

EFFECT OF A WHOOPING COUGH EPIDEMIC UPON THE SIZE OF THE NONIMMUNE GROUP IN AN URBAN COMMUNITY¹

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THE extent to which an uncontrolled epidemic of an infectious disease spreads in human populations under different environments is a matter of practical importance to the sanitarian whenever any attempt at control is made. It cannot be settled easily, however, for many factors are involved. The etiology of the specific disease; the period of its infectivity; the opportunity for effective contact between susceptible individuals and infectious cases or carriers, which is subject to so many and so varied circumstances; the proportion of the population already immune—these are only some of the most essential facts required by the epidemiologist in considering the problem for a given type of community. He is faced by a complexity of conditions, so intricately related and so difficult to evaluate in exact terms, that very precise measurements of an epidemic's behavior are well-nigh impossible. Even if he arrives at a successful answer for one population group, he cannot assume its accuracy for other groups or communities.

Precision beyond certain general limits, however, is neither always necessary nor profitable, and much can be learned from observing epidemics in populations of different general types, provided reasonably complete records of histories of previous attacks and of current cases are secured. In the

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course of the morbidity study in Hagerstown, Maryland,² the opportunity was presented of observing certain epidemiological phases of whooping cough with a greater degree of accuracy and completeness than is ordinarily possible from routine records of cases reported in compliance with regulations for disease notification. This opportunity was afforded by reason of three conditions:

1. A population of over 7,000 persons was "under observation" for incidence of sickness for twenty-eight consecutive months. Each household was visited by a competent staff of field assistants at intervals of six to eight weeks in order to obtain a record from responsible informants (usually the housewife) of cases of sickness and attacks of communicable diseases. The diagnosis of cases attended by physicians (of whooping cough, such cases were 49 per cent of the total recorded) were reviewed by the physicians themselves.

2. At the initial visit to each household a careful effort was made to ascertain for each individual enumerated the age at which he had previously been attacked by whooping cough as well as by other infectious diseases. Similar information was obtained for new persons coming into the observed population during the ensuing twenty-eight months. We had, therefore, a record, although admittedly neither absolutely accurate nor complete, of those persons who had a history of clinically obvious attacks previous to December 1, 1921, and of those who had no such history.

²A series of reports dealing with the Hagerstown morbidity study has been published in various issues of the United States *Public Health Reports*. The reader is referred especially to the following: Sydenstricker, Edgar: The Incidence of Various Diseases According to Age. Study No. viii. United States *Public Health Reports*, May 11, 1928. Reprint No. 1227.

Sydenstricker, Edgar, and Hedrich, A. W.: Completeness of Reporting of Measles, Whooping Cough, and Chickenpox at Different Ages. Supplement to Study II. United States *Public Health Reports*, June 28, 1929. Reprint No. 1294.

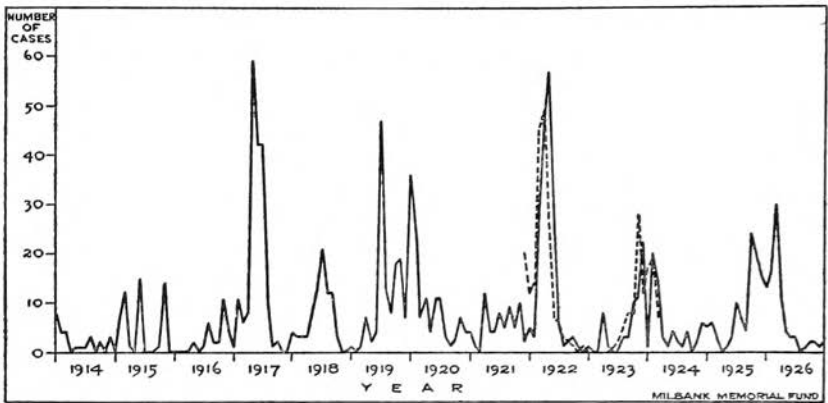


Fig. 1. Cases of whooping cough in Washington County, Maryland, reported to the State Health Department, 1914-1926, and cases recorded in an observed population in Hagerstown, Maryland, December 1, 1921 to March 31, 1924.

