THE IMMUNE STATUS OF A POPULATION AT THE TERMINATION OF A SEVERE EPIDEMIC OF POLIOMYELITIS

By C. A. EVANS, VELMA C. CHAMBERS, W. R. GIEDT and A. N. WILSON*

Department of Microbiology, University of Washington, Seattle, and the Washington State Department of Health

(With 2 Figures in the Text)

INTRODUCTION

In 1952, seventy-four cases of poliomyelitis, about half of which were paralytic, were reported to the Alaska Department of Health from Ketchikan, a community with a population of approximately 6000. Since the attack rate exceeded 1000 per 100,000, this was clearly a severe epidemic.

The present study was carried out in order to determine the immune status of a population at the time when a severe epidemic of poliomyelitis was terminating. More than 40 years ago Frost (1913) noted that poliomyelitis epidemics invariably decline in any limited area, as a single city or county, within a few months. Since in nearby communities the epidemic may start and continue to a later date, he concluded that 'the characteristic decline appears not to be due to exhaustion of sources or vehicles of infection nor to be dependent altogether upon seasonal conditions. It is difficult to account for on any hypothesis other than that of exhaustion of susceptible material in any population.' If one accepts this concept, it follows that the immune status of a population, at the time when an epidemic is terminating, may provide an indication of the proportion of immune persons required to constitute an effective barrier to free spread of virus under the circumstances prevailing in that community.

Information as to the immune status of a population at the end of an epidemic may also assist in resolving the further question as to why poliomyelitis virus of the same antigenic type will spread through a community causing relatively few cases of diagnosed poliomyelitis in one year, whereas in another year it will cause a severe epidemic. Probably the explanation most favoured by interested scientists at this time is that the virus prevalent during a severe epidemic is 'more virulent', implying that it produces paralytic disease in a higher than usual proportion of those infected. One might also suggest that it reaches a larger proportion of the susceptible population due to greater infectivity or to environmental conditions unusually favourable for spread of the virus. If epidemics are due to unusually great spread of virus, the proportion of immune persons should be higher at the end of an epidemic than at the end of a period of prevalence without an epidemic of paralytic cases.

* City Health Officer, Ketchikan, Alaska.

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It is worthy of emphasis that data pertinent to these problems may be obtained from a single collection of sera at the end of a poliomyelitis season. It is not necessary to have paired sera nor to estimate the total number of persons infected. The essential information is the proportion of the population that is immune at the end of a period of prevalence of poliomyelitis virus. Previously published investigations pertinent to this problem will be discussed after data from the Ketchikan study have been presented.

(*a*) *Description of Ketchikan and Metlakatla*

Ketchikan is on Revillagigedo Island near the southern tip of the 'panhandle' of Alaska that extends south and east between Canada and the Pacific Ocean. It is located in 55° 20′ N. and 131° 38′ W., approximately 500 miles north-west of Vancouver, British Columbia and 250 miles south-east of Juneau, Alaska. The racial origin of its residents listed in the 1950 census was 85 % white, 12 % aboriginal stock, almost entirely Indian, and 3 % other races. Persons 21 years of age and older made up 68 % of the population at that time. The principal industries are fishing, lumbering and mining.

The diet of residents of Ketchikan at the time of the epidemic differed in no material respect from that of persons in the United States, except that it was probably lower in fresh milk, vegetables and fruit.

In the general appearance of its residential and business districts, Ketchikan is a community comparable to cities of similar size in the United States. Most residences are well built houses that serve as single family dwellings. Streets near the centre of town are paved, and those more peripherally located are, on the whole, in good repair.

A community sewerage system discharges into the salt water at several points. Heavy pollution of the harbour results from this source, as well as from the numerous small fishing vessels moored at docks fronting on the city's business district. The municipal water system reaches all parts of town, and the water supply is ample and derived from several sources. There is no chlorination or filtration. Records of the local health department show that coliform organisms are found with great frequency in the water supply. The physicians of the community and other public spirited and well informed citizens have campaigned for adequate water purification for several years, but have been defeated by other influential persons who do not understand the need for such measures.

Ketchikan is built along the water front and extends back from the water up the sides of hills or mountains. The city proper is approximately 3 miles long and $\frac{1}{4}$ mile wide. Roads lead to the north and south approximately 28 miles. The native village of Saxman is located 2 miles to the south. A paper pulp mill estimated to cost 60 million dollars was under construction 5 miles to the north at the time of the epidemic.

The main routes of travel and commerce are by air and water. Pan American Airlines reported Ketchikan traffic in October, 1952, as 515 inbound passengers and 788 outbound passengers. This is good evidence that Ketchikan is not an 'isolated' community in the ordinary sense of the term.

