proudly announced, "most of the large dairies in London have now adopted my suggestion and will supply to order cream which accurately contains 16 per cent of fat".[74]

However, the majority of mothers, who were without access to such sources of supply, had to resort to other strategies. Chapin advocated the use of "top milk",[75] on the principle that if milk was allowed to stand for six to eight hours in a tall vessel until the cream rose, a definite distribution of fat throughout the different strata of the milk took place. Thus, by collecting measured quantities from the upper layer, or siphoning off the lower part, creams of any desired composition could be obtained. This method suffered from the disadvantage that the initial fat content of the bulked milk had to be assumed, although in practice it could be quite variable, and that there was increasing danger of microbial contamination as milk was left to stand for long periods.

The percentage method dominated paediatric thinking in the United States up to 1910, if not beyond. L. Emmett Holt was, perhaps, Rotch's staunchest supporter, extending the percentage method to ever more complex elaboration. His theories were expounded in *The care and feeding of children: a catechism for the use of mothers and children's nurses*, which was first published in 1894[76] and, in its subsequent editions, remained the standard work on infant feeding for decades. The percentage method did not, however, receive universal acclaim. For example, Jacobi (who was largely responsible for establishing paediatrics in the United States[77]) was scathingly critical.[78] In England, the method was far less common and it was regarded with scepticism by several leading paediatricians. G. E. Still, of the Great Ormond Street Hospital, declared: "There is nothing new in 'percentage feeding'", while Eustace Smith, of the East London Children's Hospital, considered that "the practice offers little advantage over the more homely rule-of-thumb methods prevailing in this country."[79]

By the turn of the century there was, in any event, a growing scepticism about the scientific basis of the percentage method; the fact that formulas could be prescribed accurately was no guarantee that they were applied appropriately. Thus Richmond calculated ratios which characterized the energy value of milk, the "anabolic ratios" (the energy values of fat: sugar: protein) and a, more complex, "metabolic ratio". For human milk, the anabolic ratios were: "2.5: 4.5: 1.0" and the metabolic ratio "11.3", whereas the corresponding figures for cows' milk were: "1.15: 1.4: 1.0" and "5.54", respectively.[80] Some claimed that lack of appreciation of these ratios often led to overfeeding of fat.[81] That the percentage method constituted, in reality, a large-scale experimental trial, in

[74] Pritchard, op. cit., note 68 above, p. 41.
[75] H. D. Chapin, *The theory and practice of infant feeding*, New York, William Wood, 1902.
[76] L. E. Holt, *The care and feeding of children*, New York, Appleton, 1894.
[77] A. Levinson, op. cit., note 20 above, pp. 102–3.
[78] A. Jacobi, in L. G. Straus, *Disease in milk: the remedy pasteurization*, New York, Dutton, 1917, pp. 15–18.
[79] Still, op. cit., note 45 above, p. 31; E. Smith, *On the wasting diseases of infants and children*, 6th ed., London, Churchill, 1899, pp. 41–2.
[80] Richmond, op. cit., note 40 above, pp. 355–6.
[81] J. Brennemann, 'Nutritional disorders in infancy due to overfeeding', *J. Am. med. Ass.*, 1907, **48**: 1344.

which the indications for use were largely pragmatic, came to be openly admitted. As J. S. Fowler, an Edinburgh paediatrician, put it in 1909:

> There is, I think, no doubt that the success percentage feeding has attained is due, not so much to any fidelity with which it imitates human milk, as to the power it places in the hands of the physician of exactly regulating the dosage of the various milk constituents. Percentage feeding as practised today seems to proceed on experimental lines.[82]

In 1915, a leading American authority wrote:

> From the very beginning, physicians had no end of trouble with percentage feeding, in a large proportion of their patients . . . These experiences led to a desire to vary the percentage plan according to the individual . . . Holt refers to one ambitious author with 579 formulas, a vivid commentary on the riot of mathematics inherent in the consequential study of Rotch's method.[83]

THE ROLE OF INFANT MILK DEPOTS

If milk laboratories catered for the rich, and babycare manuals describing methods of home-modification of milk for the middle classes, provision for working-class mothers was made largely through municipal milk depots. The infant milk depots, which were established in several large towns in Britain, were modelled on the well-baby clinics *(consultations de nourrissons* and *gouttes de lait)* which sprang up throughout France in the 1890s, and the milk depots founded by Nathan Straus in the United States, the first of which was established in New York in 1893.[84]

Paediatricians were almost unanimous in insisting on the superiority of breastmilk over all forms of artificial feeding, and many clinics adopted the promotion of breastfeeding as a primary objective. But when this proved impossible, the clinics ensured supplies of cows' milk which was, at the least, free from microbial contamination. Thus, Budin in Paris, claimed: "I do my utmost to encourage breastfeeding . . . but where [it] alone is manifestly impractical I prescribe a variable quantity of sterilized milk".[85] Budin advocated, largely because of its practical simplicity, the use of undiluted cows' milk, which was to be fed in small quantities at a time. He claimed a high level of success with such feeds, as assessed by low infant morbidity and mortality rates and satisfactory growth rates.

