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BLOG

Polio and the early history of wastewater epidemiology

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COVID-19 wasn't the first application for wastewater-based epidemiology.

Wastewater-based epidemiology has reached an unprecedented scale during the COVID-19 pandemic. The US government recently supported COVID-19 wastewater monitoring at over 300 wastewater facilities that together serve 100 million Americans. Many more locations are monitored by local and state governments and by academic scientists.

But COVID-19 isn't the only pathogen being monitored in wastewater. Outbreaks of norovirus, hepatitis A, and salmonella have been tracked with wastewater. Wastewater can also help public health by monitoring use of dangerous substances. Before the pandemic, Biobot worked with the City of Cary, North Carolina to monitor opioid usage to help prevent overdoses. Groups in Europe monitor drug usage in major cities.

It's hard to pinpoint the origins of wastewater-based epidemiology. Starting with the ancient Greeks, western medicine has blamed disease on the noxious smells arising from sewage. The idea that wastewater itself, rather than its stench, can transmit infectious diseases traces back to 1850s England. The pathogen that causes typhoid was isolated from sewage as early as 1928.

Not long after, in 1932 in Philadelphia, a different pathogen was isolated from wastewater for the first time: the virus that causes polio.

Polio's reign of confusion and terror

Unlike COVID-19, polio has been with humanity for a long time, possibly since ancient Egypt or even before. In the early 20th century, polio had become one of the most worrying diseases in the United States. About a thousand Americans were dying of polio every year; many more, mostly children, were being paralyzed:

> Poliomyelitis has several characteristics that make it a dreaded malady. Its exact method of transmission is unknown but it strikes swiftly and has a long duration of severe and painful symptoms with frequent residual crippling which may last throughout life. (Collins 1946)

It was known that polio was caused by a virus, called poliovirus, but the disease seemed unpredictable and treacherous. Outbreaks seemed to occur at random. No one was safe, not even the healthy, wealthy, and powerful.

A key part of the mystery was polio's transmission route. No one knew exactly how polio moved from person to person. Was polio a respiratory disease, like COVID-19 is? Or was it passed by the fecal-oral route, from infected people to contaminated wastewater to new victims? Or maybe it was transmitted via "blood-sucking arthropods", in the same way that Lyme disease and malaria are? The answer would have huge implications for public health response. For example, if it was a respiratory disease, then improving sanitation and shutting down public pools wouldn't help.

Witnessing the COVID-19 pandemic, it shouldn't be hard to imagine the confusion that comes from not knowing how a disease is transmitted. Now we know that COVID-19 is spread primarily by aerosols, which are best combated by avoiding crowded indoor spaces, wearing masks, and improving ventilation. (COVID-19 vaccines, a hugely effective intervention that could save your life, also reduce transmission.) But early on, the focus was on hand-washing and six-foot social distancing, which are more effective against droplets rather than aerosols. When it was first shown that people infected with SARS-CoV-2 shed the virus in their stool, there was concern that you could catch COVID-19 from contaminated water. It turns out that you can't: no one has caught COVID-19 from wastewater.

To add to the confusion about how polio was spread, it was suspected, but not confirmed, that only about 1% of people with polio suffer paralysis. Researchers suspected that polio outbreaks were like icebergs: 99% of cases were invisible, and what looked like an isolated case or two could in fact turn out to be a major outbreak. (As it turns out, this suspicion was correct, and wastewater monitoring is such a crucial part of polio elimination efforts today because it gives public health officials the chance to detect those 99% of cases that don't show any polio-specific symptoms.)

Peering into wastewater to solve polio's mysteries

In the 1930s, a team of leading polio scientists had an idea about how to test the hypothesis that polio was transmitted by the fecal-oral route. They would look in wastewater:

> [Poliovirus] can be readily isolated from the stools of some patients with this disease. Our own experiments, and those of many others, now testify to the ease with which this can be accomplished; […] Obviously, therefore, when an epidemic of poliomyelitis occurs within a city there must be ample opportunity for the virus to enter the local sewage system. And, considering the frequency of mild and unrecognized forms of poliomyelitis, and the length of time which such cases may be potentially infectious, it seems possible that the concentration of virus in urban sewage may become appreciable. (Paul, Trask, Gard 1940)

These scientists, led by John Paul and James Trask, carried out an early wastewater-based epidemiology study in 1932, in Philadelphia.

Like most American cities, Philadelphia did not have a modern wastewater treatment system, that kept sewage out of local rivers, until after World War II. Instead, underground sewers discharged Philadelphia's wastewater directly into the Delaware and Schuylkill Rivers. This meant that sewage was discharged on one side of a pier, while children swam in the river literally on the other side of the pier.