Temperatures are moderated by ocean currents. The average temperature in January 1953, for example, was 32·7° F. The lowest temperature during that month was 12° F. Rainfall is exceptionally heavy. The total for 1952 was 167 in. Monthly totals for the period July through December were 8·47, 12·35, 22·48, 18·13, 13·50 and 13·55 in.

Metlakatla is a village that had 817 residents in 1950 and probably changed little by 1952. Nearly all are Indians. It is located on Annette Island approximately 15 miles from Ketchikan. This community enjoys an unusually high standard of living. There is community ownership of the local electric company, a canning factory and fishing boats. The island was given to the native community by an Act of Congress, and the community derives rental income from the airfield which is used by Pan American Airlines and other major airlines serving Ketchikan. A local airline carries passengers from Annette Island to Ketchikan in seaplanes that land in the Ketchikan Harbour. Ketchikan is the main marketing centre for residents of Metlakatla. Nurses employed by the community are in residence in Metlakatla; physicians of Ketchikan serve the village and hospitalize patients in the Ketchikan hospital.

(*b*) *Previous incidence of poliomyelitis in Ketchikan*

Dr Ben L. Myers of Iola, Kansas, practiced in Ketchikan from 1910 to 1920. He wrote in 1953 that he could recall seeing only one patient with poliomyelitis during this time. The last epidemic of poliomyelitis in Ketchikan prior to 1952 occurred in 1950 when fourteen cases of poliomyelitis were reported to the Health Department; there were three deaths.

(*c*) *Description of the* 1952 *epidemic*

The total number of poliomyelitis cases reported from Ketchikan to the Alaska Department of Health in 1952 was seventy-four. At least six patients were transported to Seattle or elsewhere for orthopaedic treatment. Two persons died, a 44-year-old man and a 4-year-old native child.

During our visits to Ketchikan in December 1952, and subsequently, data concerning fifty-nine poliomyelitis patients residing in Ketchikan were obtained. Of these, thirty-three were regarded as having had paralytic disease on the basis of clinical data presented, or if this was inadequate, on the basis of the report of the attending physician's diagnosis. Data on race, dates of onset, and age are given only for persons whose illness was considered to be paralytic because diagnoses of non-paralytic poliomyelitis have a considerably higher degree of unreliability than diagnoses of paralytic disease, even though the latter are recognized as also subject to appreciable error.

There was one paralytic case in July; in August there were two and one in September. The epidemic occurred primarily in October when nineteen paralytic cases had their onset. Seven more developed in November and three in December. Only one paralytic case can be definitely established as having an onset after the dates on which serum was collected from the general population. This patient, a man 49 years old, developed a weakness of the right leg on December 14. No virus was isolated from six specimens of his faeces and throat washings collected relatively

(*b*) *Technique of virus isolation*

Stool specimens from nine patients from Ketchikan and one from Metlakatla were tested for virus. Specimens had been collected between 2 and 38 days after onset of illness. Bacteria were eliminated by centrifugation and by the use of penicillin and streptomycin in the diluent and in tissue culture media. Roller tube cultures of rhesus testicular tissue were inoculated and observed for degeneration.

(*c*) *Methods used in serum neutralization tests*

Tests for antibody were made on all available serum specimens from poliomyelitis patients. Serum from apparently healthy persons in the younger age groups of the general population were tested in order to establish the pattern of antibody change with age, which presumably reflected the occurrence of the three types of virus in recent years. Since Type 1 virus proved to be implicated as a cause of the epidemic and since a near maximal proportion of the population was found to have antibodies to Type 1 virus by age 9 years, only a relatively few specimens from older age groups were tested. The latter were largely specimens from persons who had never resided outside of Alaska. All available specimens from Metlakatla were tested.

Initial tests for neutralization of Type 1 virus were performed using roller tube tissue cultures of monkey testicular tissue and the Ketchikan strain of virus Type 1. Viability of virus was indicated by cyto-necrosis. Later cyto-necrosis of monkey kidney cells was employed in limited numbers of neutralization tests with Types 1 and 3 virus. The results of these early tests were in good agreement with the more numerous and more quantitative tests subsequently performed according to the metabolic inhibition technique of Salk, Youngner & Ward (1954).