L. Dufour, who pioneered the *gouttes de lait* in the French provinces, adopted a simple scheme of milk modification, which entailed dilution of milk with one third of its bulk of water, and addition to one litre of this mixture of 15 to 20 g of fresh cream (produced by centrifugal separation), 35 g lactose and 1.0 g sodium chloride. The modified milk was sterilized by heating at 102 °C for 45 minutes.[86] Similar procedures were adopted at the Straus depots in New York.[87]

[82] Fowler, op. cit., note 48 above, p. 114.
[83] F. L. Wachenheim, *Infant feeding*, Philadelphia, Lea & Febiger, 1915, p. 134.
[84] For a recent account of these establishments, see D. Dwork, *War is good for babies and other young children*, London, Tavistock, 1987, pp. 93–123.
[85] P. Budin, *The nursling*, transl. W. J. Maloney, London, Caxton, 1907, p. 147.
[86] Ibid., pp. 154–5.
[87] Straus, op. cit., note 78 above, pp. 75–9.

In England, the first infant milk depot opened at St Helens in 1899; and by 1904, there were others in several English and Scottish towns. McCleary provided an account of the aims and achievements of these institutions, and a detailed description of the Battersea milk depot, which he established in 1902.[88] Here the quality of the milk supply was controlled by a number of strictly observed conditions: e.g., only milk from certified tuberculin-free herds was used; the milk composition had to fall within prescribed concentration limits; milk had to be supplied in sealed churns; and cows were subject to periodic veterinary inspection. In all, 16 such conditions were specified.

Although McCleary acknowledged that Rotch had placed infant feeding on a scientific basis and that "the weight of opinion in this country [with respect to milk modification] appears to be with the American rather than the French physicians",[89] milk modification performed at the Battersea depot seems to have owed as much to the pragmatism of Bull, over 50 years earlier,[90] as to the percentage method. Thus, milk was diluted 1:2 with water for the first two months of age; 1:1 up to four months; 2:1 up to six months; and was supplied as whole milk for infants over six months. Cream and sugar were added to the modified milk to bring the fat and sugar concentrations to 3.2 per cent and 6 per cent respectively. The "humanized milk" supplied at the St Helens depot was prepared according to an even more rule-of-thumb method, namely dilution of cows' milk by one-third, followed by addition to each gallon of two ounces each of cream and sugar and a "small amount of salt".[91]

HEAT TREATMENT OF MILK

It is probable that, in the period up to 1910, measures introduced to control the microbiological quality of milk were considerably more important than modifications of its composition. Of milk delivered to houses in large towns, Carpenter complained in 1898:

> It is swarming with germs, and not only germs, but particles of manure, hair, dirt, hay, and so forth, and often contains Boracic Acid or Salicylic Acid, added by the dealer to *preserve* it. There is, further, the ever-possible invisible added danger that the milk may be contaminated by scarlet fever, typhoid fever, diphtheria, and by tubercule (consumption) germs, not to mention many others.[92]

Not surprisingly, the safety and quality of milk supplies were matters of considerable concern in the late nineteenth century,[93] which led to the introduction of several Acts of Parliament designed to improve the hygienic standards of milk production and

[88] G. F. McCleary, *The early history of the infant welfare movement*, London, H. K. Lewis, 1933, pp. 69–83.

[89] Ibid., p. 49.

[90] Bull, op. cit., note 56 above.

[91] F. Drew Harris, 'The supply of sterilised humanised milk for the use of infants in St Helens', *Br. med. J.*, 30 August, 1900: 427–31.

[92] Carpenter, op. cit., note 68 above, p. 30.

