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Health economic analysis of vaccine options for the polio eradication endgame: 2022–2036

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Abstract

Background: Multiple vaccine options are available for polio prevention and risk management. Integrated global risk, economic, and poliovirus transmission modeling provides a tool to explore the dynamics of ending all use of one or more poliovirus vaccines to simplify the polio eradication endgame.

Research design and methods: With global reported cases of poliomyelitis trending higher since 2016, we apply an integrated global model to simulate prospective vaccine policies and strategies for OPV-using countries starting with initial conditions that correspond to the epidemiological poliovirus transmission situation at the beginning of 2022.

Results: Abruptly ending all OPV use in 2023 and relying only on IPV to prevent paralysis with current routine immunization coverage would lead to expected reestablished endemic transmission of poliovirus types 1 and 2, and approximately 150,000 expected cases of poliomyelitis per year. Alternatively, if OPV-using countries restart trivalent OPV (tOPV) use for all immunization activities and end IPV use, the model shows the lowest anticipated annual polio cases and lowest costs.

Conclusions: Poor global risk management and coordination of OPV cessation remain a critical failure mode for the polio endgame, and national and global decision makers face difficult choices due to multiple available polio vaccine options and immunization strategies.

Keywords

polio; eradication; health economic analysis; dynamic modeling; interdependent risks; poliovirus vaccine

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Author contributions

KMT, DAK, and KB conceived the study and contributed to the writing of the first draft and all subsequent revisions. KMT and DAK developed the model used. DAK performed all of the modeling. KMT acquired the funding for the study. All authors read and approved all versions of the article before submission, during revision and the final manuscript, including changes introduced at the proofing stage. All authors agreed on submission to this Journal and are accountable for all aspects of the work.

Declaration of interest

The authors have no relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript. This includes employment, consultancies, honoraria, stock ownership or options, expert testimony, grants or patents received or pending, or royalties.

1. Introduction

Successful eradication of the transmission of wild polioviruses (WPVs) represents a first step in achieving the global goal of ending all cases of poliomyelitis. WPV eradication requires achieving sufficiently high immunization coverage in all countries at the same time, such that any WPVs exported from the last reservoir cannot restart transmission in WPV-free areas. Once transmission dies out in the last endemic reservoir, the endgame shifts to preventing reintroduction from stored viruses as part of global containment. This level of coordination makes eradication inherently global because eradicable infectious diseases, like polioviruses, pose interdependent risks, such that the management of risks in one country affect risks and outcomes in other countries [1,2]. Efforts by countries and the Global Polio Eradication Initiative (GPEI) led to the global certification of eradication of indigenous transmission of WPV type 2 in 2015 [3] and type 3 in 2019 [4]. During 2017–2020 type 1 WPV (WPV1) transmission remained limited to Afghanistan and Pakistan [5], but in 2021–2022, WPV1 exported from Pakistan led to reported cases in Malawi and Mozambique as of August 2022 [5].

To achieve the progress made by the end of 2021, which includes preventing an estimated nearly 30 million global cases of paralysis by polio vaccination since 1960, with 2.5–6 million of those attributable to the GPEI efforts since 1988 [6], most countries used oral poliovirus vaccine (OPV) to stop and prevent WPV transmission. As a live, attenuated vaccine virus, OPV induces immunity by infecting the vaccine recipient, which can in turn lead to infection of close contacts [7]. The benefits of this secondary spread include inducing or boosting immunity in contacts [7,8]. However OPV use comes with some risks, which become observable once WPV transmission ends [9]. First, in very rare instances, immunologically naïve OPV-recipients and/or their close contacts can develop vaccine-associated paralytic polio (VAPP) at the time of their first infection by the type of poliovirus [9,10]. Second, after WPV transmission stops, in countries that continue to use OPV but do so with low immunization coverage, the OPV-related viruses can lose their attenuating mutations as they continue transmission by infecting the susceptible individuals instead of dying out. As these OPV-related viruses spread, they can evolve and revert to vaccine-derived polioviruses (VDPVs) that behave like homotypic WPVs [9,11,12]Classification of a strain as a VDPV is based primarily on the number of nucleotide substitutions in specific regions of the viral genome compared to the Sabin sequences [13]. Designation of a VDPV as circulating (or cVDPV) follows the collection of evidence for person-to-person transmission in the community based on human and/or environmental detections of genetically linked viruses [14,15]. Finally, in very rare instances, a small fraction of individuals with primary immunodeficiencies will experience prolonged or chronic infection with OPV, which can evolve into VDPVs [9,16,17]. These individuals can excrete immunodeficiency-associated VDPVs (iVDPVs) that could potentially restart transmission [9,18,19]. The detection of WPV or cVDPV that meets specific criteria for community level transmission (e.g., detection in a human with no history of travel or two separate environmental detections at least two months apart or from catchment areas with no overlap), may trigger declaration of a poliovirus event or outbreak that requires response [14,15].