Sewer discharging from the Allegheny Avenue Sewer at Pier 126 in Philadelphia. 15 July 1918. ([Philadelphia Water Department](https://).)

Children swimming. Same day, same pier. ([Philadelphia Water Department](https://biobot.io).)

The researchers collected samples from the sewer outlets draining into the rivers and tried to grow poliovirus from the samples. Disappointed with the results, they tried again in 1937, in New Haven, Connecticut. In the authors' own words:

"The methods were crude in both series of attempts and the results, which were all either unsatisfactory or negative, were not reported."

They needed monkeys. A lot of monkeys.

After the failed attempts in 1932 and 1937, Paul, Trask, and their colleagues refined their methods. By 1939, they had developed a method that could detect and even quantify the amount of virus in sewage from the cities. The researchers analyzed samples from Detroit, Michigan; Buffalo, New York; and Charleston, South Carolina.

But for the method to work, they needed monkeys. A lot of them.

Nowadays, when we look for polio in wastewater, we use two methods. First, we can infect cells in a Petri dish with poliovirus, a methodology considered so important that its inventors won a 1954 Nobel Prize. Second, we can use polymerase chain reaction, or PCR. PCR, a technology invented in 1983, can detect very small amounts of poliovirus's genetic material in wastewater. PCR is also the technology used for many COVID-19 diagnostic nasal swab tests and COVID-19 wastewater tests.

But Paul and Trask were doing their work before PCR and before these cell culture methods. Instead, they had to use the even earlier method for detecting polio. Basically, you inject wastewater into a monkey and see if the monkey gets polio.

Viewed from the perspective of today's wastewater-based epidemiology, this monkey-based method had enormous problems. First, it was slow. Today, with PCR, results of tests for poliovirus or COVID-19 virus in wastewater can be turned around in as little as a day, fast enough to inform a public health response. With the monkey method, testing a single sample took weeks. It's important to remember that these original polio researchers were not trying to inform a public health response in real time; they were simply trying to understand whether polio could be transmitted via human stool. Second, it was unreliable. Around a third of monkey tests failed because the monkey died, not from polio, but from some other chemical or pathogen that was in the wastewater injected into them. Third, monkeys are not cheap to breed and maintain, and the supply of monkeys was a limiting factor for this research. Now that we have culture methods, PCR, and a greater regard for animals' suffering, the idea of injecting sewage into a monkey to see if it will die of a certain disease seems monstrous.

A new field is born

In some ways, the early polio wastewater work was a disappointment:

> But perhaps the most important question of all is, what does the finding of the virus mean in so far as the spread of [polio] is concerned? In answer one could say that it is not evident from this work whether or not the presence of [poliovirus] in sewage is a direct or even an indirect link in the chain which usually or even occasionally leads this infectious agent from one patient to another in this disease.

> Our report merely calls attention to the fact that during urban epidemics of this disease the local sewage may contain this virus. (Paul, Trask, Gard 1940)

In other words, Paul and Trask failed to definitively determine whether wastewater was part of polio's route of transmission. In the 1940s, Albert Sabin used autopsies of polio victims to prove that poliovirus lives primarily in the intestines. Sabin went on to invent one of the two polio vaccines. Vaccination, in combination with improved sanitation, has led to elimination of polio in the US and most other countries.

But Paul and Trask made a different contribution, which gave birth to the field of wastewater-based epidemiology. They couldn't determine if wastewater was the *source* of disease risk, but they found that wastewater could be used as an *indicator* of disease activity. For polio, both angles are important: wastewater can transmit disease, and wastewater can be used to detect disease activity. For COVID-19, only the second is important: you can't catch COVID-19 through exposure to contaminated water, but you can track population-level COVID-19 trends using wastewater.

COVID-19: a springboard for wastewater-based epidemiology

The limitations of the monkey-based test meant that, in Paul's and Trask's time, wastewater could not provide real-time data to inform public health decision-making. These barriers have fallen away. Cell culture methods, PCR, and genomic sequencing have made monitoring for pathogens in environmental samples more feasible. Advances in measuring chemicals excreted by the human body has also made drug use monitoring feasible at scale. We now have all the scientific tools needed for real-time wastewater monitoring of disease activity and substance use.

If they had the tools, Paul, Trask, and their colleagues would likely have implemented the kind of real-time wastewater monitoring we now use to track polio. The extension to other pathogens would have been a simple next step.

Now our challenges are as much logistical as scientific, optimizing our systems for collaboration between public health and public works, improving data interpretation, and developing reliable sources of financial support for wastewater monitoring. COVID-19 wasn't the beginning of wastewater-based epidemiology, but it is hopefully the springboard that ensures that we don't pass up the opportunity to build a healthier society using wastewater monitoring.

Key references

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