[93] H. Swithinbank and G. Newman, *Bacteriology of milk*, London, John Murray, 1903; W. G. Savage, *Milk and the public health*, London, Macmillan, 1912.

distribution. Despite this, well into the twentieth century, raw milk continued to be a justifiably feared means of disease transmission.[94]

Sterilization or pasteurization of milk was a universal feature of milk depots, whether or not the composition of the milk was also modified. For heat-treatment of milk in the home, there were several options, but no consensus on the best procedure. Boiling, while simple and requiring little equipment, suffered practical disadvantages, such as the need for constant attention, and it was claimed to reduce the nutritional value of milk and possibly predispose the infant to rickets and scurvy.[95] Sterilization required expensive equipment (e.g., the Soxhlet apparatus[96]), involving accurate temperature maintenance, but it, also, was claimed to cause nutritive losses. To counter the latter, Pritchard recommended that the water be kept at boiling point for only five minutes, rather than the usual 40 minutes, and that the baby be fed *some* unsterilized milk daily.[97] Pasteurization was strongly advocated by some but poorly regarded by others.[98] But terms were used very imprecisely; for example, in practice, pasteurization was interpreted to mean heating milk to anywhere in the range 60 to 90 °C, and for anything from one to sixty minutes.[99] And Ashby conflated sterilization and pasteurization, as if they were equivalent.[100]

It is interesting to note that Meigs, who made no mention of boiling of milk in his 1885 monograph, refused to accept discoveries in bacteriology, and fought against the germ theory of disease until his death in 1912.[101]

PROPRIETARY INFANT FEEDS

A detailed discussion of proprietary (patent) feeds would be inappropriate here, but they deserve mention in a limited context. As discussed above, the introduction of these feeds acted as a stimulus to the development of the percentage method. But patent feeds were also claimed to be ideal substitutes for, or in some cases to exactly correspond to, breastmilk. In the latter cases, milk modification was based on the concept of humanization.

One of the earliest patent feeds was Liebig's *Suppe für Sauglinge*.[102] In designing the feed, Liebig applied his theories of plastic and respiratory food substances, which assumed *inter alia* the equivalence of plant and animal proteins (plastic substances).[103] Using Haidlen's data on human milk composition,[104] he deduced that the ratio of plastic to

[94] For recent accounts, see P. J. Atkins, '"White poison"? The social consequences of milk consumption, 1850–1930', *Soc. Hist. Med.*, 1992, **5**: 207–27; Dwork, op. cit., note 84 above.

[95] For a discussion of conflicting views on this question during the nineteenth century, see Cone, op. cit., note 6 above, pp. 41–55.

[96] Illustrations of the Soxhlet apparatus marketed by Hawksley appear in H. Ashby, *Health in the nursery*, 3rd ed., London, Longmans, Green, 1902, p. 98.

[97] Pritchard, op. cit., note 68 above, pp. 50–2.

[98] Examples of authors in favour of pasteurization were Holt (op. cit., note 51 above) and Still (op. cit., note 45 above); among those opposed to it was Fowler (op. cit., note 48 above).

[99] Savage, op. cit., note 93 above, pp. 377–82.

[100] Ashby, op. cit., note 96 above, pp. 97–8.

[101] Meigs, op. cit., note 22 above; Cone op. cit., note 6 above, p. 23.

[102] J. Liebig, *Suppe für Sauglinge*, Brunswick, Fr. Wieweg und Sohn, 1866. A second edition also appeared in 1866 and the following year, a French edition, *Sur un nouvel aliment pour nourissons*, Paris, Reinwald, 1867.

[103] J. Liebig, op. cit., note 31 above, p. 92 *et seq.*

[104] J. Haidlen, 'Ueber di Salz und die Analyse der Kuhmilch', *Annalen der Chemie und Pharmacie*, 1843, **45**: 263–77.

respiratory elements in breastmilk was 10:38, and on this basis devised a mixture of 10 parts of cows' milk, one part of wheat flour and one part of malt flour, "which possesses almost exactly the same nutritional value as breastmilk". Potassium bicarbonate was added to neutralize the acid reaction of the two types of flour.[105] Initially, the preparation was made up as a liquid, but subsequently a dried preparation, containing less milk and some pea flour, was manufactured.[106] In addition to the erroneous nutritional theory, Liebig's formulation was distorted by its reliance on the milk compositional data of Haidlen, which closely corresponded to those of Simon.[107]

During the latter years of the nineteenth century, many proprietary preparations appeared on the market. A large proportion of them consisted of flour, starch or malted flour: they thus had high carbohydrate and low fat contents. Fowler classified these patent feeds into three groups: (i) dried milk foods; (ii) malted starches; and (iii) unaltered starch.[108] Some of these preparations, e.g. Nestlé's (group i) were intended to be made up with water, others with milk. Benger's Food (group ii) consisted of wheat flour and pancreatic extract, which, prepared according to the instructions, contained solubilized starch and partially digested protein.

Extravagant claims were frequently made for these products. For example, a 1910 Mellin's manual described the feed as "A substitute for breastmilk [which] entirely fulfils the conditions which are necessary in a perfect food adaptable for the use of infants from birth".[109] The same publication described the composition of human milk (on which Mellin's formulations were presumably based) as: 3.42 per cent protein and 4.55 per cent lactose, figures which were about three times and 60 per cent, respectively, those which had become widely accepted in the medical literature for twenty years.