To keep population immunity high and prevent any importations of WPV from restarting transmission, OPV-using countries need to keep OPV immunization coverage high [20,21]. High OPV use carries the very low risk of more VAPP cases and can increase the number of iVDPV excreters, but using less OPV leads to the emergence of cVDPVs [9,22]. Due to the paralysis risks associated with OPV use, the World Health Assembly committed to globally coordinating OPV cessation after successful eradication of WPV to end all cases of poliomyelitis from OPV use [23]. The GPEI coordinated the end of type 2 OPV use (OPV2 cessation), except for emergency outbreak response, in May 2016 [24].

Despite extensive pre-OPV2 cessation plans to manage OPV2 cessation risks, for May 2016-May 2022, type 2 cVDPVs (cVDPV2s) led to nearly 2,500 cVPDV2 paralytic cases reported by 34 countries [25,26]. The accelerated development of a genetically modified novel OPV2 (nOPV2) for outbreak response, which was designed for increased stability and thus lower risk of cVDPV2s, offers a new OPV2 tool [27]. However, integrated modeling suggests that the current trajectory for type 2 transmission is not on track to die out with current outbreak response campaign performance, even with the use of nOPV2 instead of Sabin monovalent OPV2 (mOPV2) for outbreak response [19,28–30].

In 2007, a study on eradication versus control assumed “that eradication is achievable provided that we are willing to commit the necessary resources” and it relied on a simplifying assumption that in the event that global leaders abruptly ended polio eradication efforts then endemic transmission of polioviruses would return to the level of approximately 200,000 expected cases per year in low-income countries [31]. At that time, India met the World Bank criteria as a low-income country and the feasibility of it ending poliovirus transmission came into question [32]. In the early 2000s most countries relied exclusively on Sabin trivalent OPV (tOPV) for routine immunization (RI), and over 40 countries still reported poliovirus cases. Substantial changes in polio epidemiology and the use of polio vaccines occurred since 2006, including the introduction of at least one dose of inactivated poliovirus vaccine (IPV) into the RI schedules of all countries by 2018, albeit with low coverage in some countries [33].

As the world recovers from the disruptions caused by the COVID-19 pandemic and the GPEI competes with other global health initiatives for funding for its new strategic plan [34], modeling potential control options for the polio endgame may provide useful insights for policy makers. Insights from modeling can offer policymakers, particularly those in low- and middle-income countries facing numerous vaccine and immunization options, understand long-term implications of choices based on simulation of the polio endgame as a germ game [35]. One recent study provided an updated health economic analysis of the GPEI compared to a counterfactual world without the GPEI [36]. Another recent study compared vaccine costs of very high control using numerous doses of both IPV and OPV in perpetuity (without WPV1 eradication) to very high control for a shorter period of time and assuming successful WPV1 eradication followed by cessation of all OPV use 3 years later and all IPV use at some point at least 7 years after ending all OPV use [37]. Fifteen years after the 2007 eradication vs. control study [31], we revisit the polio endgame and highlight the risks and costs associated with poor performance and poorly coordinated OPV cessation.

2. Methods

For this analysis, we applied an existing integrated global risk, economic, and poliovirus transmission model [19] to provide the current expected trajectory for prospective global poliovirus transmission with current GPEI and country performance, which we refer to as the *Baseline*. The model employs the conceptual characterization of variability in the global population using 72 blocks, each consisting of 10 subpopulations of approximately 10.7 million people, and assigning these to World Bank Income Level (WBIL) (i.e., low-income, LI; lower middle-income, LMI; upper middle-income, UMI; high-income, HI) and current vaccine use (OPV+IPV, IPV/OPV, IPV-only) policies [19]. The age distributions within the subpopulations simulate the variability in the global population, and mixing within blocks occurs homogenously in space and heterogeneously by age [19]. Mixing between blocks occurs according to nine varying preferential mixing areas of different size, which in abstract represent larger geographical regions (e.g., continents, large countries like India or China).

