Outbreak risks, cases, and costs of different vaccination strategies against wild poliomyelitis

Short title: how we used simple models to inform economic decision-making

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BMGF OPP1191821 // INV-049298
We focus on the challenge of polio supplementary immunization activities (SIAs) in non-endemic countries, given a fixed (limited) budget.

- **Context**: wild poliovirus serotype 1 (WPV1) in AFRO
- **Current status of pSIAs**: average number of preventative SIAs (pSIAs) have declined in recent years and some countries have not conducted a pSIA in over a decade...

- Explore corresponding costs and trade-offs
  - Global Polio Eradication Initiative (GPEI) perspective (future funding and programmatic needs)
  - Non-GPEI perspective (including health system perspective)
  - Global perspective (eradication goals)
Model assumptions and parameters

- Extended SIR model, stochastic simulations to allow for variability
  - Account for differential immunity with dose exposure (i.e. not all or nothing for vaccination)
  - RI includes both bOPV and IPV
  - Allow for importations of infection
  - Case to infection ratio (WPV 1:200)
  - $R_0 = 3$, so, herd immunity threshold is ~ 67%

- 5-year time horizon to align with GPEI strategic plan
- Model a “hypothetical” population for an LMIC country in Africa (~8 Million children <5 years of age)
- Model outputs for each vaccination strategy:
  - Expected cases of paralytic polio
  - Disability adjusted life-years (DALYs)
  - Number of outbreaks
  - Probability no outbreaks occur
  - Adverse events of vaccination (vaccine associated paralytic polio, VAPP)
Comparator vaccination strategies

3 Vaccination strategies – outbreak is defined as ≥1 case of paralytic polio

1. RI + oSIAs: vaccination via RI, no preventative SIAs, only outbreak response in simulations with ≥1 case **baseline comparator**
2. Annual pSIAs: RI + annual preventative campaigns in all simulations
3. Biannual pSIAs: RI + biannual preventative campaigns in all simulations
Opportunities for vaccination

- RI
- pSIAs
- oSIAs

Vaccination increases population immunity

Increasing RI coverage or the frequency of SIAs increases the number of vaccine doses administered

- Number of paralytic poliomyelitis cases
- Probability of outbreaks
- Number of VAPP cases

Effect on DALYs from paralytic poliomyelitis cases
Effect on DALYs from outbreaks
Effect on DALYs from VAPP cases

Number of paralytic poliomyelitis cases
Costs from outbreaks
Costs from VAPP cases

London School of Hygiene & Tropical Medicine
Economic assumptions:
- SIA cost data from GPEI (operational, procurement, social mobilization)
- oSIAs are more expensive than pSIAs
- Cost and DALYs per paralytic poliomyelitis case = VAPP case
- Who pays for what?
  - **Health system (non-GPEI) costs =**
    - bOPV via RI + cases + VAPP
  - **GPEI costs =**
    - SIAs + IPV via RI
Vaccination strategy

- oSIAs
- Annual pSIAs
- Biannual pSIAs

Total costs over 5 years

Size of the circles is proportion to the number of expected AFP cases
Solid points indicate >80% probability of no outbreak

Health system and non-GPEI costs

GPEI costs

Fewer cases
Greater probability no outbreaks occur
From **GPEI perspective**, in comparison to oSIAs alone (baseline comparator)…

**Low RI**

DALYs averted
Annual pSIAs >> Biannual pSIAs

Cost per DALY averted
Annual pSIAs cost-effective

**High RI**

DALYs averted
Annual pSIAs = Biannual pSIAs

Cost per DALY averted
Annual pSIAs >>> Biannual pSIAs

Biannual pSIAs cost-effective
Implications for decision-making

<table>
<thead>
<tr>
<th>RI coverage</th>
<th>Implications for decision making</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;50%</td>
<td>pSIA removal would have high risks and consequences</td>
</tr>
<tr>
<td>50-70%</td>
<td>Removal of pSIAs altogether could lead to a high risk of outbreaks in subsequent years</td>
</tr>
<tr>
<td>80-90%</td>
<td>Reducing the frequency of pSIAs could still maintain a low risk of large outbreaks</td>
</tr>
<tr>
<td>100%</td>
<td>Even if pSIAs are removed, there is low to no risk of outbreaks</td>
</tr>
</tbody>
</table>
Pros and cons of using a simple model

- Assumptions made:
  - Homogenous mixing
  - SIAs reach 25% of children missed by RI
  - Use a simple single value for $R_0$ alongside other parameters

- We do not consider the costs of further delaying the eradication timeline

- By limiting our analysis to a 5-year time horizon, we underestimate the benefits of pSIAs as they will increase the likelihood of eradication

- Model is implemented using R package SimInf
  - Easy to code
  - Easy to manipulate parameters
  - Can be used across wide range of settings

- Simple model with clear cost inputs and outputs is easy to communicate

- Model clearly shows risks and benefits of different vaccination strategies and can be used to inform imminent policy and funding decisions
1. What experiences do you have using models to answer economic or financial needs?