Generally speaking, up to the end of the period of this study (although the situation changed radically thereafter), the medical profession had severe reservations about the use of patent babyfoods.[110] Rotch was highly critical of their use; and Holt was convinced that in the long term they did harm, e.g. in promoting scurvy and rickets, although he conceded that they had their uses in short term treatment of disease states.[111]

In Britain, much criticism was dismissive: "The value of proprietary infant foods is extremely small, and were it not that they are widely used, and still more widely advertised, it would scarcely be necessary to mention them".[112] Pritchard's condemnation was even more peremptory:

> These patent foods were, and I regret to say, still are, the delight of mothers, they are so easily digested, in fact they require no digesting at all. Under their persuasive influence the infant grows visibly and ponderably fatter, and to the parents' inexpressible delight present [*sic*] the appearance of an infant Hercules. Who cannot recognise at sight a patent food baby veiling under his outward serenity the germs of latent and inevitable trouble?

[105] Liebig, op. cit., note 102 above.
[106] See J. C. Drummond and A. Wilbraham, op. cit., note 63 above, p. 376.
[107] Simon, op. cit., note 12 above.
[108] Fowler, op. cit., note 48 above, pp. 142–4.
[109] Mellin's Food Ltd, *The care of infants: a manual for the care and feeding of infants from birth to the age of two years*, London, 1910, pp. 17–24.
[110] Apple, op. cit., note 6 above.
[111] Rotch, op. cit., note 66 above; Holt, op. cit., note 51 above, pp. 155–7.
[112] Fowler, op. cit., note 48 above, p. 142.

> Large and square headed, fatuously complacent, pot-bellied, spade handed and dumpy footed, for all the world presenting the appearance of animated jelly.[113]

Such blanket criticism was probably unjustified, since some feeds were undoubtedly better than others. Moreover, the disadvantages of their use depended to a high degree on when in the infant's life they were first used. For example, Burney Yeo advised that farinaceous feeds should never be used before four months of age.[114]

From the 1870s, some infants were fed on condensed milk. This was prepared by heating cows' milk to 100 °C and then evaporating it *in vacuo* to 25 to 30 per cent of its original volume.[115] It was then preserved in cans, after addition of cane sugar, at about six ounces to the pint (approximately 328 g/litre). When used for infants it was diluted considerably, 12 to 24-fold, with water, but the imbalance of nutrients made it impossible to avoid one or other of two conditions thought to cause rickets, viz. deficiency of fat and excess of carbohydrate.[116] A cheaper version made from skimmed milk, and therefore devoid of fat, was considered even more unsuitable; and following discussions by the Select Committee on Food Products Adulteration (1894), legislation was introduced in Britain making it compulsory for containers of condensed skimmed milk to be labelled as unsuitable for infants.[117] Some brands were, however, designed specifically for babies. For example, the Aylesbury Dairy Company marketed a product called "Humanoid", in which, Still claimed, "the proportions of proteid, fat and sugar are theoretically excellent".[118]

By the turn of the century, a very wide range of foods was being used in infant feeding. Apart from those discussed above, they included: asses' milk; goats' milk; whey; white wine whey; sherry whey; buttermilk; butter-flour mixture; albumin water; beef juice; beef tea; various meat broths and raw meat juices; soya bean milk; bread jelly; barley jelly; kumyss; and yogurt.[119] They constituted a veritable armamentarium for combatting infant dietary problems, many of which, it seems clear, were in no small measure "commerciogenic",[120] if not iatrogenic.

SCIENTIFIC PUBLICATIONS ON INFANT FEEDING

In assessing the rate of growth of research in this field, a useful information source is the *Bibliographia lactaria*, compiled by Henri de Rothschild at the turn of the century.[121] Rothschild's aim was to list all papers which had been published on the production and utilization of milk, by title, author, date and place of publication, and subject category. It is

[113] Pritchard, op. cit., note 68 above, p. 13.
[114] Burney Yeo, op. cit., note 72 above, p. 251.
[115] For example, see J. Long, *British dairy farming*, London, Chapman and Hall, 1885, pp. 35–42.
[116] Still, op. cit., note 45 above, p. 70.
[117] Drummond and Wilbraham, op. cit., note 63 above, pp. 377–8.
[118] Still, op. cit., note 45 above, p. 71.
[119] Sources of information are: C. Watson, *The book of diet*, London and Edinburgh, Nelson, (undated) *c*. 1911, pp. 141–61; Cheadle, note 61 above; Burney Yeo, note 72 above; Holt, note 51 above; Still, note 45 above; and Cone, note 6 above.
[120] This term was introduced to describe the aggressive advertising practices of modern day babyfood manufacturers which are believed to have exacerbated infant malnutrition in less developed countries. The term was coined by D. B. Jelliffe, 'Commerciogenic malnutrition? Time for a dialogue', *Nutrition Reviews*, 1972, **30**: 199–202.
[121] H. de Rothschild, *Bibliographia lactaria*, Paris, Octave Doin, 1900; supplements were published in 1901.