Recognizing the large number of vaccine policy options available, we focus this analysis on identifying bounding scenarios for the predominantly low- and middle-income countries that currently use OPV as their primary vaccine for controlling polio. Similar to prior analyses, we assume that high-income countries will continue to use IPV-only schedules with high RI coverage [38]. For each scenario, we specify the vaccine used for RI and for any supplemental immunization activities (SIAs). For the *Baseline* scenario, we assume current SIA performance characteristics and the use of bivalent OPV (bOPV, containing types 1 and 3 OPV) for RI and for some limited, preventive SIAs (pSIAs) (i.e., at most one round per year in subpopulations that continue to use OPV) [19,29,30]. For outbreak response SIAs (oSIAs) for the *Baseline*, we assume 2 OPV rounds 30 days apart with 2 additional rounds after breakthrough transmission that target children <5 years of age in the outbreak subpopulation when WPV1 R_0<10 or the outbreak subpopulation and its four worst-performing neighbor subpopulations within the same block when WPV1 $R_0 \geq 10$ [19,29,30]. We use bOPV for pSIAs and type 1 and 3 oSIAs, and mOPV2 for type 2 oSIAs. We assume the same immunization intensity for both pSIAs and oSIAs in a given subpopulation, and vary the intensity for different subpopulations to reflect the observed differences in experience, ranging from 15% true coverage and 95% repeatedly missed probability to 80% true coverage and 50% repeatedly missed probability [19,29,30]. For the *Baseline*, we considered the conditions that existed globally at the end of 2021 and included sufficient immunization such that WPV1 transmission dies out by the end of 2023 [39] to simulate a trajectory that meets the WPV eradication objective of the 2022–2026 GPEI Strategic Plan [34]. However, type 2 transmission continues, and in the *Baseline* we do not implement globally coordinated bOPV cessation because the current Strategic Plan remains vague about whether and when this might occur [34, last page]. In the *Baseline*, OPV use continues throughout the model time horizon.

As an alternative, we consider a scenario that ends all OPV use in RI and all SIAs rapidly (simulated in the model as starting January 1, 2023) and without globally coordinated prospective risk management efforts (*IPV RI only*). This represents a worst-case concept of what might occur if OPV-using countries chose to simply use only IPV, which is currently

the only poliovirus vaccine available for RI that contains all 3 serotypes. We assume countries continue with 2019 IPV RI coverage levels for the time horizon. Specifically, all countries with an IPV/OPV sequential schedule shift to a 3 dose IPV-only schedule, while those using an OPV+IPV schedule shift to a 2 dose IPV-only schedule. Recognizing that the assumption of no OPV use (even for outbreak response) may seem extreme in the context of outbreaks, we also consider this same scenario, which ends all OPV use for RI and preventive SIAs (pSIAs) and shifts to IPV RI only, but we allow OPV use for oSIAs (*IPV RI with OPV for oSIAs*). Recognizing the failure to stop all type 2 OPV use as of 2022 and that expectations for long-term use of OPV for oSIAs could lead to calls to restart type 2 OPV [28,40], we consider a contrasting bounding scenario in which all OPV-using countries revert to tOPV use for RI and oSIAs and they end all use of IPV to save immunization program costs (*restart tOPV, no IPV*) on January 1, 2023. For this scenario, we assume that countries would not conduct pSIAs, which largely occurred historically with support from GPEI resources as part of global polio eradication efforts.

We use the cost and valuation inputs from a prior study [41] and report economic estimates in 2019 US dollars (US$2019). Similar to the framing of a study that characterized the health economics of vaccine policy options for 2019–2029 [38], we focus on the incremental cost-effectiveness ratios (ICERs) and incremental net benefits (INBs) of the alternative bounding cases compared to the *Baseline* using a societal perspective and a discount rate of 3%. For this analysis, all scenarios implicitly assume the same global programmatic and surveillance costs such that these cancel out in the incremental economic analyses.

We consider a prospective analytical time horizon of T_0 of January 1, 2022 to T_{end} of December 31, 2036. With continued OPV use anticipated by the GPEI throughout the 2022–2026 time horizon of its current strategic plan and beyond [34], we considered a 10-year extension of the time horizon sufficient for this analysis of our bounding scenarios. We implement the model in the JAVA™ in the integrated development environment Eclipse™, and perform 100 stochastic iterations with a fixed set of random number seeds and initial conditions.

3. Results

Figure 1 (panels a-c) shows the expected value of annual polio cases for the time horizon caused by type 1, 2, and 3 polioviruses, and the total cases (panel d) for 100 iterations of the modeled scenarios. Table 1 provides summary statistics for the 100 iterations summed over the entire time horizon for all three poliovirus types, including the mean, median, and range, which provide information about the variability in the results.

