RESEARCH PAPER

The Estimated Health and Economic Benefits of Three Decades of Polio Elimination Efforts in India

ARINDAM NANDI, DEVRA M BARTER, *SHANKAR PRINJA AND #T JACOB JOHN

*From The Center for Disease Dynamics, Economics and Policy, Washington, USA; *School of Public Health, Chandigarh, India; and #Retired Professor of Clinical Virology, Christian Medical College, Vellore, TN, India.*

Correspondence to: Dr Arindam Nandi, The Center for Disease Dynamics, Economics and Policy, Washington, USA. nandi@cddep.org.

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Objective: In March 2014, India, the country with historically the highest burden of polio, was declared polio free, with no reported cases since January 2011. We estimate the health and economic benefits of polio elimination in India with the oral polio vaccine (OPV) during 1982-2012.

Methods: Based on a pre-vaccine incidence rate, we estimate the counterfactual burden of polio in the hypothetical absence of the national polio elimination program in India. We attribute differences in outcomes between the actual (adjusted for under-reporting) and hypothetical counterfactual scenarios in our model to the national polio program. We measure health benefits as averted polio incidence, deaths, and disability adjusted life years (DALYs). We consider two methods to measure economic benefits: the value of statistical life approach, and equating one DALY to the Gross National Income (GNI) per capita.

Results: We estimate that the National Program against Polio averted 3.94 million (95% confidence interval [CI]: 3.89–3.99 million) paralytic polio cases, 393,918 polio deaths (95% CI: 388,897– 398,939), and 1.48 billion DALYs (95% CI: 1.46–1.50 billion). We also estimate that the program contributed to a $1.71 trillion (INR 76.91 trillion) gain (95% CI: $1.69–$1.73 trillion [INR 75.93–77.89 trillion]) in economic productivity between 1982 and 2012 in our base case analysis. Using the GNI and DALY method, the economic gain from the program is estimated to be $1.11 trillion (INR 50.13 trillion) (95% CI: $1.10–$1.13 trillion [INR 49.50–50.76 trillion]) over the same period.

Conclusion: India accrued large health and economic benefits from investing in polio elimination efforts. Other programs to control/eliminate more vaccine-preventable diseases are likely to contribute to large health and economic benefits in India.

Keywords: *Deaths averted, Disability-adjusted life years, Economic benefits, Polio elimination, value of statistical life.*

Since the launch of the Global Polio Eradication Initiative (GPEI) in 1988, the annual number of polio cases worldwide has decreased 99.99% from an estimated 350,000 cases in more than 125 countries to 74 cases in 2015 in two remaining endemic countries, Pakistan and Afghanistan [1,2]. Until 2009, India reported the majority of global polio cases, but India was officially declared polio free in 2014 [3].

The marked decrease in polio incidence in India was due to the Indian government's commitment to polio eradication, with close to $2 billion (INR 92 billion) apportioned to the polio eradication initiative [4]. During 1978-1992, India used the oral polio vaccine (OPV) through the Expanded Programme of Immunization (EPI, later called Universal Immunization Programme). In 1997, the National Polio Surveillance Project (NPSP) was launched in collaboration with the World Health Organization (WHO), aiming to detect all cases and to vaccinate 99% of children in India, even in the remotest areas [5,6]. Together with large-scale supplemental immunization activities called the Pulse Polio Programme (PPP), the NPSP has administered an estimated 12.1 billion doses of the OPV, and 172 million children were vaccinated each National Immunization Day under PPP [7,8].

Several prior studies have provided important economic rationale for polio eradication efforts [9-15], but some of them evaluated only prevented treatment costs and did not include productivity losses, and others assumed that vaccination would cease by 2005 or 2010. Some studies assessed the benefits of the GPEI as a whole or evaluated the benefits only for certain countries. No study to date has robustly estimated the economic benefits of polio elimination in India, a country with historically the highest burden of the disease. Quantifying the health and economic benefits of polio elimination in India will enable better understanding of the benefits of polio elimination in the two remaining endemic countries, and it will allow for researchers and policy makers to recognize the potential benefits of eliminating other vaccine-preventable diseases in India and other low- and middle-income countries through large-scale immunization programs.

METHODS

Disease Burden

As OPV was introduced in the EPI in India in a staggered manner during 1978-1982 [6], we used 1982 as the starting year for our analysis, continuing through 2012, the first full year without any documented polio case.

In order to estimate the benefits of polio elimination in India, we computed the differences in terms of annual incident cases of paralytic polio, polio-related deaths, and disability-adjusted life years (DALYs) [16-18] under two scenarios: under the National Polio Program, and under a counterfactual scenario, *i.e.* in the hypothetical absence of the National Polio Program during 1982-2012. The differences between the two scenarios were then attributed to the benefits of the polio elimination program. To estimate the disease burden, we used disease parameters from Joseph, *et al*. (2003) [19] and John (2003) [20], as presented in ***Table* I**.

Estimating the polio incidence under the National Polio Program scenario during our study period was challenging because data on the number of polio cases during the first decade of the national program suffered from underreporting, as there was no surveillance. During the 1970s and 1980s, the number of new cases of paralytic polio was estimated to be between 200,000 – 400,000 per year [6,21]. The sentinel surveillance system of the Government of India which collected annual incidence data from only a few hospitals might have missed as much as 90% of these cases in the early years [6]. We assume that the NPSP program (along with the PPP), which began active surveillance activities in 1997, took three years to reach optimal level of surveillance sensitivity. Therefore, reported polio incidence data during 2000-2012 are considered to be representative of the true number of cases in our study. For the period 1982-1999, however, we adjusted the number of reported polio cases for underestimation in the following way:

First, we projected the number of new paralytic polio cases in 1981 using the incidence rate of 15.0 per 100,000 people and the total population size based on Joseph, *et al.* [19]. Next, we extrapolated the time trend of reported annual incidence from John [20] in order to estimate the change in year-to-year incidence during 1982-1999. For example, the number of reported new polio cases in 1981 was 38,090, which decreased to 26,297 (30.1% reduction) in 1982, and then to 24,663 (another 6.2% reduction) in 1983, and so on [20].