In the latter, the virus stocks used and the techniques employed were the same as those used in our laboratory in the vaccine evaluation programme sponsored by the National Foundation for Infantile Paralysis in the summer of 1954. Sera in 0·25 ml. amounts diluted 1/4, 1/32 and 1/128 were mixed with equal volumes of virus suspension. The virus used represented approximately 500 ID_{50} of the Mahoney strain of Type 1, or the Saukett strain of Type 3, or 50 ID_{50} of the MEF-1 strain of Type 2. After incubation of this mixture for 15 to 20 min. at room temperature, 0·25 ml. of a standardized suspension of monkey kidney cells was added and the tubes were transferred to the 37° C. incubator.

Before the metabolic inhibition methods were available, more than 100 serum specimens were tested for antibodies to Type 2 virus in four experiments using mice. In the mouse neutralization tests for antibody to Y-SK virus, groups of eight mice were inoculated with serum-virus mixtures containing 2–8 ID_{50} of virus and serum diluted ten-fold. Neutralization was considered to have occurred if all, or all but one, of the mice survived.

The results shown in Tables 1–5 and in Figs. 1 and 2 are derived primarily from metabolic inhibition tests. Data from tests based on cyto-necrosis or the inoculation of mice are used as an aid to interpreting the significance of titres of 1/4 or 1/8 in the metabolic inhibition tests.

The 'titre' of a serum was taken as the highest dilution which, when mixed with an equal volume of virus suspension, inactivated the virus as shown by survival of cells (depressed metabolic activity or normal microscopic appearance) after control tubes without serum had degenerated, or by failure of mice to die after intracranial injection of mixtures containing a mouse-virulent strain of Type 2 poliomyelitis virus.

RESULTS

(*a*) *Isolation of virus*

Only one strain of virus was isolated. This was from a faecal specimen collected from a 24-year-old male resident of Ketchikan 19 days after onset of non-paralytic poliomyelitis. The virus was neutralized by Type 1 poliomyelitis antiserum but not by Types 2 or 3. This Type 1 virus was designated as the Ketchikan strain. No virus was isolated from the other nine faecal specimens. Attempts to isolate virus from the throat washings of 2 patients also failed.

(*b*) *Antibodies in sera from poliomyelitis patients*

Sera from twenty poliomyelitis patients, whose illness began prior to our visit to Ketchikan, were tested. The results are shown in Table 1. Neutralization of virus

Table 1. *Neutralization of poliomyelitis viruses by sera from patients who contracted poliomyelitis in Ketchikan* 1952

	Neutralization of Type 1 virus				Neutralization of Type 2 virus				Neutralization of Type 3 virus			
Titre* ...	128	32	4	0	128	32	4	0	128	32	4	0
12 paralytic patients	9	2	0	1	2	1	3	6	4	4	3	1
8 non-paralytic patients	4	1	0	3	1	1	0	6	1	2	1	4

* A titre of 128 means that virus lost its infectivity, as shown by continued metabolic activity of cells, when mixed with serum diluted 1/128. A titre of 0 means that there was no inactivation of virus mixed with serum diluted 1/4.

by serum in a dilution of 1/32 or higher is presumed to be significant and is interpreted as evidence of antibodies against the virus concerned. Type 1 virus was neutralized to a significant titre by serum from eleven of the twelve paralytic patients. Eight of these patients exhibited neutralizing capacity for Type 3 virus and serum from three neutralized Type 2. One patient, previously mentioned as the last one to develop paralytic disease, had no antibodies to Type 1 virus. His serum neutralized Types 2 and 3 virus in a titre of 1/128. Among the eight non-paralytic patients, results were less consistent.

(*c*) *Antibodies to poliomyelitis viruses in sera from the general population of Ketchikan*

In Tables 2–4 data are presented to show the proportion of persons from various age groups in the general population whose serum was positive for neutralizing antibodies. As in the test of specimens from patients, a result was considered

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positive if virus was neutralized by serum in a dilution of 1/32 or higher in the metabolic inhibition test. This interpretation was substantiated by numerous duplicate tests in which cyto-necrosis of tissue cultures was used with Types 1 and 3 virus and infectivity for mice was used with Type 2 virus.

Estimates of error of random sampling. In Tables 2–5 and in Figs. 1 and 2 the 95% confidence limits of observed results are shown. These values were obtained from the tables and charts of Mainland (1952). As a rule data are grouped so that twenty or more persons are represented in each estimate of '% positive'. χ^2-analyses, with Yates's correction for small numbers, were made wherever needed to support assertions relative to the significance of differing results in two different age groups or in the same age group with different viruses. Whereas serological studies of the immune status of a population are subject to many sources of inaccuracy other than those inherent in random sampling, it is, nevertheless, necessary to keep this source of error constantly in mind when interpreting data of this sort.

