EPIDEMIOLOGY *and* PUBLIC HEALTH *in 1906 England*

Arthur Newsholme's Methodological Innovation to Study Breastfeeding and Fatal Diarrhea

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In 1906 Arthur Newsholme linked artificial feeding and fatal diarrhea in infants aged one year and younger on the basis of two independent sources of information: mortality registration and a three-year (1903–1905) census of infants from Brighton, United Kingdom. Artificial feeding was more common in the infants who had died (89.3%) than in those in the survey (22.3%). However, boldly assuming the two data sources were nested, Newsholme computed the risks of fatal diarrhea: these were 48 times greater for infants fed fresh cow's milk and 94 times greater for those fed condensed milk than for infants who were exclusively breastfed. This mode of computing risks and risk ratios before the invention of the cohort study design was more innovative than was the usual investigation techniques of his contemporary epidemiologists. Newsholme's conclusions were consistent with the current knowledge that breastfeeding protects against fatal diarrhea. *(Am J Public Health*. 2013;103:e17–e22. doi:10.2105/AJPH.2013.301227)

AROUND 1900, MANY INFANT deaths in the United Kingdom were from diarrhea, which peaked at epidemic levels in the summer months.[1] This "summer diarrhea" was an important public health problem. Its etiology remained elusive for decades until 1906, when Arthur Newsholme finally related it to the contamination of fresh, powdered, or condensed cow's milk in the infants' homes.[2] The epidemiological study that led to this discovery was different from the typical epidemiological investigations of that time. Its innovative aspects are of great interest to trace, with hindsight, the evolution of epidemiological methods. Newsholme attempted to push as far as possible the interpretational potential of vital statistics–based epidemiology. In doing so, he anticipated the more formal epidemiological designs to come, in particular the cohort study, the first report of which date from 1912.[3]

Sir Arthur Newsholme (1857–1943), a British physician, served as chief medical officer of health in Brighton, England, from 1888 to 1908. Newsholme later went on to become the medical officer of the local government board, 1908–1919, the nominal head of the English public health service.[1] A self-trained but experienced methodologist in epidemiology, his 1889 textbook *Vital Statistics* had gone through three editions by 1906 and was important in late Victorian public health.

The innovative aspects of Newsholme's study on summer diarrhea stand out when it is compared with the typical epidemiological techniques that medical officers of health at that time employed. As Hardy showed for typhoid outbreak investigations, a disease that was one of the central concerns of the medical department of the local government board in the 1880s, epidemiological techniques "varied little" and "followed a fairly standard formula."[4(p334)] The primary approach consisted of comparing the mortality from typhoid in ever smaller geographic areas to identify the places the outbreak affected and to understand what they had in common (e.g., drinking water drawn from the same river, purchasing milk originating from the same farm). The investigators then visited the identified area and narrowed down the culprit by using field detective work. For localized peaks of incidence, the source could be a sick person or a singular event that had allowed a sick person to contaminate other people and initiate the outbreak. For example, when Newsholme investigated an outbreak of scarlet fever in Brighton

in 1905, he was able to plot the primary and secondary cases of scarlet fever among the customers of one dairy, inside and outside Brighton, and show that they were much more numerous than were those in the rest of Brighton. He eventually showed that one farm was the *fons et origo mali* (Latin for "source and origin of the bad"), even though he could not identify an index case.[5] A comparable approach had been used 36 years earlier by medical officer of health Edward Ballard in his "first epidemiological study to establish the hypothesis that milk could act as a vehicle for typhoid"[6(p12)] and by inspector F. W. Barry, in 1890–1891, when he linked an outbreak of typhoid in Teesdale to contamination of the Tees River following a breached weir in the village of Barnard Castle.[4]

These typical local government board techniques did not work to elucidate the cause of summer diarrhea because the disease did not produce localized outbreaks. It was a diffuse epidemic that could not be tracked to an index case or triggering event. Many children died in many places from independent contamination processes. Indeed, mortality studies, such as those Edward Ballard conducted in the 1880s, suggested that there were many local conditions that could favor summer diarrhea, but these studies failed to single out causes that could be acted on.[1]

Around 1895, Newsholme began to suspect that bottle-feeding—as opposed to breastfeeding—was the culprit for fatal infant diarrhea. Inspections and home inquiries revealed that the overwhelming majority of the infants who died had been bottle-fed.[1] Yet, this key observation could not be interpreted as causal until the fraction of infants in the population at large who were bottle-fed was known. This is most likely why Newsholme began to systematically collect information on feeding practices for infants who had died as well as in the population at large.[1] Newsholme launched a "census" of infants in Brighton in 1903. His inspector visited households on a yearly basis, counted the children aged one year and younger, and collected information about their modes of feeding.[2] This population survey provided Newsholme with indispensable information about the distribution of feeding habits in the population basin of the mortality statistics. This new combination of exposure data among living and deceased infants resulted in an analytic approach for which we know of no equivalent before the 1906 publication "Domestic infection in relation to epidemic diarrhoea,"[2] which we have dissected.