3. A record was obtained of all births, deaths, and of migration of persons from and into the group during the period.

For the purpose of this particular study another rather interesting and favorable condition was found to exist. For about twenty months prior to December 1, 1921, no unusual prevalence of whooping cough had occurred in Hagerstown, a fact evidenced by our own record of previous attacks in the observed population and by the records of the Maryland State Department of Health. Almost immediately after the study was begun, an outbreak of the disease occurred. In fact, two outbreaks apparently took place, one in December, 1921 - July, 1922, and another in September, 1923 - March, 1924, but they occurred in different parts of the City and, taken together, constituted a fairly widespread epidemic over the entire area in which the observed population resided. It is proper, therefore, to regard them as a single epidemic.

In the present communication it is proposed to present such data as we were able to collect during the twenty-eight-month period that relate more particularly to the effect of the outbreak of whooping cough upon the size of the "sus-

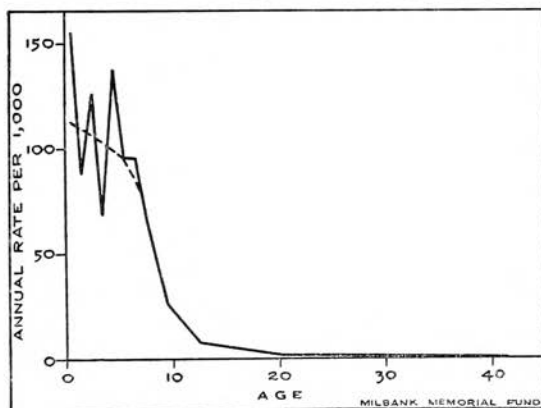
ceptible" moiety of the population so observed, in the hope of throwing some light upon the relation of immunity to the magnitude of recurring epidemic outbreaks in a typical small urban community. Hagerstown, in 1921, had a total population of about 30,000. The group observed comprised a little less than one-fourth of this total and was from areas inhabited only by white residents.

In Figure 1 the position of the outbreak is shown in relation to the chronology of the disease from 1914 through 1926 in Washington County, Maryland, of which Hagerstown is the principal center.³ The seasonal distribution of cases in the observed population also is portrayed in Figure 1. A total of 374 cases was recorded as incident during the twenty-eight-month period, or at an annual rate of 27.8 per 1,000 years of life observed.

The incidence of whooping cough according to age upon the total observed population is shown in Figure 2 for the period of twenty-eight months.

The concentration of cases among persons under

Fig. 2. Incidence of whooping cough among persons of different ages in a white population group in Hagerstown, Maryland, December 1, 1921 to March 31, 1924.



³The data for Washington County, with a total population of about 65,000 are cases reported to the State Health Department. The dotted line in Figure 1 shows the cases recorded for the population observed. The fact that the latter are approximately equal to the numbers for the entire County is due principally, of course, to more complete records in the observed population. Notification of whooping cough in Hagerstown was about 15 per cent of the incident cases. The chronological picture for Washington County, however, seems fairly similar to that for Hagerstown.

AGE IN YEARS	PERCENTAGES		NUMBERS		
	Having Had Prior Attack	Not Having Had Prior Attack	Total Considered	Having Had Prior Attack	Not Having Had Prior Attack
TOTAL—15	49	51	1,891	928	963
Under 1	5	95	131	6	125
1	6	94	125	7	118
2	15	85	124	18	106
3	22	78	109	24	85
4	37	63	169	62	107
5	40	60	139	55	84
6	49	51	150	74	76
7	64	36	118	75	43
8	65	35	150	97	53
9	72	28	125	90	35
10	77	23	116	89	27
11	72	28	113	81	32
12	77	23	108	83	25
13	76	24	106	80	26
14	81	19	108	87	21

Table 1. History of whooping cough among white persons at different ages up to fifteen years as of December, 1921, in Hagerstown, Maryland.