Interpretation of low titres. Many serum specimens that showed a titre of 1/4 or 1/8 in the metabolic inhibition test were retested by other methods. (Dilutions of 1/8 were tested only in the few instances in which the amount of serum was insufficient for the usual test at a dilution of 1/4.) Results showed that these low titres had a different significance depending upon which of the three viruses was involved. Twenty specimens giving a titre of 1/4 or 1/8 with Type 2 virus in the metabolic inhibition test were retested using mice, and all but one were negative. Therefore, except for the one specimen that was positive when tested in mice, serum specimens giving a titre of 1/4 or 1/8 with Type 2 virus in the metabolic inhibition test are considered as negative in Table 3 and in Table 5.

Nine serum specimens with a neutralizing titre of 1/4 or 1/8 against Type 3 virus in the metabolic inhibition tests were tested by the method involving cyto-necrosis of rhesus testicular cells. The serum dilution in these tests was 1/5. Five neutralized virus and four did not. Two of the three serum specimens with neutralization titres of 1/4 or 1/8 against Type 1 virus in the metabolic inhibition test were retested by the method based on cyto-necrosis. One serum neutralized the virus and the other did not. Therefore, specimens with a titre of 1/4 or 1/8 in the metabolic inhibition tests with Types 1 and 3 viruses are considered positive or negative according to results of duplicate tests of the same specimens. The specimens that were not retested were excluded from the calculations of the per cent. positive for antibody to Type 1 or Type 3 virus as shown in Tables 2, 4 and 5.

Antibodies to Type 1 virus. The results of neutralization tests with Type 1 poliomyelitis virus are shown in Table 2. The sera from 74% of the children 5–7 years of age and sera from 86% of those 8 and 9 years old were positive. The values in these age groups were not significantly different. About one-third of the children less than 5 years of age were positive.

Antibodies to Type 2 virus. Results obtained with Type 2 virus (Table 3) indicated a considerably lower incidence of past infection with this virus than with Type 1. The data for all age groups up to and including 7 years do not differ significantly. Less than 10% of the specimens in this age range were positive.

Table 2. *Neutralization of Type* 1 *poliomyelitis virus by sera of subjects from the general population, Ketchikan* 1952

Age in years	No. of sera with a neutralization titre of: 128	32	4 or 8*	0	Total	No. pos./ total†	% pos.†	95% confidence limits	% pos.	95% confidence limits
<1	0	0	0	1	1					
1	1	0	0	4	5					
2	2	0	0	2	4	8/25	32	15–54	—	—
3	3	1	0	3	7					
4	1	0	0	7	8					
5	12	1	0	4	17					
6	13	1	0	8	22	27/39	69	53–83	74	61–84
7	17	0	(1+)	4	22	18/22	82	60–95		
8	19	1	(1)	3	24	20/23	87	66–97	86	72–95
9	16	2	0	3	21	18/21	86	64–97		
10–14	10	3	0	0	13					
15–24	3	0	(1−)	0	4	24/26	92	75–99	—	—
25–39	3	5	0	1	9					
40 and older	0	1	0	0	1	—	—	—	—	—
Total	100	15	3	40	158	—	—	—	—	—

See footnote to Table 1.

* Because titres of 1/4 or 1/8 in the metabolic inhibition tests were regarded as equivocal, duplicate tests for neutralizing antibodies were made by another method with many of these specimens. + indicates results were positive for antibodies, − indicates results were negative. Numbers in parentheses without a + or − denote specimens that were not retested.

† Titres of 1/32 or higher in metabolic inhibition tests with suspensions of kidney cells are considered positive. Interpretation of a titre of 1/4 or 8 was as follows: only three specimens gave this titre with Type 1 virus. Two of these were retested and recorded accordingly; the third was eliminated from tabulations of positive and negative sera.

From 8- and 9-year-old children 31 % were positive, and 58% of the specimens from persons 10–39 years old were positive. It is clear that the distribution of antibodies to Type 2 virus was significantly different from the distribution of antibodies to Type 1 virus.

Antibodies to Type 3 *virus.* Data obtained with Type 3 virus (Table 4) present a picture different from that of either Type 1 or Type 2. Of the specimens from children under 5 years 39 % were positive and approximately 20 % of the 103 specimens from the age group five to nine inclusive were positive. χ^2-analysis indicates that these differences are significant at approximately the 5 % level. These data do not constitute adequate evidence to justify a conclusion that the younger children were infected to a greater extent than the older ones. Indeed, such a conclusion would be contrary to any current concepts of the epidemiology of poliomyelitis and seems highly unlikely. There is, however, good reason to conclude that past infection with Type 3 was appreciably more restricted than with Type 1 among children less than 10 years of age.

