POLIO THEN AND NOW
ancient Egypt and contemporary southern Asia

Egyptian stele, 14th century BC

Wikipedia, 2009

POLIOMYELITIS REVISITED
an epidemiological and historical perspective (to 1973)
Neal Nathanson, University of Pennsylvania

• Polio emerges: ancient history and the early outbreaks, through 1916
• Polio triumphant: annual epidemics in the United States, 1916-1955
• Polio in retreat: IPV to first eradication, 1955-1973
• Polio deconstructed: epidemiological enigmas and explanations

Wikipedia, 2009
EMERGENCE OF POLIO AS AN EPIDEMIC DISEASE
United States, 1885-1916

Lavinder et al Public Health Bulletin #1, 1918

EMERGENCE OF POLIO AS AN EPIDEMIC DISEASE
the world, 1880-1916

Lavinder et al Public Health Bulletin #1, 1918
EMERGENCE OF POLIO AS AN EPIDEMIC DISEASE

first enigma

OBSERVATION

• Between the years 1890 and 1910 polio appeared as an epidemic disease in the USA and many European countries?

ENIGMA

• What explains the transition from a sporadic to an epidemic disease?

POLIO DECONSTRUCTED

epidemiological enigmas and hypotheses

HYPOTHESIS

• Poliovirus was ubiquitous prior to appearance of epidemic polio: epidemics do NOT reflect an increase in the number of polio infections
• Appearance of polio epidemics does NOT reflect an increase in virulence of poliovirus
• The appearance of epidemic poliomyelitis was due to a delay in initial infection from infancy to childhood
• Infants infected prior to age 6-12 months were protected against paralysis by maternal antibody while toddlers were not

EVIDENCE TO TEST THE HYPOTHESIS

• Seroepidemiological comparison of pre- and post-epidemic regions
• Comparison of two populations in a single city: Casablanca, 1947-1953
• Sero-epidemiology in pre-epidemic population: Casablanca, 1953
poliovirus is ubiquitous prior to the emergence of epidemic polio infections are delayed in regions where polio is epidemic

![1953 seroepidemiology](image)

Paul WHO Monograph 26, 1955

polio incidence in two populations in a single city: Casablanca, 1947-1953

<table>
<thead>
<tr>
<th></th>
<th>European</th>
<th>Moroccan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>125,000</td>
<td>530,000</td>
</tr>
<tr>
<td>Paralytic polio cases, 1947-1953</td>
<td>117</td>
<td>25</td>
</tr>
<tr>
<td>Average annual attack rate per 100,000</td>
<td>13.4</td>
<td>0.7</td>
</tr>
<tr>
<td>Epidemic</td>
<td></td>
<td>Pre-epidemic</td>
</tr>
<tr>
<td>1953 cases by age group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-1</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>2-9</td>
<td>15</td>
<td>2</td>
</tr>
<tr>
<td>10-39</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

POLIO DECONSTRUCTED
age-specific poliovirus antibody prevalence
Moroccan population, Casablanca, 1953


Pre-existing serum antibody will confer protection against paralytic poliomyelitis at a titer of ≥1:4

Francis et al. 1954 Field Trial of poliovirus vaccine, 1957
POLIO TRIUMPHANT: ANNUAL EPIDEMICS
Polio age distribution, Massachusetts, 1912-1952

Dauer Pro NY Acad Sci 1955, 61: 943

POLIO TRIUMPHANT: ANNUAL EPIDEMICS
Paralytic polio incidence, USA, 1915-1954

Serfling and Sherman Pub Hlth Rep 1953, 68: 453; and CDC, 1955
POLIO TRIUMPHANT: ANNUAL EPIDEMICS
second enigma

OBSERVATIONS
• After its appearance polio became an annually recurring epidemic disease (USA, 1900-1954)
• During this period the age distribution increased quite dramatically, evolving from “infantile paralysis” into a disease mainly of children and young adults

ENIGMA
• Why did the age distribution evolve?
• Did the advancing age of infection result in an overall increase in incidence?