The higher transmissibility and neurovirulence of WPV1 leads to it accounting for most of the expected total cases for most of the scenarios. The *Baseline* trajectories in all of the panels of Figure 1 (also see supplementary Figure S1, which shows the y-axis using a logarithmic scale (base 10) to allow visualization of smaller numbers) show that the model does not anticipate successful die out of transmission of types 1 or 2 by the end of 2036, and shows the best performance for the *Baseline* for types 1 and 3, due to assumed continued use of bOPV throughout the time horizon, but not for type 2. The model demonstrates

that rapidly ending all OPV use and relying only on IPV to prevent paralysis leads to a global burden of approximately 150,000 expected annual polio cases per year as shown in Figure 1 (panel d) due to reestablished endemic transmission of live polioviruses. Given the high population immunity to transmission as of early 2022, the transition back to endemic transmission takes 6 years on average for all types (panel d). However, the different properties of the poliovirus types lead to the reestablishment of a new endemic equilibrium in the model approximately 6 and 10 years (panels a and b) into the time horizon on average for types 1 and 2, respectively. For type 3, the model behavior does not lead to reestablished transmission for most iterations. However, as suggested by the upper bound of the range in Table 1, even with successful WPV3 eradication and high population immunity to transmission for type 3 prior to bOPV cessation, the model behavior includes a small number of explosive outbreaks in 5 of the 100 iterations related to reintroduction events that restart transmission in the high transmission blocks of the model (i.e., 2 iterations with containment breach events and 3 iterations with iVDPV-related introductions). Overall, these results suggest a high chance of successful OPV3 cessation if performed while population immunity to type 3 transmission remains high enough, although Table 1 conveys some of the variability in the results [42], and supplementary Figure S2 shows the individual trajectory of each iteration for each scenario.

Although WPV1 transmission dies out in all the scenarios by 2023, type 1 transmission restarts in the historically worst performing subpopulations of the high transmission blocks within the first year of no OPV vaccination for scenarios that abruptly end OPV use in RI. In these scenarios, type 1 polioviruses spread within those blocks during an additional 1 to 6 years, depending on the residual population immunity in the subpopulations. The actual trajectory of resurgence of transmission would depend on the places and times of actual reintroduction events, but the expected value of the iterations provides an overall signal of the expected trend.

In the event that countries make a shift to using only IPV for RI with or without continuing to use OPV reactively for oSIAs, successful polio elimination will not occur, because population immunity to transmission will not contemporaneously lead to die out of all poliovirus transmission. Overall, this IPV use would only reduce the burden of disease for the individuals who receive it, but not stop live poliovirus transmission. Compared to just using IPV for RI, the option of using OPV for oSIAs reactively reduces the expected cases by nearly 3-fold. However, this still represents an option with much higher expected cases than the *Baseline* (Table 1).

Alternatively, ending IPV use in OPV-using countries, while focusing on reintroduction of the tOPV use in RI and for oSIAs, may mitigate the global burden of cases by 50% compared to the current *Baseline* (Table 1). This suggest that restarting tOPV in OPV using countries presents a better option that continuing the current *Baseline*, even without any IPV use.

Table 2 summarizes the results of the incremental economic analyses for alternative global policy options compared to the *Baseline* by WBIL and the total global INBs over the 15-year time horizon. Compared to the *Baseline*, both *IPV RI only* and *IPV RI only with OPV for*

oSIAs scenarios lead to expected decreases in INBs by 48.3 and 13.2 billion US$2019, respectively, which implies an overall worse investment than the current trajectory. In contrast, the *restart tOPV, end IPV* option offers an expected increase in INBs of 17.0 billion US$2019, which represents a better investment than the current trajectory. Restarting tOPV and ending IPV use in OPV-using countries offers a cost- and lifesaving (better) option compared to the *Baseline*, whereas shifting to the use of IPV only in RI in 2023 in all countries is a dominated (worse) option.

4. Discussion

Despite the feasibility of successfully eradicating indigenous transmission of all WPVs, the risks posed by poor global coordination of OPV cessation represents a recognized critical failure mode for the polio endgame. Notably, delays in achieving the objectives of global polio eradication continue to lead to increasing costs, which continue to decrease the expected INBs of the GPEI [36,43], despite full financial support from donors for GPEI strategic plans [44]. If the GPEI partners and countries cannot align behind a strategy expected to lead to ending all poliomyelitis cases and some OPV use remains inevitable (i.e., Sabin or novel strains), then the option of restarting tOPV in OPV-using countries would likely save substantial expected costs and cases. More importantly, ending OPV use without coordination leads to substantially more expected cases than continuing its use, even with countries shifting to use IPV. Modeling [21,45] and actual experiences with the detection of transmission of live polioviruses in countries with high IPV immunization coverage (e.g., WPV1 in 2013 [46] and cVDPV3 in 2022 [47] in Israel) demonstrate the limited ability of IPV to stop poliovirus transmission, although its use prevents paralytic cases in IPV-only vaccine recipients upon first infection with each poliovirus type.