METHODS

There are two sources of data in Newsholme's 1906 study[2]: a repeated population survey and death registration.

From 1903 to 1905, Newsholme commissioned a yearly census of all infants aged one year and younger living in working-class homes in Brighton, East Sussex County, on the south coast of Great Britain, with an estimated population of 123 478 in 1901.[7] Sanitary inspectors from the Brighton Department of Health visited 10 308 houses on an annual basis over the three-year period. They obtained from unspecified members of the household the age and method of feeding of infants aged one year and younger. The 1259 infants, often called "babies" by Newsholme, came from an undetermined number of families.[2] The unknown response rate to the census was presumably high. Sanitary inspectors had access to all homes and, according to Newsholme, "in most houses information [had] been given without difficulty."[2(p139)]

For the same three years (1903–1905), Newsholme gathered the age in months, the method of feeding, and the profession of the parents of 121 infants who died from epidemic diarrhea in Brighton. The article states that the infants who died belonged "approximately to the same social stratum" as the surveyed infants,[2(p140)] but these were two independent sources of information.

RESULTS

Table 1 is a rendering of Newsholme's Table I except for the marginal row and column percentages, which we added. In Newsholme's article[2] the data we presented in Table 1 as column marginal percentages are shown in a separate table. Table 1 contains all the population data reported and used in the 1906 publication. There were some differences in the first decimal points between our calculations and Newsholme's table. For clarity, Table 1 gives our calculations.

In the age distribution of the 1259 living and 121 deceased infants (Table 1), the four age trimesters were uniformly distributed, as we would expect for an infant count in a modern low-income population using a commonly accepted method. One fourth of the children aged three to six months experienced 41.3% of the deaths.

TABLE 1—Methods of Feeding Infants Younger Than One Year of Age: Brighton, UK, 1903–1905

	Age, Months					
	0–3	3–6	6–9	9–12	Total[a]	Column %[a]
Census of 10 308 houses in house-to-house inspection in the 3 years						
I						
Suckled only	271	237	186	92	786	62.4
Suckled and farinaceous food	14	29	41	69	153	12.2
Suckled and cow's milk	5	6	7	4	22	1.7
Suckled and condensed milk	3	6	7	1	17	1.4
II						
Cow's milk only	12	32	28	18	90	7.2
Cow's milk and farinaceous food	4	26	33	33	96	7.6
III						
Condensed milk only	6	12	10	11	39	3.1
Condensed milk and farinaceous food	2	6	10	7	25	2.0
IV						
Farinaceous food, including patent food only mentioned or "same food as parents"	4	1	2	18	25	2.0
V						
Unknown	0	0	1	5	6	0.5
Total[a]	321	355	325	258	1259	100.0
Row %[a]	25.5	28.2	25.8	20.5	100.0	
Infants who died from epidemic diarrhea in the 3 years						
I						
Suckled only	5	3	0	0	8	6.6
Suckled and farinaceous food	1	1	0	1	3	2.5
Suckled and cow's milk	1	0	0	0	1	0.8
Suckled and condensed milk	1	0	0	0	1	0.8
II						
Cow's milk only	11	22	7	4	44	36.4
Cow's milk and farinaceous food	1	0	4	6	11	9.1
III						
Condensed milk only	2	16	12	7	37	30.6
Condensed milk and farinaceous food	0	3	0	1	4	3.3
IV						
Farinaceous food, including patent food only mentioned or "same food as parents"	1	1	0	0	2	1.7
V						
Unknown	2	4	2	2	10	8.3
Total[a]	25	50	25	21	121	100.0
Row %[a]	20.7	41.3	20.7	17.4	100.0	

Source. Based on Newsholme, 1906.[2]
[a]Not in original table.