POLIO DECONSTRUCTED
epidemiological enigmas and hypotheses

HYPOTHESIS
• Improved sanitation and personal hygiene reduced the probability of transmission and led to a delay in the age of infection (USA, 1900-1950)
• The data are unclear whether this led to an increase in overall incidence of paralytic poliomyelitis

EVIDENCE TO SUPPORT THE HYPOTHESIS
• Studies of the case:infection ratio by age
• Polio incidence in New York City, 1910-1954
### POLIO DECONSTRUCTED
*Age-specific paralytic case:infection ratio*

<table>
<thead>
<tr>
<th>Age</th>
<th>Number of seroconverters</th>
<th>Paralytic cases</th>
<th>Cases per 100 seroconverters</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1</td>
<td>450</td>
<td>3</td>
<td>0.66</td>
</tr>
<tr>
<td>1-2</td>
<td>1,000</td>
<td>10</td>
<td>1.00</td>
</tr>
<tr>
<td>3-4</td>
<td>741</td>
<td>12</td>
<td>1.62</td>
</tr>
<tr>
<td>5-9</td>
<td>1,042</td>
<td>25</td>
<td>2.40</td>
</tr>
<tr>
<td>10-14</td>
<td>716</td>
<td>13</td>
<td>1.82</td>
</tr>
<tr>
<td>TOTAL</td>
<td>3,949</td>
<td>63</td>
<td>1.59</td>
</tr>
</tbody>
</table>

Melnick and Ledinko Am J Hyg 1953, 58: 207

### POLIO DECONSTRUCTED
*Average annual polio incidence, New York City, 1910-1952*

![Bar chart showing average annual polio incidence from 1910 to 1950](chart.png)

Siegel et al. NE J Medicine 1955, 252: 752
### POLIO TRIUMPHANT: SEROTYPE DIFFERENCES
Frequency of isolates from poliomyelitis cases, by serotype, USA, 1952

Data by regions with different overall attack rates

<table>
<thead>
<tr>
<th>Regions by attack rates per 100,000</th>
<th>Number of isolates</th>
<th>Percent of isolates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Continent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Type 1</td>
</tr>
<tr>
<td>445-103 270</td>
<td>94%</td>
<td>4%</td>
</tr>
<tr>
<td>94-43 156</td>
<td>77%</td>
<td>10%</td>
</tr>
<tr>
<td>40-16 235</td>
<td>77%</td>
<td>20%</td>
</tr>
<tr>
<td>15-4 133</td>
<td>59%</td>
<td>28%</td>
</tr>
</tbody>
</table>

*Shelokov et al Proc NY Acad Sci 1959, 61: 998*

### POLIO DECONSTRUCTED
third enigma

**OBSERVATION**
- The three serotypes of poliovirus appear to vary in epidemic significance: type 1; type 2; type 3
- Wild type 2 poliovirus has been eradicated while types 1 and 3 have not

**ENIGMA**
- Is this due to differences in environmental survival; infectivity; viremogenicity; neuro-invasiveness; or neurovirulence?
POLIO TRIUMPHANT: SEASONALITY
Poliomyelitis cases by month, New England, 1915-1954

NEW ENGLAND
PEAK MONTH: 31%
TROUGH MONTH: 0.3%

MONTH

0 5 10 15 20 25 30 35
PERCENT OF ANNUAL TOTAL

Serfling and Sherman Pub Hlth Rep 1953, 68: 453; and CDC, 1955

POLIO TRIUMPHANT: A DREAD DISEASE
Past images from the USA
**POLIO TRIUMPHANT: A FRIGHTENING SPECTER**
Iron lung ward at Rancho los Amigos, Downey, California, USA, 1953

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**POLIO DECONSTRUCTED**
fourth enigma

**OBSERVATIONS**
- Polio seasonality is marked in cold climates and peaks in late summer
- Seasonality is marked for many viral diseases but peaks occur at different times of year