The global plans for ending all use of OPV remain uncertain, but this analysis suggests that ending all OPV use suddenly without an effective, globally coordinated risk management strategy for cVDPVs would lead to expected resumption of endemic transmission of polioviruses in some countries and global exportation risks. The level of endemic expected transmission depends on the extent of vaccine use by national immunization programs for prevention and/or reaction to outbreaks and the specific vaccine(s) used. At the same time, continuing to use OPV anywhere will pose some risks of restarting transmission and prevent global containment activities, which become unnecessary if OPV use continues. Thus, global health leaders will need to decide whether they will and can commit to successful OPV cessation or not [25]. For example, some have suggested declaring victory with successful WPV eradication and not pursuing OPV cessation [48], and issues with containment after OPV2 cessation lead to questions about its feasibility [28].

The GPEI partners continue to pursue strategies that focus on developing different vaccine tools (e.g., monovalent OPV (mOPV) then bivalent OPV (bOPV) then IPV then novel OPV (nOPV)), but none of these options deals with a fundamental issue related to the use of either wild or attenuated live poliovirus strains in vaccine production. This includes the genetically modified nOPV2 currently in wide use under an emergency use listing (EUL) and the nOPVs for types 1 and 3 in early-stage clinical trials (nOPV1 and nOPV3). Instead of Sabin OPV or nOPV strains, non-replicating (e.g., vaccine-like particle or mRNA) based

vaccines could offer substantially more opportunities for managing polio endgame risks, if feasible to develop [49–52].

Similar to prior applications of the integrated model [53], this analysis comes with several limitations. The results depend on the model structure, available information, and our assumptions, including those related to characterizing the initial conditions as of the end of 2021 and expected future policies and actions [19,54]. In addition, for each scenario, we implicitly assume unlimited vaccine supplies (e.g., the shift back to tOPV in January 2023 could occur), although real constraints exist on global supplies for OPV vaccines. We also do not consider the uncertain impacts of nOPV introduction from 2021 on for nOPV2 or potential future use of nOPV for types 1 or 3 or in combination formulations (e.g., trivalent novel OPV). By focusing on bounding scenarios, the results give more extreme outcomes than would likely occur for less extreme transitions and some other potential options. Notably, the model representation of countries using a high level of abstraction and assuming homogeneous mixing within subpopulations may also lead to faster transmission across relatively large groups of individuals than would actually occur. However, we include heterogeneous age mixing and mixing between the subpopulations by applying mixing matrices that limit transmission to some degree. In addition, we also assumed that outbreak response would likely not improve, even with increasing numbers of cases. This assumption is consistent with the performance of many countries that responded to cVDPV2 outbreaks since 2016 [19,28–30,40,55]. Although we assumed the same global programmatic and surveillance costs for the alternative scenarios and the *Baseline*, for some of the alternatives the investments in programmatic activities and surveillance would likely decline. Notably, with a shift back to tOPV use, countries would likely end environmental surveillance, and all GPEI programmatic costs could end as well, which would further increase the expected INBs. We did not consider different permutations of the scenarios that could lead to higher costs but lower cases, for example assuming that some countries currently using IPV/OPV sequential schedules in the *Baseline* (e.g., China) continue that option while countries that use OPV+IPV shift back to tOPV.

Future studies may need to consider other variations of options, including sequential IPV/OPV schedules in upper-middle and potentially some high-income countries, shifting to use of OPV containing types 1 and 2, if the GPEI can successfully implement OPV3 cessation. In addition, future studies will need to consider the consequences of using nOPVs and/or other polio vaccine options as their development and use leads to a good understanding of their properties. Although nOPV2 is currently in use for outbreak response under an EUL, this analysis did not include nOPV2 for several reasons. First, prior modeling suggests that the current trajectory for type 2 transmission is not on track to die out with current outbreak response campaign performance, even with the use of nOPV2 [19,28–30]. Second, nOPV2 could perform better than or similarly to mOPV2 with respect to the overall trajectory, depending on its effectiveness and characteristics when used in real populations, the results of which (e.g., phase 4 clinical trials or post-licensure clinical data) are still not publicly available in spite of several hundred million doses distributed under EUL (see a recent summary of nOPV2 data [56]). Notably, if nOPV2 comes with lower (but not zero) risk of reversion and lower transmissibility, then the reduction in seeding of new outbreaks when using nOPV2 may be offset by its relatively lower effectiveness than mOPV2 when