(*d*) *Tests of sera from Metlakatla*

As shown in Table 5, serum was available from sixteen Metlakatla children aged 8 to 14 years. All sera were positive in tests with Type 1 poliomyelitis virus. Eleven of the specimens were clearly positive and only one was clearly negative in

Table 3. *Neutralization of Type 2 poliomyelitis virus by sera of subjects from the general population, Ketchikan* 1952

Age in years	No. of sera with a neutralization titre of 128	32	4 or 8	0	Total	No. pos./ total†	% pos.†	95% confidence limits	% pos.	95% confidence limits
<1	0	0	0	1	1					
1	1*	0	(1−)	3	5					
2	0	0	(2−)	2	4	1/21	5	0–24	—	—
3	0	0	(3−)	3	6					
4	0	0	(3−)	2	5					
5	1	2	(2−)	11	16					
6	1	0	(4)	17	22	4/38	11	3–25	9	3–20
7	0	1	(7−)(1)	9	18	1/18	6	0–27		
8	3	2	(1+)(6)	12	24	6/24	25	10–47	31	18–46
9	6	2	(1−)(6)	6	21	8/21	38	18–62		
10–14	4	2	0	5	11					
15–24	2	0	0	2	4	11/19	58	34–80	—	—
25–39	2	1	0	1	4					
40 and older	1	0	0	0	1					
Total	21	10	37	74	142					

See footnotes to Tables 1 and 2.

* An 18-month-old child who moved to Ketchikan from Texas at the age of 3 months.

† Titres of 1/32 or higher are considered positive. Thirty-seven specimens gave titres of 1/4 or 1/8. Twenty of these were retested by mouse inoculation, and all but one were negative. Therefore, specimens that were not re-tested are tabulated as negative.

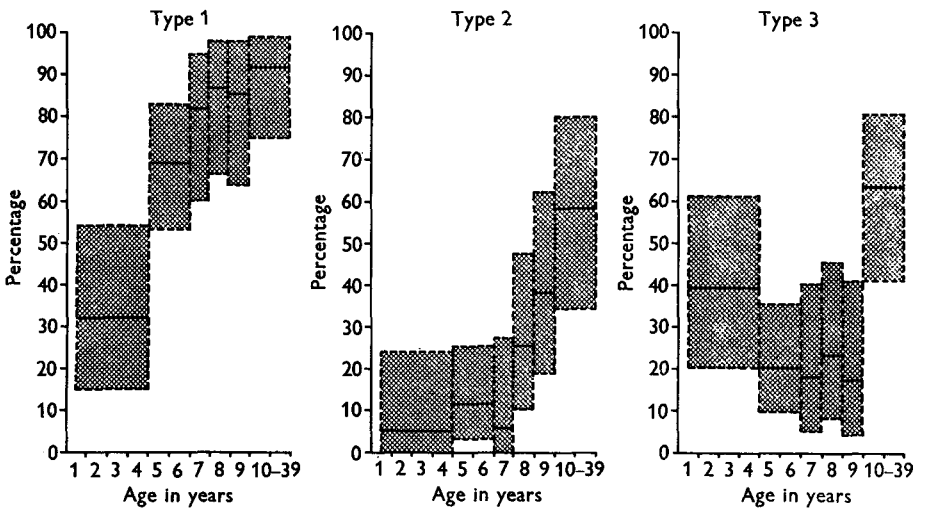

Fig. 1. Results of a survey of the general population of Ketchikan, Alaska, for neutralizing antibodies to the three types of poliomyelitis virus. The solid horizontal line represents the percentage of persons whose serum was positive. The 95% confidence limits of this value are indicated by the area enclosed in the broken line. (Example: 32% of twenty-five children less than 5 years old were positive for antibodies to Type 1 virus. The 95% confidence limits of this value are 15 and 54%.)

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Table 4. *Neutralization of Type 3 poliomyelitis virus by sera of subjects from the general population, Ketchikan 1952*

Age in years	No. of sera with a neutralization titre of 128	32	4 or 8	0	Total	No. pos./ total*	% pos.*	95% confidence limits
<1	0	0	(1)	0	1			
1	0	0	0	4	4			
2	0	0	0	4	4	9/23	39	20–61
3	*4*	*0*	*(1+)*	*2*	*7*			
4	2	2	0	4	8			
5	3	1	0	13	17			
6	1	3	(3−)	17	24	8/41	20	9–35
7	0	4	0	18	22	4/22	18	5–40
8	3	2	(2)	17	24	5/22	23	8–45
9	2	1	(3)	15	21	3/18	17	4–41
10–14	3	2	(1−)(1)	6	13			
15–24	1	0	(1+)	2	4	15/24	63	41–80
25–39	2	3	(3+)(1)	0	9			
40 and older	1	0	0	0	1			
Total	22	18	17	102	159			

See footnotes to Tables 1 and 2.