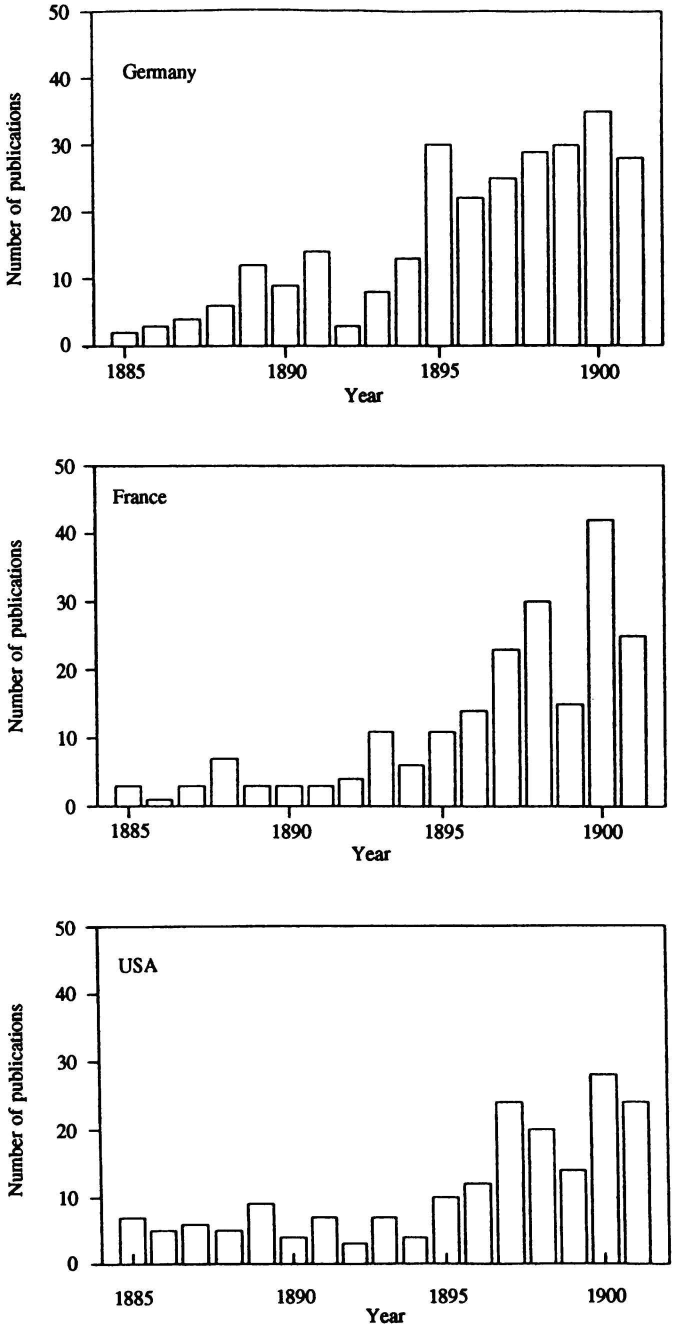

Figure 2: Scientific publications on artificial feeding of infants (1885–1901). Histograms show numbers of publications published annually in Germany, France and the USA, between 1885 and 1901 (inclusive). The data are derived from publications listed under 'Allaitement Artificiel' and 'Laits Modifiés et Succédanés' in Rothschild's *Bibliographia lactaria* (1900; 1901); see note 121.

not known how this data base was compiled or how comprehensive the data retrieval system was; but in view of the very wide range of publications included, it seems likely that the bibliography presents a fairly accurate picture of the growth of research on lactation and milk utilization.

Figure 2 was constructed by combining information listed under *"Allaitement Artificiel"* and *"Lait Modifiés et Succédanés"* between 1885 and 1901. It is clear that there was a considerable increase in the number of publications in these categories from the mid-1890s (values for 1900 and 1901 are likely to be underestimated because the numbers for earlier years were substantially inflated by those appearing in the 1901 Supplements). The breakdown of data by country of publication shows that over this period, the vast majority were published in Germany, France and the United States. German publications were predominant up to the mid-1890s, and while there was a considerable increase in the numbers of such publications thereafter, it was augmented by proportionately even greater increases in the numbers of French and American publications. Very few scientific publications on infant feeding originated from Britain throughout the whole of this period.