used in populations, which all else equal would lead to results similar to the results in this analysis. Third, the specific low dose formulation of nOPV2 selected for the EUL may combine differently with bOPV than mOPV2, which may mean that a trivalent OPV created using nOPV2 would lead to different relative take rates for the three types of OPV than observed with Sabin tOPV. In the absence of trials related to co-administration of bOPV and nOPV2, we did not attempt to model the impacts of a new trivalent OPV that combines bOPV and nOPV2. Fourth, under the EUL, co-administration of nOPV2 with bOPV cannot occur, and nOPV2 use is only permitted in the context of outbreak response. Thus, the only RI schedule that we could include for this analysis would use bOPV and nOPV2 delivered at different times instead of tOPV, and due to the challenging logistics and costs associated with additional contacts required to deliver bOPV and nOPV2 separately, simply changing back to tOPV would save substantially on RI costs. Future studies will need to consider the potential role of trivalent OPV containing one or more nOPV component as those options develop and the use of OPV2 returns to use in RI.

In the event that tOPV use restarts in RI, national health leaders will likely want to consider the cost-effectiveness of sequential schedule options for their countries, particularly as the burden of paying for both the vaccines and their administration shifts entirely to national health budgets when the GPEI ends. We anticipate the upper-middle income countries like China that currently use IPV/OPV sequential schedules would likely continue a sequential IPV/OPV policy. In addition, in a world with increasing global population size and connectivity in which pathogens like polioviruses can rapidly spread [1], the observation of limited transmission of live polioviruses from sewage samples in high-income countries using IPV-only for RI [57], may lead to future consideration of restarting sequential IPV/OPV schedules in some IPV-only countries with high risks of importation of live polioviruses, as occurred in Israel following the WPV1 importation [46,58]. If any countries continue to use OPV, then importation risks will pose an ongoing threat [2].

5. Conclusions

In response to a 2022 GPEI Investment Case statement that “cutting back current efforts is expected to result in a global resurgence of polio” [59] that referred to a 2007 study, this analysis provides an updated and model-based perspective on the consequences of abruptly shifting from the *Baseline* to bounding alternative scenarios of control with a single polio vaccine. Considering the option of ending either OPV use in RI or IPV use in low and middle-income countries compared to the *Baseline*, we find better expected health and economic outcomes associated with ending IPV use and restarting tOPV given current global performance on OPV cessation in OPV-using countries. Most importantly, poor global risk management and coordination of OPV cessation remain a critical failure mode for the polio endgame.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Appendix: CHEERS 2022 Checklist

Note: Please see references cited in the main text for details of each component in the integrated model, which has been developed and described in a large number of prior publications and used for over a dozen health economic analyses (reviewed and demonstrated [36,38] elsewhere).

	Item	Guidance for reporting	Reported in section
TITLE			
Title	1	Identify the study as an economic evaluation and specify the interventions being compared.	Page 1
ABSTRACT			
Abstract	2	Provide a structured summary that highlights context, key methods, results and alternative analyses.	Page 1
INTRODUCTION			
Background and objectives	3	Give the context for the study, the study question and its practical relevance for decision making in policy or practice.	Intro, pages 1–2
METHODS			
Health economic analysis plan	4	Indicate whether a health economic analysis plan was developed and where available.	NA
Study population	5	Describe characteristics of the study population (such as age range, demographics, socioeconomic, or clinical characteristics).	Methods, pages 4–5
Setting and location	6	Provide relevant contextual information that may influence findings.	Methods, pages 4–5
Comparators	7	Describe the interventions or strategies being compared and why chosen.	Methods, pages 5–6
Perspective	8	State the perspective(s) adopted by the study and why chosen.	Methods, page 6
Time horizon	9	State the time horizon for the study and why appropriate.	Methods, page 7
Discount rate	10	Report the discount rate(s) and reason chosen.	Methods, page 6
Selection of outcomes	11	Describe what outcomes were used as the measure(s) of benefit(s) and harm(s).	Methods, page 6
Measurement of outcomes	12	Describe how outcomes used to capture benefit(s) and harm(s) were measured.	Methods, page 6
Valuation of outcomes	13	Describe the population and methods used to measure and value outcomes.	Methods, page 6
Measurement and valuation of resources and costs	14	Describe how costs were valued.	Methods, page 6
Currency, price date, and conversion	15	Report the dates of the estimated resource quantities and unit costs, plus the currency and year of conversion.	Methods, page 6