* Titres of 1/32 or higher are considered positive. Of the seventeen specimens that had titres of 1/4 or 1/8 by the metabolic inhibition test, five were positive and four were negative when retested using cyto-necrosis in kidney cell cultures as evidence of infection. The remaining nine specimens were not retested and are, therefore, omitted from calculation of % positive.

Table 5. *Neutralization of poliomyelitis viruses by sera from healthy children 8–14 years of age, Metlakatla, Alaska*

Virus	No. of sera with a neutralization titre of 128	32	4 or 8	0	No. pos.*/ total	% pos.	95% confidence limits
Type 1	15	1	0	0	16/16	100	72–100
Type 2	0	3	10*	3	3/16	19	4–46
Type 3	7	5	3	1	12/13	92	64–100

See footnote to Table 1.

* A titre of 1/32 or higher is considered positive. The ten sera with a titre of 1/4 or 1/8 to Type 2 virus were considered negative in view of the duplicate tests of Ketchikan sera, in which nineteen of twenty sera which gave a titre of 1/4 or 1/8 by the metabolic inhibition test, were negative when retested by mouse inoculation. The three sera with a titre of 1/4 or 1/8 to Type 3 virus were not retested and were, therefore, eliminated from the data. See footnotes to Tables 3 and 4.

tests with Type 3 virus. Only three were clearly positive for antibodies to Type 2 virus. The ten that neutralized this virus at a dilution of 1/4 or 1/8 but, not at 1/32, are regarded as negative for reasons stated previously. However, they add an element of uncertainty to conclusions relative to past infection with Type 2 virus. The possibility of a heterotypic antibody response to Types 1 and/or 3 virus must

be considered. Sabin (1952) and Miller & Wenner (1954) have presented discussions on heterotypic antibody response as a possible explanation for rise and fall of Type 2 antibodies in patients convalescent from Type 1 infections.

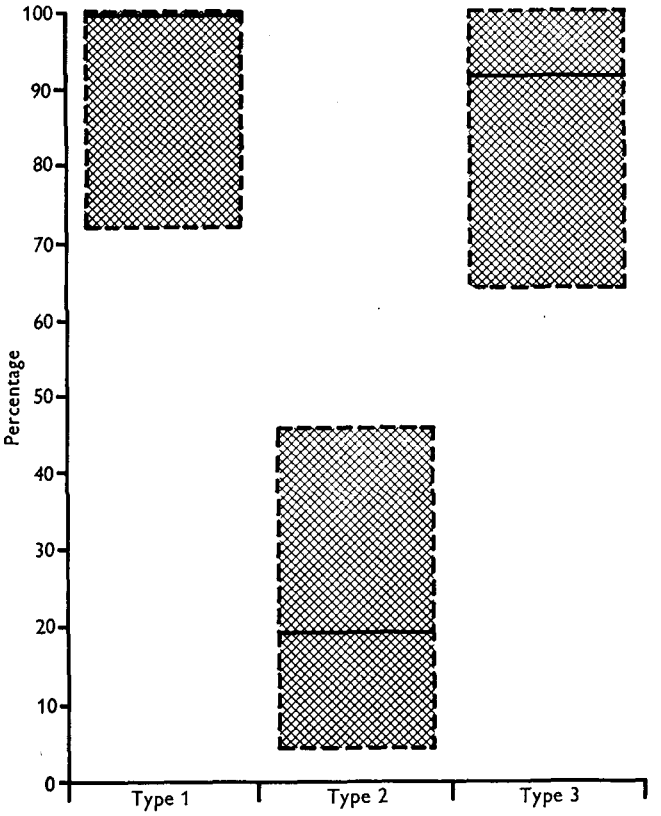

Fig. 2. Frequency of antibodies to the three poliomyelitis viruses in serum from sixteen children aged 8 to 14 years who resided in Metlakatla, Alaska. For reasons explained in the text, ten specimens with titres of 1/4 or 1/8 to Type 2 virus are regarded as negative and three specimens with titres of 1/4 or 1/8 to Type 3 virus are omitted.

DISCUSSION

(*a*) *Evidence for independent spread of the three poliomyelitis viruses in Ketchikan*

The age specific patterns of occurrence of antibodies to the three antigenic types of poliomyelitis virus presumably reflect the prevalence of these viruses in previous years. It seems evident that from year to year the three kinds of poliomyelitis virus varied greatly in prevalence and occurred more or less independently of each other.