DISCUSSION

The humanization of milk constitutes a technology. It is a medical technology in that infant feeding is medicalized,[122] while it is a food technology to the extent that the products are commodities.

Successful technological application of scientific knowledge would seem to depend on several factors. In addition to economic viability, three criteria are important: (i) accurate determination of empirical "facts"; (ii) valid scientific theory; and (iii) expertise in implementing the technology. For the humanization of milk, these criteria are expressed as: (i) accurate determination of the chemical compositions of human and cows' milk; (ii) understanding of the principles of chemical analytical technique and of the role of milk in infant nutrition; (iii) the practical capability of modifying cows' milk to mimic effectively human milk. The yardstick of success of this technology (iv) is the extent to which infants receiving such dietary regimens survive and prosper, by comparison with babies under otherwise identical circumstances who are breastfed. The following discussion aims to analyse the extent to which humanization of milk met these criteria in Britain during the period 1850–1910.

(i) Accuracy of compositional analysis. Current estimates of the amounts of the major classes of nutrients in 100 g of human milk are: 1.3 g protein, 7.0 g lactose and 4.2 g fat.[123] These values are very similar to those reported by Meigs over 100 years ago,[124] and to virtually all research reports during the intervening period. However, between 1845 and 1885 research reports of the protein concentration in human milk showed a gradual decrease over time, while those for lactose showed exactly reciprocal changes. As discussed above, there would seem to be a strong case for believing that J. F. Simon exerted an inhibitory influence on accurate reporting of milk compositional data in the

[122] I. Illich, *Limits to medicine*, Harmondsworth, Penguin, 1977, pp. 47–129.

[123] Department of Health and Social Security, *Present day practice in infant feeding*, London, HMSO, 1988, p. 8.

[124] Meigs, op. cit., note 21 above. However, the methods of milk analysis now used are quite different from those used by Meigs.

years following publication of his book *Animal chemistry* in 1842.[125] In this, he explicitly promoted his own analytical techniques and decried those of others, whose results have, in fact, proved to be far more accurate than his own.

According to this claim, during the years up to 1885, chemists were in a quandary; they were torn between the desire, on the one hand, to publish representative results of their analyses and, on the other hand, not to deviate from "authoritative" opinion. Simon's book, one of the first in the emergent field of "animal chemistry" (and soon to be made accessible to many more by its translation into English in 1846),[126] is likely to have won wide recognition, and thus to have established several scientific norms. In a research field where publications were sparse, it is understandable (though hardly excusable) that chemists tended to report data which did not deviate too greatly from previous citations. However, with time, as reported results diverged more and more from the Simonian norms, allegiance to this authority was weakened.

If this analysis is correct, and Meigs' coded implication of dishonest reporting provides strong support,[127] the gradual shift in reported values would seem to constitute a variation on the Kuhnian notion of "normal science".[128] Here, where merely quantitive data were involved, and there were no obvious constraints related to biochemical theory, change was achieved by gradualism rather than by revolution. Even so, though weakened over time, the paradigm induced a powerful conformism. After the mid-1890s, the sheer volume of publications on artificial feeds, many of which reported data on milk composition, put the composition of human milk beyond any doubt.

While the progressive change in values reported in research papers is clear-cut (Figure 1), values quoted in the secondary literature were often out of date or unrepresentative. For example, Liebig formulated his infant feed on the basis of Haidlen's data for just two samples of human milk, which were reported, almost as an addendum, in a paper on the composition of cows' milk.[129] At the time of Liebig's publication, many analyses contradicted Haidlen's data. Similarly, Cheadle employed spurious results in prescribing procedures for milk modification, while the Mellin company betrayed a remarkable ignorance of developments in chemistry over the previous quarter of a century.[130]

(ii) Chemical and nutritional theory. In that the primary aim of humanization was simply to mimic human milk, it might be imagined that theory played a negligible role. Yet this view is false, for at least two reasons. Firstly, compositional analyses were predicated on the validity of theories of chemical identity and reactivity. Thus, the great variation in reports of milk composition before 1850 represented not only a lack of technical precision, but also the inadequacies of theories underpinning chemical analysis.

[125] Simon, op. cit., note 12 above.

[126] It is reported that 2,250 copies of the English edition were printed. See G. G. Meynell, *The two Sydenham societies*, Folkestone, Winterdown Books, 1985.

[127] Meigs, op. cit., note 22 above.