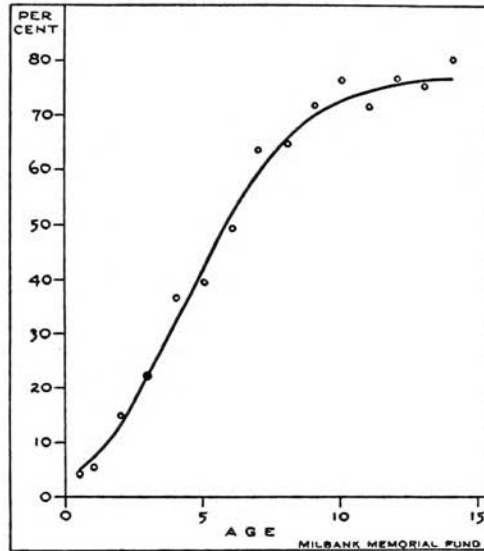
five years of age, the sharp drop in incidence upon persons five-nine years old, and the low rate after fifteen years of age at once suggest that an immunity, increasing with age, existed at the beginning of the period of observation. This indication is confirmed by the records of persons at each age for whom positive histories of whooping cough were obtained as of December 1, 1921, upon the assumption that an attack of the disease usually confers immunity. The percentages at each age with positive history are given in Table 1 and are plotted in Figure 3. The logistic curve fitted by Collins⁴ to similar data for whooping cough from various sources, including that obtained in the Hagerstown study, is also shown.

⁴Collins, Selwyn D.: Age Incidence of the Common Communicable Diseases of Children. United States *Public Health Reports*, April 5, 1929. Reprint No. 1275.

The Hagerstown percentages fall closely on Collins' curve.

Now if the histories of previous attacks of whooping cough could be assumed to afford a complete and accurate record of all of the persons immune to the disease on December 1, 1921, it would be easy to determine how much of the remaining susceptible human material was "exhausted" before an epidemic "burned itself out." The facts that in an urban population the percentage of persons with positive histories of whooping cough practically reaches its asymptote at about fifteen years of age, and that this

Fig. 3. Percentage of the observed population at different ages who had had attacks of whooping cough prior to December 1, 1921. (Smooth line from Collins, see footnote page 306.)



asymptote is approximately 75 per cent constitute unmistakable evidence that such an assumption is not sufficiently precise. On the contrary, it is obvious that 25 per cent of the population over fifteen years of age possessed an immunity not accounted for by histories⁶ of clinically obvious attacks.

⁶It is realized that some of the persons *with* positive histories of whooping cough are still susceptible since second attacks do occur. The proportion of persons suffering clinically obvious multiple attacks is not large, however. In the outbreaks under consideration only 20 of the 363 cases under fifteen years of age were among persons reported to have a previous attack. Assuming this record to be absolutely correct, the immunity conferred by an attack of whooping cough is high, only 1.7 of total persons under fifteen having suffered a second attack during this period. Or, assuming the immunity conferred to be 100 per cent, the error in the record is relatively slight, being only 5.5 per cent.

The question then arises: at what ages did the individuals comprising this 25 per cent of the population acquire immunity to the disease?

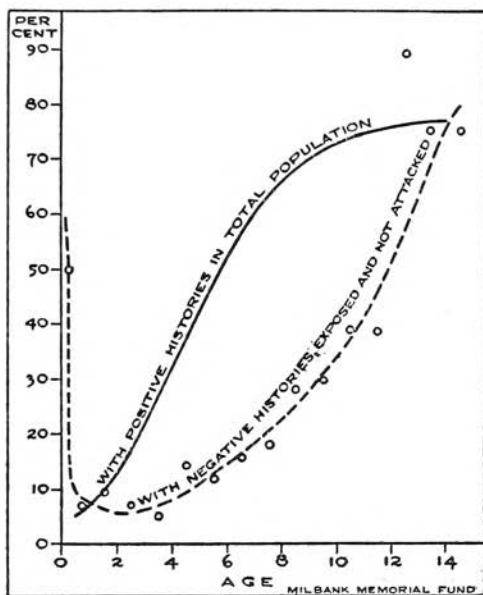
A satisfactory answer would be afforded if the experiment could be tried of taking a statistically adequate number of persons at different ages who had no history of clinically obvious whooping cough, exposing them sufficiently to active cases when such cases were at a fully infectious stage, and observing the number of such persons attacked by the disease as the result of the exposure. Such an experiment is, of course, impracticable, but we can approximate it by ascertaining the attack rate of whooping cough among persons of different ages *without histories of the disease but residing in households that were attacked during the outbreaks under consideration*. This has been done in Table 2. It will be noted

Table 2. Attack rate of whooping cough among white persons of different ages *without* previous history of whooping cough and resident in households attacked by the disease in 1922 and 1923, Hagerstown, Maryland.