The most widely used methods of infant feeding were, in the census, exclusive breastfeeding (62.4%) and, among the deaths, fresh "cow's milk only" (36.4%) and "condensed milk only" (30.6%).

Observed vs Expected Deaths

Newsholme started by comparing the observed number of deaths in exclusively breastfed infants with the expected number of deaths in this group:

> The number of deaths from epidemic diarrhea among breastfed infants was not much more than one-tenth of the number which would have occurred had the deaths from diarrhea been evenly distributed among all the infants.[2(p140)]

This "one tenth" can be obtained as follows: first, compute the overall mortality by dividing the total number of infant deaths by the total number of infants surveyed, 121/1259=96 per thousand, and then multiplying the 786 breastfed-only infants ("suckled only") by 96 per thousand (0.096). The result is 76 expected deaths (786 x 0.096), compared with which the 8 observed deaths are "not much more than one-tenth."

Death vs Census Analysis

Newsholme went on to use a comparison of the proportions of feeding characteristics among the deaths as if they were a case group and among the census infants as if they were a control group:

> Taking all forms of artificial feeding together, Table II [which corresponds to the column percentages in our Table 1] shows that of the sample infantile population 22.3% were artificially fed, while 89.3% of the total deaths from diarrhea were among artificially fed infants. The chance of death from diarrhea during the first year of life is quadrupled by artificial feeding, or by conditions associated with it.[2(p142)]

The column percentages in Table 1 indicate that 22.3% of the surveyed infants had not been breastfed at all, compared with 89.3% of the infants who died. The ratio of these two proportions is almost exactly a quadruple (89.3/22.3=3.999; Table 2. Interestingly, Newsholme interprets this ratio of

artificial feeding as a risk ratio, saying that "the chance of death from diarrhea during the first year of life is quadrupled by artificial feeding"[2(p142)] instead of saying that the chance of being artificially fed is quadrupled among the infants who died from diarrhea during the first year of life. Yet, as he also shows, the corresponding risk ratio is much greater than four.

Newsholme repeated the same approach for each trimester of life, finding

> in the first trimester the liability to fatal diarrhea is 8 times, in the second 4.5 times, in the third 4 times, and in the fourth trimester 2.5 times as great among artificially fed as among breastfed babies.[2(p142)]

As before, Newsholme interpreted the exposure ratio as a "liability to fatal diarrhea,"[2(p142)] which we would call a risk ratio today.

Exposed vs Unexposed Analysis

Newsholme then moved to compute a risk ratio of feeding practices and death. He looked at his data as if the infants who died had originated from the cohort enumerated by the census:

> Of the total eight deaths from epidemic diarrhea among breast-fed infants none occurred after the sixth month of life. If we then consider separately infants aged 6–9 months, bearing in mind the fact that breast-fed infants at this age must have been breast-fed from birth, the figures show that although 57 per cent [57.2%] of the infants aged 6–9 months in the sample population were entirely, and an additional 17 per cent [16.9%] were partially breast-fed, not one of the 25 deaths from diarrhea at these ages occurred among breast-fed or partially breast-fed infants.[2(p141)]

Newsholme computed probabilities of death by dividing the number of deaths by the number of infants in the census. These ratios are approximations of risks if one assumes, as Newsholme did, that the infants who died had been included in the census before dying. From these risks, Newsholme derived risk ratios, interpreting that "the probability of death from diarrhea was twice as great among infants fed on condensed milk as among infants fed on fresh cow's milk" or that

> the probability of death from diarrhea was 48 times as great among infants fed on cow's milk and 94 times as great among infants fed on condensed milk as among those breast-fed.[2(p142)]

The calculations, which Newsholme said, "embodied the main teaching" [2(p142)] of his article, are shown in Table 3. Here is the explanation in Newsholme's terms:

> The group fed on cow's milk [only] in the sample population formed 7.2% of the total, while the deaths from diarrhea in the corresponding group were 36.0% [36.4%] of the total. The group fed on condensed milk [only] formed 3.1% of the total, the deaths in the corresponding group 30.3% [30.6%] of the total. Thus the probability of death from diarrhea was twice as great among infants fed on condensed milk as among infants fed on fresh cow's milk. Comparing these figures with those for breast-fed infants, the probability of death from diarrhea was 48 [47.3] times as great among infants fed on cow's milk and 94 [92.5] times as great among infants fed on condensed milk as among those breast-fed.[2(p142)]

The Laboratory Section

The assistant medical officer, T.B. Heggs, MD, DPH,[2] Newsholme assigned to count bacteria in samples found that condensed milk had lower bacteria content than did fresh cow's milk. This suggested that this form of milk was not contaminated before its domestic consumption.