	Item	Guidance for reporting	Reported in section
Rationale and description of model	16	If modelling is used, describe in detail and why used. Report if the model is publicly available and where it can be accessed.	Methods, pages 5–7
Analytics and assumptions	17	Describe any methods for analysing or statistically transforming data, any extrapolation methods, and approaches for validating any model used.	Methods, pages 5–7
Characterizing heterogeneity	18	Describe any methods used for estimating how the results of the study vary for sub-groups.	Methods, pages 5–7
Characterizing distributional effects	19	Describe how impacts are distributed across different individuals or adjustments made to reflect priority populations.	Methods, pages 5–7
Characterizing uncertainty	20	Describe methods to characterize any sources of uncertainty in the analysis.	Methods, pages 5–7
Approach to engagement with patients and others affected by the study	21	Describe any approaches to engage patients or service recipients, the general public, communities, or stakeholders (e.g., clinicians or payers) in the design of the study	NA
RESULTS			
Study parameters	22	Report all analytic inputs (e.g., values, ranges, references) including uncertainty or distributional assumptions.	Methods, pages 5–7
Summary of main results	23	Report the mean values for the main categories of costs and outcomes of interest and summarise them in the most appropriate overall measure.	Results, Fig and Tables
Effect of uncertainty	24	Describe how uncertainty about analytic judgments, inputs, or projections affect findings. Report the effect of choice of discount rate and time horizon, if applicable	NA
Effect of engagement with patients and others affected by the study	25	Report on any difference patient/service recipient, general public, community, or stakeholder involvement made to the approach or findings of the study	NA
DISCUSSION			
Study findings, limitations, generalizability, and current knowledge	26	Report key findings, limitations, ethical or equity considerations not captured, and how these could impact patients, policy, or practice.	Pages 10–11
OTHER RELEVANT INFORMATION			
Source of funding	27	Describe how the study was funded and any role of the funder in the identification, design, conduct, and reporting of the analysis	Page 12
Conflicts of interest	28	Report authors conflicts of interest according to journal or International Committee of Medical Journal Editors requirements.	Page 12

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Papers of special note have been highlighted as:

* of interest

** of considerable interest

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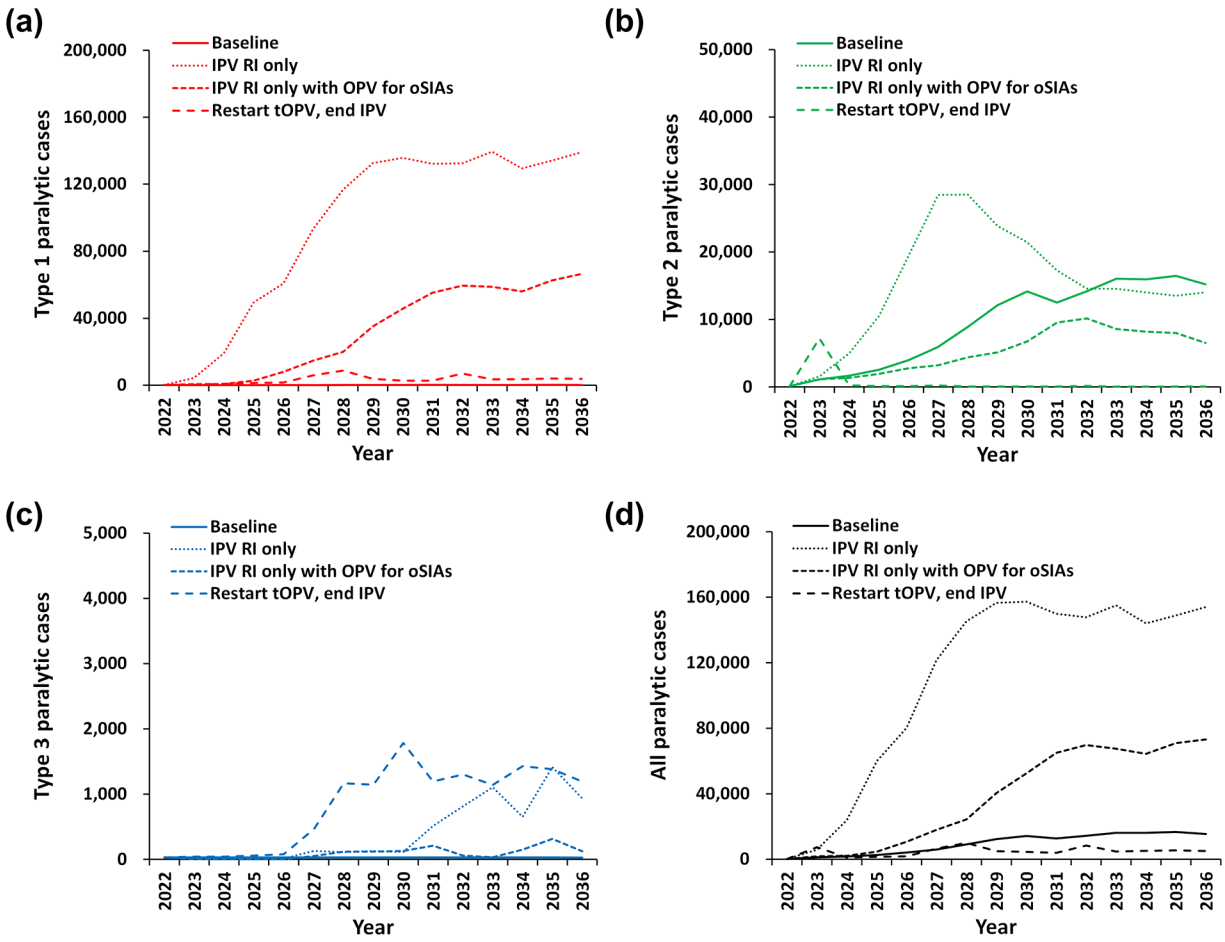