Type 1 virus had infected approximately one-third of the tested children under age 5 years and two-thirds of those 5 and 6 years old. The only child under age 5 whose serum was definitely positive for antibodies to Type 2 virus was an 18-month-old infant born in Texas and brought to Ketchikan at the age of 3 months. In the age

group 5–9, only about one-quarter as many children had antibodies to Type 2 virus as had antibodies to Type 1 virus.

The following conclusions with respect to Type 3 virus appear to be justified from our data. Virus of this type was prevalent sometime within the 3-year-period preceding December 1952, since sera from four of seven children 3 years old were positive in a titre of 1/128. Whether that virus was prevalent during the epidemic of 1952 or prior to it, within the 3-year-period, cannot be stated from our data. Sera from nine children less than 3 years of age were tested; none neutralized virus. This, however, does not constitute good evidence of absence of Type 3 virus from Ketchikan during their lifetime; nine sera do not constitute an adequate number to establish this point. There is a notable uniformity in the incidence of positive tests for Type 3 antibodies in all age groups from 3 to 9 years. This suggests that the virus was absent for several years prior to the time of its most recent prevalence. If this had not been true, the proportion of sera with antibodies should have been higher among older children than among younger children. It is evident that spread of Type 3 virus terminated when 40% or less of the children of preschool age and early school age were infected. This conclusion can be reached without knowing in which year the spread of Type 3 virus occurred. It is based on the upper level of the 95% confidence limits of the observed proportions of positive results as shown in Table 4.

(*b*) *Comparison of the pattern of immunity to Type* 1 *poliomyelitis virus in Ketchikan with the patterns of immunity to poliomyelitis viruses in other communities*

It is of interest to compare the pattern of immunity to Type 1 virus in Ketchikan in December 1952, at the end of a severe epidemic, with the pattern of immunity to poliomyelitis viruses in other communities that did or did not experience an epidemic of poliomyelitis shortly before the time of study. Data suitable for such comparisons are meagre. Widespread use of vaccine may be expected to decrease the possibility of getting useful information of this kind in the future.

Three previous reports have been selected for discussion and comparison with the Ketchikan data. The New York study is included because it concerns virus of an antigenic type, or types, capable of causing a severe epidemic and constitutes an estimate of the spread of such virus during non-epidemic years. The Baltimore study is of interest because it is one of the most reliable reports, in terms of statistical adequacy, on the subject of spread of poliomyelitis virus. The fact that it concerns only Type 2 virus, which has rarely been found to cause epidemics, decreases its significance relative to the present discussion. The report concerning Winston–Salem is included as a previous study that provides useful information on the pattern of immunity in a population at the termination of an epidemic of poliomyelitis.

Spread of poliomyelitis virus in New York City during the years preceding the epidemic of 1916. In 1916 there were more than 9000 cases of paralytic poliomyelitis in New York City in one of the world's most extensive epidemics of this disease. Although the presence or absence of antibodies is not synonymous with immunity or susceptibility to poliomyelitis, there is a general pattern of relation-

ship between results of surveys for poliomyelitic antibodies and the occurrence of poliomyelitic disease, which allows one to use this approach when determining the immune status of a given population (Paul, 1955). On this basis it has been estimated (Sample & Evans, 1957) from the age specific-attack rates during the epidemic of 1916 that poliomyelitis virus of the same antigenic type or types that caused the epidemic infected and immunized approximately 30% of susceptible children in New York City each year for six successive years prior to 1916. Yet in these years there were so few cases of poliomyelitis that it was not regarded as a disease of major epidemiological importance.

The age specific-attack rates in New York in 1916 can be accepted with little doubt as reflecting the pattern of immunity that resulted from spread of poliomyelitis in previous years. The attack rate was maximum in children of age 1 and 2 years and did not differ significantly in these two age groups. The rate in children 5 and 6 years old was approximately 25% as great as that in 1- and 2-year-olds. It may be inferred that approximately 75% of children 5 and 6 years old were immune. This compares with data from Ketchikan indicating that at the end of a severe epidemic 69% of a sample of children of this age were immune. Similar comparisons can be made for children of other age groups.

It appears probable that during non-epidemic years prior to 1916 poliomyelitis virus of the type or types responsible for the subsequent epidemic, spread in New York City at least as extensively as Type 1 virus did during a severe epidemic in Ketchikan in 1952.