[128] T. S. Kuhn, *The structure of scientific revolutions*, 2nd ed., University of Chicago Press, 1970.

[129] Liebig, op. cit., note 102 above; Haidlen, op. cit., note 104 above.

[130] Cheadle, op. cit., note 61 above. By 1892, Cheadle had become aware of this from reading the work of Rotch. Consequently, he asked a colleague, A. Luff, to analyse human milk to clarify the issue. Luff's data, showing protein and lactose concentrations of 2.35 per cent and 6.39 per cent, respectively, formed the basis of the milk humanization procedures described in the second edition of Cheadle's book; see W. B. Cheadle, *Artificial feeding of infants*, 2nd ed., London, Smith, Elder, 1892. Mellin's op. cit., note 109 above.

https://doi.org/10.1017/S0025727300058439 Published online by Cambridge University Press

Secondly, nutritional theory assumed importance when attempts were made to bypass full-scale humanization, by providing equivalent nutrients in the feeds. For example, the lack of success of Liebig's artificial baby food must have been due, in no small measure, to the inadequacy of his theory of plastic and respiratory substances.[131] Liebig appeared unable to countenance any possibility that the theory could be deficient, quoting with approval the views of Hecker:

> if we were to say that this preparation does not agree with new-born babes, such a statement could not be supported on theoretical grounds, since in the food they get the very same ingredients as in mother's milk. As therefore this milk agrees with them, I cannot understand why they should be unable to digest Liebig's Food.[132]

The limitations of nutritional theory were also evident when paediatricians attempted to treat digestive disorders or employ feed formulas prophylactically. Here, pragmatism frequently preceded theory, e.g. "A mixture is ordered which experience has shown to be likely to suit; it is then altered or not according to the indications which arise . . .".[133] But, what was deemed "scientific reasoning" was commonly applied, frequently on the principle of *post hoc, ergo propter hoc.*

From a modern perspective, doctors of the period were severely hampered by poor appreciation of factors such as the role of vitamins, the immunological significance of colostrum, and the depressant effect on milk secretion of supplementary feeding (which may well have been responsible for much perceived lactational failure).[134] However, by the end of the period significant progress had been made in some areas, for example in recognizing the species-specificity of milk constituents.

By contrast to the major deficiencies in chemical and nutritional theory, it is possible that germ theory had a significant impact on infant health and survival in the early years of the twentieth century through measures taken to improve the microbiological quality of milk.[135]

(iii) Technological capability. The expertise involved in modifying milk needs to be considered on four distinct levels: home modification; modifications performed at milk depots; modifications performed in milk laboratories; and large-scale industrial processes involved in production of patent feeds.

Successful home modification of milk depended on a number of factors such as access to accurate information; cognitive and manual skills; the ability to purchase suitable equipment (e.g., sterilizers); and the availability of appropriate resources (e.g., cream of specified fat content). It is probable that few parents possessed all these requirements.[136] At worst, attempts might consist of the overfeeding of inappropriately diluted, condensed

[131] To quote one report: "M. Gouibourt, the eminent chemical philosopher, brought this substance [Liebig's milk] before the Academy of Medicine of Paris, and showed that it presented many defects", *Lancet*, 6 July 1867, **ii**: 26.

[132] See Drummond and Wilbraham, op. cit., note 63 above, p. 376.

[133] Fowler, op. cit., note 48 above, p. 114.

[134] For example, see T. B. Mepham, *Physiology of lactation*, Milton Keynes, Open University Press, 1987.

[135] See Atkins, op. cit., note 94 above; and Dwork, op. cit., note 84 above.

[136] For a recent account of the severe deprivation experienced by families in London, see L. Marks, 'Mothers, babies and hospitals, "The London" and the provision of maternity care in east London, 1870–1939' in V. Fildes, H. Marks and H. Marland, *Women and children first*, London and New York, Routledge, 1992.

skimmed milk, which had become microbially contaminated. At best, certified milk would be appropriately modified and subjected to effective heat treatment, and the diet would be supplemented with fruit juice.