Newsholme posited, therefore, that the only plausible explanation for the excess mortality in infants who were given condensed milk compared with those given fresh cow's milk was "the special proneness of condensed milk to domestic infection" [2(p145)] such as flies and dust depositing infectious material from local garbage and human excrement into the milk stored in homes.

TABLE 2—Percentages of Exclusive Artificial Feeding Among Infants in Census and Those Who Died From Epidemic Diarrhea, by Age Group: Brighton, UK, 1903–1905

Age, Months	Census, %	Deaths, %	Deaths-to-Census Ratio
All	22.3	89.3	4.0
0–3	8.7	68.0	7.8
3–6	21.7	92.0	4.2
6–9	25.8	100	3.9
9–12	35.7	95.2	2.7

Source. Newsholme, 1906.[2]

TABLE 3—Mode of Calculation Used by Newsholme to Approximate Risks (Deaths/Census) and Risk Ratios of Fatal Infant Diarrhea by Feeding Method: Brighton, UK, 1903–1905

Feeding Mode	Deaths, %	Census, %	Risk	Risk Ratio	
Breastfed only	6.6	62.4	0.1		1.0 (Ref)
Fresh cow's milk only	36.0	7.2	5.1	1.0 (Ref)	48.0
Condensed milk only	30.3	3.1	9.8	1.9	94.0

Note. Newsholme computed probabilities of death by dividing the number of deaths by the number of infants in the census. These ratios are approximations of risks if one assumes, as Newsholme did, that the infants who died had been included in the census before dying. From these risks, Newsholme derived risk ratios.
Source. The numbers in the tables are those reported by Newsholme.[2]

DISCUSSION

To connect deaths from diarrhea and feeding method, Newsholme combined mortality

TABLE 4—Risk Ratios of Deaths From Infant Diarrhea by Infant-Feeding Type: Brighton, UK, 1903–1905

	Aged 0–6 Months			Aged 6–12 Months		
Feeding Mode	Deaths, No.	Census, No.	Risk Ratio[a]	Deaths, No.	Census, No.	Risk Ratio[a]
Breastfed only	8.0	508.0	1.0 (Ref)	0.0	278.0	0.0
Breastfed mixed	4.0	63.0	4.0	1.0	129.0	0.5
Weaned off	57.0	105.0	34.5	41.0	170.0	15.3

[a]The reference for all risk ratios is the category of "breastfed only" among infants aged 0–6 months.

data with a survey of Brighton's households as if they were nested and used three modes of data analysis: observed versus expected deaths comparison, deceased versus census comparisons, and exposed versus unexposed comparisons. He concluded that infectious material contaminated milk at home after the fresh cow's milk or condensed milk had been purchased.

Newsholme observed that over the entire first year of life, the risk of dying from diarrhea was 48 times higher in infants fed with fresh cow's milk only and 94 times higher in infants fed with condensed milk only, compared with exclusively breastfed infants. Still, there were cases of epidemic diarrhea among exclusively breastfed infants. Newsholme reasoned that these cases stemmed from domestic infections transmitted by "dirty fingers" or "dirty dummy-teats"[2(p141)] because it was certain that mother's milk was sterile.[2] It is unclear whether Newsholme took into consideration the possibility of indirect contamination of breastfed infants by fluids other than milk such as water, tea, or juice.[8–10]

Analyses stratified by age revealed that breastfeeding was more protective in infants aged 6 months and older. Although mortality declined in all feeding groups as infants grew older, this decline was most steep in the exclusively breastfed group, in which no death occurred after six months. The latter observation is at odds with the current literature that shows that the protection of breastfeeding against undernutrition and death declines sharply with age.[11] It is now well accepted that from six months onward, infants need additional sources of nutrients to get the optimal trade-off of the "weanling dilemma," that is, between the pros (lower risk of infections, particularly diarrhea) and cons (slower growth and greater risk of undernutrition) of extending exclusive breastfeeding beyond aged six months.[12,13]

Bacteriological Analyses

Newsholme's use of bacteriological analyses to elucidate the source of milk contamination deserves attention. Source of contamination was a key issue for Newsholme, because the milk sold in Brighton at the time was unpasteurized. In the case of epidemic diarrhea, he was able to elucidate the domestic contamination of the milk without the support of bacteriological analyses:

> The few experiments made in our municipal laboratory (page 146) . . . show that neither a simple bacterial count, nor a statement of the presence or absence of the kinds of bacteria enumerated hereafter, throws light on the specific pathogenicity of condensed milks.[2(p143)]

Newsholme's dismissive judgment about the usefulness of the bacteriological analyses he commissioned in the diarrhea study is additional evidence that in 1906 epidemiologists were still not the "handmaids" of bacteriologists, as has been debated elsewhere.[14–16] Rather, most of the methods that Newsholme used to isolate the cause of epidemic diarrhea relied on population thinking (which in this case consisted of estimating risk from the combination of mortality and census data) and group comparisons. Population thinking and group comparisons are central features of epidemiology.

Stretching the Limits of Vital Statistics

The originality of Newsholme's design was juxtaposing census data and vital statistics contingent on the assumption that these two sets of data were nested. This design provided the data for comparison testing the association of feeding practices and fatal diarrhea.

There are several differences between Newsholme's design and the cohort studies that began to be reported relatively shortly afterward. In 1912, Janet Lane-Claypon reported her retrospective cohort study about the impact on breastfeeding versus bottle milk feeding on infant growth in Berlin.[3] In 1913, Wilhelm Weinberg published a book titled *Children of the Tuberculous*[17,18] in which he described a huge retrospective cohort study performed in Stuttgart. The use of a case–control design had to wait 20 more years.[19–21] Compared with these later studies, Newsholme's design had no directionality; rather, he switched back and forth between comparing deaths and census and comparing infants exposed and unexposed to the different forms of artificial feeding. This clearly situates the article in the phase of the history of epidemiology preceding the emergence of formal comparative designs for cohort and case–control studies.[21]

Newsholme's interpretation of ratios of feeding practices as if they were mortality ratios is surprising. There is no reciprocity between these two measures of effect. For example, in 1912, William H. Davis, a vital statistician of the Boston Board of Health, discussed the same issue as Newsholme's:

> If 74% of infant deaths above the age of two weeks are among bottle-fed babies and only 32% of babies over 2 weeks are bottle-fed, then the bottle-fed infant over two weeks old is six times as likely to die as the breastfed infant.[22(p70)]

Had Davis used the same interpretation scheme as Newsholme, he would have said that the bottle-fed infant older than two weeks is twice as likely (0.74/0.32=2.3) to die as the breastfed infant. Instead, he computed the odds ratio of 74% and 32%, which is 6.05, and wrote "six times as likely."

Limitations

Today, we still face some of the challenges Newsholme met,

such as separating diarrhea cases caused by different etiological agents.[23] Fatal cases could be attributed to multiple conditions, including typhoid fever. Even at present, population-based studies of diarrhea mortality treat all fatal episodes as a single entity.

However, with hindsight, we see two potential limitations in Newsholme's design, which he does not discuss, that could have—even if modestly—affected his conclusion. An intrinsic limitation of combining two sources of data was that the infants who died from diarrhea might not have belonged to the same socioeconomic stratum as the surveyed infants. The survey was conducted in a relatively poor area of Brighton, but deaths may have originated from wealthier neighborhoods because wealthy mothers were less likely to breastfeed than were the poor mothers. If this were true, Newsholme's study could have underestimated the deleterious effect of artificial feeding.

Another potential limitation of the vital statistical source of information about the infants who died is that Newsholme did not specify whether feeding practices were those before the onset of illness. If infants who got sick while being breastfed could have been categorized on the death certificate as being artificially fed, this would have resulted in reverse causation and overestimation of the deleterious effect of artificial feeding.

Conclusions

Newsholme's findings are largely in agreement with the modern literature. The protection breastfeeding affords against diarrhea is one of the most consistent findings in the epidemiological literature on any type of outcome, similar to the association between smoking and lung cancer. Moreover, consistent with Newsholme's observation (Table 4) recent studies show that infants receiving both breast and nonhuman milk have intermediate levels of risk between those who are exclusively breastfed and those who are fully weaned.[11]

Newsholme's 1906 article on breastfeeding and epidemic diarrhea provides a new look into the state of epidemiological methods and strategies around 1900. By combining death certificates with a specific census of infants in Brighton, Newsholme was able to compute risks and risk ratios in a way that anticipated the still to be invented cohort study design. ■

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