AGE	NUMBER OF		PER CENT	
	Persons	Cases	Attacked	Not Attacked
TOTAL UNDER 15	441	356	81	19
Under 6 months	6	3	50	50
6 months—1 year	15	14	93	7
1 year	12	11	92	8
2 years	59	55	93	7
3 "	41	39	95	5
4 "	49	42	86	14
5 "	48	42	88	12
6 "	55	46	84	16
7 "	45	37	82	18
8 "	43	31	72	28
9 "	20	14	70	30
10 "	18	11	61	39
11 "	13	8	62	38
12 "	9	1	11	89
13 "	4	1	25	75
14 "	4	1	25	75

that the proportion of such persons attacked (*i.e.*, for whom clinically obvious cases were recorded) was over 90 per cent at ages six months to four years, and thereafter declined to approximately 25 per cent at ages thirteen and fourteen. The numbers are too small to yield dependable results for any one year of age, but the resulting curve (Fig. 4) of the percentages of persons presumably exposed to cases in the same households but *not* attacked at least suggests that the proportion of the population which has acquired an immunity without suffering clinically obvious attack rises rapidly with age (after the first six months of life) to a point which approximates

Fig. 4. Percentage of population with positive histories of whooping cough and percentage of those with negative histories who were not attacked when exposed to familial cases.



the 25 per cent for whom no history of previous attack is ordinarily given. The further suggestion is afforded that the percentage of persons acquiring an immunity without any clinically obvious or remembered attack does not rise with age at the same rate at which the percentage of persons with clinically obvious attacks rises with age; the curve of the former, as depicted in Figure 4, lags considerably behind that of the latter. Obviously, the older the child the greater is the likelihood of exposure to the disease in some previous epidemic and of a subclinical attack which conferred immunity.

It may also be that attacks of the disease tend to be milder and more frequently "subclinical" as age advances.

Whatever may be the value of these indications at different ages, the point with which this discussion is particularly concerned is the gross proportion of the population under fifteen years of age which was immune to whooping cough at the beginning of the period of observation. Of 441 persons without any history of whooping cough (*i.e.*, attacks that were remembered by the informants) and then presumably exposed to it through familial or other effective contact, 356 persons contracted the disease and 85 did not. These 85 persons may be assumed to have either acquired an immunity previous to the epidemic, or to have suffered sub-clinical attacks during its course.

Applying the percentages at each age obtained in our "experiment" to the number of persons of corresponding ages who were recorded as having no history of the disease on December 1, 1921, it may be estimated that a maximum of 195, or 20.6 per cent, of the 963 persons under fifteen years of age without a history of a previous attack actually possessed immunity. Subtracting, this leaves 768 persons who may be assumed to have been susceptible at that time, which is 41 per cent of the entire population in the age group under fifteen years. The method of estimation obviously is rough and the estimate itself must be regarded as only an approximation to the actual number of nonimmune persons. It is, however, more accurate for this purpose than the number of persons recorded as not having had a previous attack.

Starting with these 768 persons⁷ on December 1, 1921, it is now possible to estimate the effect of the ensuing out-

⁷If practically 100 per cent of this urban population over fifteen years of age was no longer susceptible to whooping cough, these 768 persons constituted nearly all of the nonimmune in the group observed.

breaks upon the size of the "susceptible" population. In making the necessary computations, the following facts were taken into account: (1) births, (2) deaths, (3) persons reaching the age of fifteen years, (4) persons actually attacked by the disease in clinically obvious forms, and (5) persons acquiring an immunity without clinically obvious attacks, during the twenty-eight month period. Emigration and immigration of individuals from and into families constituted a negligible factor and were disregarded. Births were added to the susceptible group,⁸ but persons dying, persons attacked by the disease, persons presumably acquiring an immunity during the epidemic (estimated upon the ratio of one to five clinically definite cases), and susceptible persons reaching the age of fifteen, were subtracted.⁹ The computations were made as of several dates in the twenty-eight months, as shown in Table 3, and the variations in the proportion of the entire population under fifteen years of age which remained susceptible are plotted in Figure 5.

With a full realization of the necessarily crude procedure in making these approximations and of the caution that

⁸Strict accuracy would demand that persons born into the population should not be added to the susceptible group until after some period of possible "natural" immunity had elapsed. The data were inadequate for a determination of such a period or to ascertain whether or not it existed.