Figure 1.

Expected global number of paralytic polio cases by year for 100 stochastic iterations of the different scenarios for 2022–2036 compared to the baseline. Type-specific results are shown in panels (a) to (c) for poliovirus types 1 to 3, respectively. Panel (d) shows the total number of paralytic cases for all three serotypes.

Table 1.

Estimated expected value ((median) and [range]) of global poliovirus cases by type in 100 stochastic iterations for 2022–2036 for the scenarios modeled (see main text for descriptions).

Scenario	Type 1 cases (median) [range]	Type 2 cases (median) [range]	Type 3 cases (median) [range]	Total cases (median) [range]
Baseline	1,666 (1,491) [1,193 – 2,934]	140,899 (157,491) [310 – 219,587]	1,235 (1,235) [1,232 – 1,238]	143,801 (160,515) [2,833 – 222,727]
IPV RI only	1,417,883 (1,420,033) [960,205 – 1,693,033]	226,765 (230,695) [131,502 – 256,676]	6,006 (85) [85 – 257,328]	1,650,654 (1,666,101) [1,202,812 – 2,082,349]
IPV RI only with OPV for oSIAs	486,086 (480,397) [200,632 – 760,707]	77,737 (94,447) [139 – 160,061]	1,381 (85) [85 – 95,442]	565,203 (569,208) [286,073 – 869,310]
Restart tOPV, end IPV	49,642 (49,542) [44,099 – 57,580]	8,990 (8,905) [8,759 – 9,793]	13,326 (13,163) [9,467 – 17,408]	71,958 (71,960) [66,553 – 79,929]

Abbreviations: IPV, inactivated poliovirus vaccine; OPV, oral poliovirus vaccine

Table 2.

Incremental economic analysis estimates (US$2019) for different immunization options for different policy options by World Bank Income Levels (2022–2036)

Vaccine policy	Baseline vaccine costs	Policy vaccine costs	Baseline paralytic cases	Policy paralytic cases	Incremental financial costs*	Incremental cost-effectiveness ratio (ICER)	Incremental net benefits (INBs)
IPV RI only vs. *Baseline*						Dominated	
LI	4.1	3.1	36,502	414,663	−0.9		−2.5
LMI	12.2	7.7	96,537	1,100,706	−4.6		−24.8
UMI	13.0	14.5	10,742	134,636	1.6		−21.0
Total	**29.3**	**25.3**	**143,782**	**1,650,005**	−4.0		**−48.3**
IPV RI only with OPV for oSIAs vs. *Baseline*						Dominated	
LI	4.1	4.8	36,502	158,825	0.8		−1.8
LMI	12.2	11.3	96,537	384,014	−0.9		−7.2
UMI	13.0	15.4	10,742	22,223	2.4		−4.2
Total	**29.3**	**31.5**	**143,782**	**565,062**	2.2		**−13.2**
Restart tOPV, end IPV vs. *Baseline*						Cost & life saving	
LI	4.1	2.5	36,502	13,506	−1.6		1.8
LMI	12.2	6.2	96,537	51,690	−6.0		7.3
UMI	13.0	5.6	10,742	6,747	−7.4		7.9
Total	**29.3**	**14.3**	**143,782**	**71,944**	−15.0		**17.0**

Notes:

* includes treatment costs

Abbreviations: IPV, inactivated poliovirus vaccine; LI, low-income; LMI, lower middle-income; OPV, oral poliovirus vaccine; tOPV, trivalent OPV.