2. What experiences do you have using models in interdisciplinary research?
Not included in main talk- these figures are additional outputs from the model described in this presentation (cut from presentation for time sake, left here hidden at the end in case of questions)
Routine immunisation (RI) coverage & historical preventative SIAs (pSIAs)

A

RI coverage
- <60%
- >60% RI <80%
- >80% RI <90%
- >90%


Historical pSIAs per year

B

<table>
<thead>
<tr>
<th>Country</th>
<th>DTP3 coverage 2021</th>
<th>Year of last pSIa</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAZ</td>
<td>42%</td>
<td>2021</td>
</tr>
<tr>
<td>Somalia</td>
<td>42%</td>
<td>2021</td>
</tr>
<tr>
<td>Guinea</td>
<td>47%</td>
<td>2021</td>
</tr>
<tr>
<td>South Sudan</td>
<td>49%</td>
<td>2021</td>
</tr>
<tr>
<td>Madagascar</td>
<td>55%</td>
<td>2019</td>
</tr>
<tr>
<td>Nigeria</td>
<td>56%</td>
<td>2021</td>
</tr>
<tr>
<td>Chad</td>
<td>58%</td>
<td>2021</td>
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<tr>
<td>Mozambique</td>
<td>61%</td>
<td>2011</td>
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<tr>
<td>DRC</td>
<td>65%</td>
<td>2021</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>65%</td>
<td>2021</td>
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<tr>
<td>Cameroon</td>
<td>69%</td>
<td>2021</td>
</tr>
<tr>
<td>Côte d'Ivoire</td>
<td>76%</td>
<td>2018</td>
</tr>
<tr>
<td>Benin</td>
<td>76%</td>
<td>2018</td>
</tr>
<tr>
<td>Mali</td>
<td>77%</td>
<td>2019</td>
</tr>
<tr>
<td>Gambia</td>
<td>82%</td>
<td>2014</td>
</tr>
<tr>
<td>Niger</td>
<td>82%</td>
<td>2019</td>
</tr>
<tr>
<td>Togo</td>
<td>83%</td>
<td>2014</td>
</tr>
<tr>
<td>Sudan</td>
<td>84%</td>
<td>2019</td>
</tr>
<tr>
<td>Senegal</td>
<td>85%</td>
<td>2016</td>
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<tr>
<td>South Africa</td>
<td>86%</td>
<td>2010</td>
</tr>
<tr>
<td>Zimbabwe</td>
<td>86%</td>
<td>2007</td>
</tr>
<tr>
<td>Burkina Faso</td>
<td>91%</td>
<td>2016</td>
</tr>
<tr>
<td>Kenya</td>
<td>91%</td>
<td>2019</td>
</tr>
<tr>
<td>Uganda</td>
<td>91%</td>
<td>2019</td>
</tr>
<tr>
<td>Zambia</td>
<td>91%</td>
<td>2008</td>
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<tr>
<td>Sierra Leone</td>
<td>92%</td>
<td>2018</td>
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<tr>
<td>Malawi</td>
<td>93%</td>
<td>2010</td>
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<tr>
<td>Burundi</td>
<td>94%</td>
<td>2011</td>
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<tr>
<td>Botswana</td>
<td>95%</td>
<td>2004</td>
</tr>
<tr>
<td>Ghana</td>
<td>98%</td>
<td>2015</td>
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Quadrant I
MORE costly
LESS effective

Quadrant II
MORE costly
MORE effective

Quadrant III
LESS costly
LESS effective

Quadrant IV
LESS costly
MORE effective

Interventions falling in the shaded area are usually more cost-effective and therefore adopted.
Vaccination strategy

• Annual pSIAs
• Biannual pSIAs

*Baseline comparator: oSIAs

Includes cost of SIAs and IPV RI, but not costs of paralytic poliomyelitis cases or VAPP

When RI coverage exceeds 67%, the point when herd immunity is achieved in this simple homogenously mixed model, the annual pSIA strategy becomes less efficient in averting DALYs

DALYs AVERTED (across 1,000 model simulations)