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Silent circulation of poliovirus in small populations

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ABSTRACT

Background: Small populations that have been isolated by conflict make vaccination and surveillance difficult, threatening polio eradication. Silent circulation is caused by asymptomatic infections. It is currently not clear whether the dynamics of waning immunity also influence the risk of silent circulation in the absence of vaccination. Such circulation can, nevertheless, be present following a declaration of elimination as a result of inadequate acute flaccid paralysis surveillance (AFPS) or environmental surveillance (ES).

Methods: We have constructed a stochastic model to understand how stochastic effects alter the ability of small populations to sustain virus circulation in the absence of vaccination. We analyzed how the stochastic process determinants of the duration of silent circulation that could have been detected by ES were affected by R_0, waning dynamics, population size, and AFPS sensitivity in a discrete individual stochastic model with homogeneous contagiousness and random mixing. We measured the duration of silent circulation both by the interval between detected acute flaccid paralysis (AFP) cases and the duration of circulation until elimination.

Results: As R_0 increased and population size increased, the interval between detected AFP cases and the duration of circulation until elimination increased. As AFPS detection rates decreased, the interval between detected AFP cases increased. There was up to a 22% chance of silent circulation lasting for more than 3 years with 100% AFP detection. The duration of silent circulation was not affected by the waning immunity dynamics.

Conclusion: We demonstrated that small populations have the potential to sustain prolonged silent circulation. Surveillance in these areas should be intensified before declaring elimination. To further validate these conclusions, it is necessary to realistically relax the simplifying assumptions about mixing and waning.

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Abbreviations

AFP acute flaccid paralysis
AFPS acute flaccid paralysis surveillance
ES environmental surveillance

1. Introduction

After polio was on the precipice of elimination in Nigeria based upon the WHO criteria of three years without a paralytic case (Henderson, 1989), there were several new paralytic cases of poliovirus type 1 in an area of small villages in Borno State (Nnadi et al., 2017). After an attempt at exhaustive vaccination coverage, there was unanticipated emergence. A possible cause is that communities were not reachable by the intervention program. This could either be due to political impediments such as Boko Haram terrorism or due to noncompliance (MM & Ayivor, 2012). Furthermore, Fulani communities are migratory populations that are present in this and in neighboring states in Northern Nigeria (Callaway, 2013; Molineauz & Gramiccia, 1980). Their nomadic lifestyle makes them difficult to reach with comprehensive vaccination coverage, which represents a second potential source of an unanticipated paralytic case following the three years with no such observed case.

The paralytic cases are a result of a silent circulation of the virus in the population. In this paper, we focus on small and somewhat isolated populations that have endemic circulation of poliovirus. The question we aim to answer is: how long, and under what conditions, can a silent circulation persist in small populations in the absence of vaccinations? A silent circulation either ends when there are no longer infected individuals in the population or a paralytic case of polio is detected. We investigate this situation using a microsimulation model of polio transmission in village sizes between $3,500$ and $10,000$. We assume transmission takes place in the absence of intervention against polio. This allows for the understanding of polio transmission in a natural setting, and, in particular, to ascertain the distribution of times until the infected population reaches zero as well as the distribution of times between consecutive appearances of paralytic cases. It also raises the question as to whether AFPS is a sufficient monitoring strategy to declare areas of small populations free of poliovirus.

There are two surveillance systems used to detect poliovirus in a population: AFPS and ES. AFPS uses reported cases of polio-induced AFP to detect circulating poliovirus. This surveillance system can only be used to identify an individual's first contact with the virus since these are the only individuals with the potential to be symptomatic (Koopman et al., 2017; Thompson, Pallansch, Tebbens, Wassilak, & Cochi, 2013). ES can be used to detect silently circulating poliovirus in a population. Poliovirus is excreted when an individual has an active infection regardless if they are symptomatic or asymptomatic (Fine & Carneiro, 1999; Grassly et al., 2012; Mayer et al., 2013; Tebbens et al., 2013; Thompson et al., 2013). ES involves testing sewage for evidence of the virus. In the case where there are no symptomatic individuals, poliovirus found in the sewage can demonstrate that the virus is silently circulating in the population (Fine & Carneiro, 1999). ES may not be feasible either due to monetary limitations or to the lack of a sewage system or at least a common drainage area for defecations. For these reasons, AFPS is, currently, the most used method of poliovirus detection. AFPS is not without its limitations. This method of detection requires that individuals report the symptoms of paralysis to a healthcare worker. Instances of under-reporting can cause cases of polio to go undetected. This may lead to countries being declared polio-free prematurely. Under-reporting of polio-induced paralysis cases can be the result of political instability or geographical isolation.

The waning of immunity and subsequent reinfections can cause silent circulation or asymptomatic transmission. Neither infection from poliovirus nor infection from vaccination provide life-long immunity from the virus (Famulare et al., 2016; Grassly et al., 2012). Once immunity to poliovirus has waned, there is a possibility of reinfection. To capture the waning immunity dynamics, Koopman et al. (2017) explored three different waning scenarios. The first is that the immunity wanes quickly after recovery from the infection, but the individual retains a significant amount of immunity. This is defined as fast-shallow waning. The second is that the individual preserves a high level of immunity for a long period of time, but then loses a large portion of their immunity to the virus. This is defined as slow-deep waning. The third is an intermediate between fast and slow in both speed and depth. In this paper, we focus on these three waning scenarios.

The small population sizes that are emphasized in this paper are, indeed, realistic village sizes in Nigeria. There is a cluster of villages in Pampaida, Nigeria that are associated with the Millennium Villages Project (Millennium Villages Project: Pampaida, Nigeria, 2006). These villages are comprised of both the Hausa and the Fulani, two of the main tribal groups found in Nigeria. There are a total of four villages with approximately $27,000$ individuals. This implies that the average village size contains $6,750$ individuals. The Garki project provided a population census for the Garki District in northern Nigeria from 1969 to 1976 (Molineauz & Gramiccia, 1980). In February of 1972, the 8 villages that were considered for the project had a total of $7,540$ individuals. If we assume a constant growth rate of 0.0088 individuals per year (birth rate minus death rate) (Molineauz & Gramiccia, 1980) then, over the last 44 years, the population of these villages has increased to $10,459$ individuals. On a per village basis, the population sizes are all within the range considered in our simulations.