Milk depots, like those at Battersea, supplied sterilized milk at low cost, but economic factors precluded complex modification, so that formulas employed were coarsely graded. Milk laboratories, especially those in Britain, were essentially the preserve of the rich. Humanization according to the percentage method concentrated on quantitative modification of the major milk constituents, but generally paid little attention to their chemical nature (for instance, as reflected in the "case:whey protein" ratio). Nevertheless, such preparations were claimed to promote much better weight gains in newborn babies than cows' milk, although these rates were still inferior to those of breastfed babies.[137]

Patent babyfoods were available on a large scale after 1887, when the first malted milk powder (consisting of a combination of dried milk, extracted malted barley and wheat flour) was put on the market; but in the United States it was not until 1898 that a simple dried milk powder was manufactured.[138] This technological limitation seems likely to account for the early use of malted milk foods for babies, when simple dried milk would have been preferable. Patent feeds rapidly gained popularity in the United States, doubtless because of their ease of administration, long shelf-life, and "modern" image. However, their defective composition earned the scornful criticism of most paediatricians during the period of this study, particularly when they were used as the exclusive dietary over a prolonged period. Condensed milks, except when specifically "humanized", had a similarly low reputation.

Industrial processes were also crucially important in the manufacture of the appurtenances of artificial feeding, e.g., bottles, rubber teats, and sterilizing equipment, upon which the whole process depended.[139]

(iv) The impact of artificial feeds on infant health. Assessment of the effects of milk humanization is complicated by the diversity of forms which it took. Moreover, it is probable that very few women adhered exclusively to the categories "breastfeeding", "feeding humanized milk", and "other forms of artificial feeding". The quality of the data available certainly does not permit a rigorous analysis of the question.

One, rather crude, measure of the effectiveness of infant feeding practices is provided by a comparison of the infant mortality rate (IMR) of breastfed and artificially fed babies. Fildes' recent analysis shows that during the period 1894–1911, IMR from diarrhoea in 14 British towns was much lower in babies which were exclusively breastfed than for those fed "other foods" (with or without breastmilk supplementation), the median percentages of total deaths in these two categories being 14.5 per cent and 83.6 per cent respectively. Equivalent data for deaths from all causes for the period 1891–1918 were 36.6 per cent and 59.9 per cent respectively.[140]

[137] Cautley, op. cit., note 44 above, pp. 156–8.

[138] O. F. Hunzicker, *Condensed milk and milk powder*, La Grange Illinois, Hunzicker, 1935, p. 459.

[139] V. Bullough, 'Technology and female sexuality and physiology: some implications', *J. Sex Research*, 1980, **16**: 59–71.

[140] V. Fildes, 'Breast feeding practices during industrialisation 1800–1919', in F. Falkner (ed.) *Infant and child nutrition worldwide*, Boca Raton, CRC Press, 1991, pp. 1–20.

However, such data reveal little about the adequacy of artificial feeds *per se*, because they take no account of social factors. Indeed, in London during the period 1905–1919 (largely, it should be noted, outside the period of this study), the IMR was lowest in boroughs such as Hampstead and Lewisham in which rates of artificial feeding were highest.[141] This suggests that the disadvantages of artificial feeding evident in society as a whole could be overcome where, as in these socially privileged areas, there were adequate improvements in education, medical provision, and the environment.

The instigators of municipal milk depots claimed a high level of success by appealing to reduced mortality figures for depot-fed babies, but it is again impossible to know to what extent any improvements were attributable to milk modification as opposed to the use of sterilized milk, or to the benefits of advice on babycare which were also provided. The analysis is further complicated by the fact that the original objective of the milk depots, to supply pasteurized and sterilized milk, proved to be short-lived. By 1907, many had begun to abandon this practice in favour of supplying the dried milk powders which were becoming increasingly available.[142]

CODA

Some conclusions of general applicability may, perhaps, be drawn from this study. Despite frequent appeals to "science", the practice of humanizing milk owed more to pragmatism than to biochemical theory. Even when relevant chemical knowledge was obtained, it was often resisted (by chemists) or overlooked (by paediatricians). When practice was strictly in accordance with theory, it frequently proved unsatisfactory because of defects in the theory.

There was thus a marked disparity between the certainty claimed by "experts" and the inadequacy of many of their prescriptions. In that experts only maintain credibility by claiming to speak with authority, the dichotomy is understandable. However (to relate this conclusion to a modern context), in an increasingly complex world, in which experts assume more and more power over the lives of others, it is a characteristic which deserves wide recognition.

The Simonian norms of milk composition were able to impede subsequent developments both because they were vested with authority and because so few chemists were in a position to challenge them. This situation is often paralleled today, when funding restrictions preclude adequate replication of investigations in independent laboratories and hence compromise the rigour with which scientific theories can be tested.[143]

[141] *Idem*, 'Breast-feeding in London, 1905–1919', *J. biosoc. Sc.*, 1992, **24**: 53–70.

[142] C. Dyhouse, 'Working class mothers and infant mortality in England, 1895–1914' in C. Webster (ed.) *Biology, medicine and society 1840–1940*, Cambridge University Press, 1981, pp. 81–98.

[143] T. B. Mepham (1989), op. cit., note 43 above.