Spread of Type 2 virus in Baltimore. The studies of Turner, Hollander, Buckley, Kokko & Winsor (1950) show that Type 2 poliomyelitis virus spread among Baltimore children during a time of low incidence of clinical poliomyelitis as extensively as Type 1 virus spread among the children of Ketchikan in the epidemic of 1952. Their data indicate that 20–30% of 3-year-old children and 45–50% of 4-year-old children were positive for neutralizing antibodies. Data for children 5 years of age and older are not given for age groups of 1 year. Approximately three-quarters of those 5–9 years old were positive. The analyses of these data 'are based on the assumption that the attack rate in the population has been fairly stable from year to year'. This assumption, while justified in the Baltimore study, is clearly not justified for any of the three types of poliomyelitis virus in Ketchikan. Turner and his associates concluded that during the period of their observations Type 2 virus infected approximately 20% of susceptible children annually in the population studied. From their data it appears that this conclusion is valid for children 3 years old and older. The immune status of the population at the end of each season under these circumstances would be approximately the same as that for Type 1 virus in the Ketchikan population at the end of the 1952 epidemic.

It should be noted, however, that Type 2 virus evidently was much more restricted in its spread in Ketchikan in the years prior to December 1952, than it was in Baltimore at the time of the above studies. As previously noted, it spread much less than Type 1 in Ketchikan.

Spread of Type 1 virus in Winston-Salem, North Carolina during an epidemic. The study of Winston-Salem before and after the poliomyelitis epidemic of 1948, as

reported by Melnick & Ledinko (1953), is of especial interest. The prevailing virus during the epidemic was of Type 1. The epidemic terminated when approximately one-third of children under 5 years of age and two-thirds of those 5 to 10 years were immune. These results are similar to those obtained in the Ketchikan study.

SUMMARY AND CONCLUSIONS

In October, November and early December 1952, an epidemic of poliomyelitis, with an attack rate exceeding 1 %, occurred in Ketchikan, Alaska, a community of approximately 6000 persons. Approximately half of the cases were paralytic.

Type 1 virus was regarded as the principal cause of the epidemic because Type 1 virus was isolated from one patient, and sera from eleven of twelve paralytic patients tested were positive for neutralizing antibodies to Type 1 virus. Three patients had antibodies to Type 2 virus and eight to Type 3.

Serological tests were made to determine the immune status of the general population at the time the epidemic terminated. Approximately one-third of twenty-five children from 6 months to 4 years of age had antibodies to Type 1 virus. Of the 105 children aged 5 to 9 years, approximately three-quarters were positive for antibodies to this virus. All but two of the twenty-six persons more than 9 years of age who were tested were similarly positive.

Spread of Type 2 and Type 3 viruses was more limited in Ketchikan than spread of Type 1 virus. Serological evidence is presented to show that Type 3 poliomyelitis virus was present in Ketchikan some time within the 3-year-period prior to the collection of serum in December 1952. Since the proportion of children showing antibodies to Type 3 virus did not increase with age from 3 to 9 years, it is surmised that virus of this type was not prevalent for a number of years prior to its last occurrence. It is further concluded that spread of Type 3 virus must have terminated when 40 % or less of the children of pre-school age and early school age had been infected and developed antibodies.

Type 2 virus apparently had not been prevalent for several years prior to December 1952. Only one of twenty-one specimens of serum from children under age 5 showed definite evidence of neutralizing antibodies and this child had resided elsewhere during the first 3 months of its life. The proportion of positive results in all ages to 9 years inclusive was well below that obtained in tests with Type 1 virus.

From a review of published data concerning the age distribution of cases in the 1916 epidemic in New York, it is concluded that termination of the spread of Type 1 virus in Ketchikan occurred when the proportion of susceptibles in the general population was comparable to that in New York in each of several non-epidemic years preceding 1916. It is further evident that spread of Type 2 virus in Baltimore during a period of low prevalence of poliomyelitic disease was comparable to that of Type 1 virus in Ketchikan in 1952, in that the proportion of susceptibles in the population at the end of the period of spread of virus was similar.

Serological studies of residents of Metlakatla, an Indian community near Ketchikan, showed evidence of essentially uniform infection with Type 1 virus, a

very high incidence of antibodies to Type 3 virus, and a much lower incidence of antibodies to Type 2 virus.

The epidemiological aspects of poliomyelitis in Ketchikan cannot be reasonably attributed to susceptibility resulting from isolation of the community, since travel to and from Ketchikan was considerable and a relatively large proportion of persons with paralytic disease were adults who had travelled extensively, and resided for periods of years in various parts of the United States. It is noted that the municipal water supply showed frequent evidence of faecal pollution.

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