⁹Calculation of susceptible population under fifteen years of age at successive dates.¹

DATE	NUMBER OF SUSCEPTIBLES UNDER FIFTEEN YEARS OF AGE	ADD BIRTHS	SUBTRACT			NET + OR -
			Deaths	6/5 Cases	Fifteen Years Old	
1921, December	768	109	9	210	5	-115
1922, December	653	100	18	63	5	+ 14
1923, December	667	18	8	65	1	- 56
1924, March	611					

¹To calculate susceptibles in case no epidemic had occurred, do not use the figures in column headed 6/5 cases, i.e., persons who had the disease and an additional 20 per cent who acquired immunity without a clinically obvious attack.

DATE	POPULATION UNDER FIFTEEN YEARS	TOTAL SUSCEPTIBLES UNDER FIFTEEN YEARS		SUSCEPTIBLES IF NO EPIDEMIC HAD OCCURRED	
		Number	Per Cent	Number	Per Cent
1921, Dec. 1	1,891	768	41	768	41
1922, June 1	1,894	634	33	822	43
1922, Dec. 1	1,878	653	35	863	46
1923, June 1	1,869	695	37	906	48
1923, Dec. 1	1,858	667	36	940	51
1924, Mar. 31	1,834	611	33	949	52

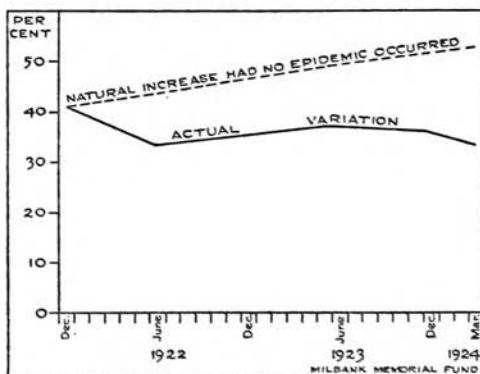
Table 3. Variations in the number and percentage of a population group under fifteen years of age who were nonimmune to whooping cough and who would have been nonimmune if no epidemic had occurred during twenty-eight months, December 1, 1921 to March 31, 1924, in Hagerstown, Maryland.

must be exercised in drawing too precise conclusions, the following observations may be ventured:

1. The proportion of the *total* population in a typical small urban community (as judged from a sample of nearly one-fourth of the total) which was nonimmune to whooping cough after an interepidemic interval of about twenty months was about 10 per cent. Of persons under fifteen years of age, the percentage nonimmune was about 40.

2. After an outbreak of the disease which immediately began in December, 1921, was acute for four months, and affected only certain areas, the proportion of the population under fifteen

Fig. 5. Variation in the proportion of persons under fifteen years of age who were nonimmune to whooping cough during twenty-eight months, December 1, 1921 to March 31, 1924, in Hagerstown, Maryland.



years of age which was nonimmune declined to 35 per cent in December, 1922. Had this outbreak not occurred, the percentage of nonimmunes under fifteen years of age in the families actually observed would have risen to 46 on the assumption that no new immunity had been conferred on the older children¹⁰ and that the infants added by birth were susceptible.

3. After a second outbreak, beginning in August, 1923, and lasting through March, 1924, and affecting chiefly the areas not attacked in 1921-1922, the proportion of nonimmunes in the general population was further reduced to about 8 per cent and of the group under fifteen years of age to 33 per cent.

Our inquiry thus may be regarded as an approach to the observation—admittedly incomplete—of a single epidemic in a series of epidemics of whooping cough that occur more or less periodically in a small urban community. So regarded, it indicates that when the proportion of total children under fifteen years of age nonimmune to whooping cough was as high as 40 per cent and an epidemic of the disease occurred, the total nonimmune population was not exhausted but only reduced by about one-fifth. This result is indicated in spite of the facts that opportunity for contact was afforded under the usual conditions of urban life and that no effort to control the infection was exercised by the community except to exclude cases from the schools after they became clinically manifest.

To reiterate, this is but one experience, a single "case history," as it were, of an epidemic of whooping cough. The variations in the size of the nonimmune population in prior

¹⁰The possibility that some of our observed population acquired immunity from carriers or from cases outside of the City could not, of course, be explored in this study.

or later epidemics in this community may have been quite different from those indicated for this particular outbreak, and the experience of a small urban community cannot be assumed to be in any way representative of rural areas or other types of towns and cities.