**HYPOTHESIS**
- Seasonality does NOT reflect differences in human activity
- Seasonality reflects seasonal differences in humidity but NOT in temperature

**EVIDENCE**
- Rotaviruses (another enterovirus) has totally different seasonality
- Polio seasonality is associated with seasonal changes in indoor humidity, but not in tropics where humidity is constant and high
- Environment duration of poliovirus infectivity is much greater at elevated relative humidity and constant temperature (20°C)
POLIO DECONSTRUCTED
Seasonality of polio and rotaviruses, USA


POLIO DECONSTRUCTED
Seasonality, New England and Hawaii compared

Nathanson and Martin Am J Epidemiology 1979, 110: 672
**POLIO DECONSTRUCTED**

Poliovirus survival at 20°C is sensitive to reduced humidity

Hemmes et al. Ant V Leeuwenhoek 1962, 28: 221

**POLIO IN RETREAT: IPV TO FIRST ERADICATION**

Polio incidence, USA, 1952-1979

Nathanson and Martin Am J Epidemiology 1979, 110: 672
POLIO DECONSTRUCTED
fifth enigma

OBSERVATIONS
• Prior to the introduction of polio vaccine in 1955, ~16% of the population (24 million) were susceptible to polio
• In the USA, by 1970, vaccination programs (IPV and OPV) had reduced susceptibles to ~2.6% of the population (>5 million)
• It was assumed that the residual susceptible group would continue to circulate wild polioviruses: control not eradication

HYPOTHESIS
• IPV and OPV-induced “herd immunity” that reduced circulation of wild polioviruses
• Seasonality played a key role in the disappearance of wild polioviruses in the USA

EVIDENCE
• Both OPV and IPV reduced circulation of wild polioviruses?
• Wild polioviruses faded out during winter trough?
• Stepwise fadeouts in individual States

<table>
<thead>
<tr>
<th>Polio incidence by year</th>
<th>Expected if no vaccine</th>
<th>Expected if 65% IPV protected</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1958</td>
<td>27,316</td>
<td>11,794</td>
<td>3,795</td>
</tr>
<tr>
<td>1959</td>
<td>28,224</td>
<td>10,191</td>
<td>6,358</td>
</tr>
<tr>
<td>1960</td>
<td>28,964</td>
<td>8,964</td>
<td>2,556</td>
</tr>
<tr>
<td>1961</td>
<td>29,521</td>
<td>8,471</td>
<td>1,002</td>
</tr>
<tr>
<td>1958-1961</td>
<td>114,025</td>
<td>39,420</td>
<td>13,711</td>
</tr>
<tr>
<td>Percent of baseline</td>
<td>100%</td>
<td>35%</td>
<td>12%</td>
</tr>
</tbody>
</table>

Vaccine protection: (% immunized with IPV) X (% IPV efficacy)
### POLIO DECONSTRUCTED

**Calculated perpetuation of wild polioviruses during seasonal trough in New England, 1950 and 1970**

<table>
<thead>
<tr>
<th></th>
<th>Pre-vaccine 1950</th>
<th>Post-vaccine 1970</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total population</td>
<td>1,000,000</td>
<td>1,000,000</td>
</tr>
<tr>
<td>Polio susceptible population</td>
<td>160,000</td>
<td>26,000</td>
</tr>
<tr>
<td>Annual polio infections</td>
<td>20,000</td>
<td>1,000</td>
</tr>
<tr>
<td>Polio infections per generation period at seasonal trough (0.1% of annual total)</td>
<td>20</td>
<td>~1</td>
</tr>
</tbody>
</table>


### POLIO DECONSTRUCTED

**States reporting any polio, USA, 1960-1973**

- **1963**: ORAL POLIOVIRUS VACCINE INTRODUCED
- **1973**: WILD POLIOVIRUS ERADICATED

Nathanson and Martin Am J Epidemiology 1979, 110: 672
FINIS