We multiplied the annual population size in India [22] with polio incidence to estimate 107,266 new paralytic polio cases in 1981. Then, following the time trend mentioned above, the number of new cases reduced to 74,055 (30.1% reduction) in 1982, then 69,454 (further 6.2% reduction) in 1983, and so on. Thus, our estimated number of new cases of paralytic polio, and the associated mortality during 1982-1999 followed a trend similar to the reported number of cases, but at much higher levels.

To estimate the burden of paralytic polio under the counterfactual scenario, we assumed that annual incidence was constant at 15.0 per 100,000 people during 1982-2012. For simplicity, we ignored disease transmission dynamics and estimated the annual number of paralytic polio cases by multiplying the estimated

TABLE I MODEL INPUT PARAMETERS

Parameter type	*Value*	*Source*
Disease parameters		
Annual incidence rate of paralytic polio	15.0 per 100,000 people	Joseph et al. (2003) [19]
Case fatality rate	0.10	Khan and Ehreth (2003)[14]
Years lived with disability	Life expectancy at birth – 3 years	Assumed
Disability weight	0.369	World Health Organization
Population parameters		
Estimated annual population of India	731 million in 1982 to 1.2 billion in 2012	World Bank [22]
Life expectancy at birth	55.8 years in 1982 to 66.2 years in 2012	World Bank [22]
Economic parameters		
Gross Domestic Product (GDP) per capita (2005 US$)	$305.9 in 1982 to $1,123.2 in 2012	World Bank [22]
Gross National Income (GNI) per capita, (2005 US$)	$305.4 in 1982 to $1,090.0 in 2012	World Bank [22]

The parameters in the table pertain to the base case scenario. We also conduct a 500 simulation sensitivity analysis by varying the incidence rate of polio from 11.25-18.75 per 100,000 people [19]. Following Khan and Ehreth [14], we assume that all polio cases occur within the first three years of life.

annual population size (obtained from the World Bank [22]) with the constant rate of incidence.

After calculating the number of incident cases for each of the two scenarios, we calculated annual DALYs following the WHO guidelines [16–18] as below:

$$DALY = YLL + YLD$$

Where YLL denotes years of life lost and YLD denotes years of life lived with disability due to paralytic polio. YLL is calculated as below:

$$YLL = \frac{D\,(1 - e^{-rL})}{r}$$

Where D is the number of polio deaths. L is the life expectancy at birth, and r is the discount rate (5%). D is calculated as:

$$D = CFR * P$$

Where CFR is the case fatality rate of polio (proportion of paralytic cases that are fatal—assumed to be 10% [14]) and P is the number of new paralytic polio cases.

YLD is calculated as:

$$YLD = \frac{(P - D) \times dw \times R \times (1 - e^{-rR})}{r}$$

where dw is the disability weight of polio, equal to 0.369 [11], R denotes the duration of disability, equal to life expectancy at birth minus three years since most polio cases occur during early childhood [14,22] and r denotes the discount rate, equal to 5%.

Economic Burden

In order to calculate the economic costs of polio, we used the value of statistical life (VSL) measure. VSL is based on the concept of human capital, assuming that the value of a year of life can be measured in terms of annual economic productivity [23,24]. Following Stenberg and colleagues [25], we assumed that the value of one statistical life-year (VSLY) was 1.5 times the per capita gross domestic product (GDP) of India in our base case model. We obtained annual per capita GDP data for 1982-2012 from the World Bank [22] and calculated the VSLY for year t as:

$$VSLY_t = 1.5 \times PCGDP_t$$

where $PCGDP_t$ is the per capita GDP for the t-th year. For simplicity, we considered a fixed VSLY over the life course of an individual, which is the estimated economic value of one DALY. The total estimated annual economic cost of polio is the sum of all VSLYs lost in one year.

We also used an alternative method for estimating the economic benefits of the polio program. Under this approach, each DALY adverted was valued at the gross national income (GNI) per capita in India [22] in a given year [24,25]. The costs saved due to polio elimination are first calculated in terms of constant 2005 US dollars. All estimates in this study are then reported in 2011 US dollars after adjusting for inflation and also converted to 2011 INR (assuming US$ 1=INR 45).

The difference in the aggregate number of incident polio cases, DALYs lost and deaths due to polio during years 1982-2012 between the counterfactual and actual burden scenarios is the total health gain from the National Polio Program in India. Similarly, the difference in the aggregate VSLYs lost to polio between the two scenarios is the total economic gain from the program. We report the total health and economic gains from the base case model with a pre-vaccine paralytic polio incidence rate of 15.0 per 100,000 people as our main result. We also conducted sensitivity analyses by running the model with 500 randomly selected incidence rates in the range 11.25–18.75 (i.e. 75%–125% of the initial value) per 100,000 people [19]. The health and economic gains by the National Polio Program estimated from these additional simulations were then used to construct 95% confidence intervals for the base case results.

RESULTS

Fig. 1 presents the trends in annual incidence of polio in India. The estimated number of cases (with an upward adjustment of reported cases during 1982-1999) shows a similar declining trend over time, with large outbreaks of polio in certain years such as 1987 and 1992. In comparison, the counterfactual number of new cases,

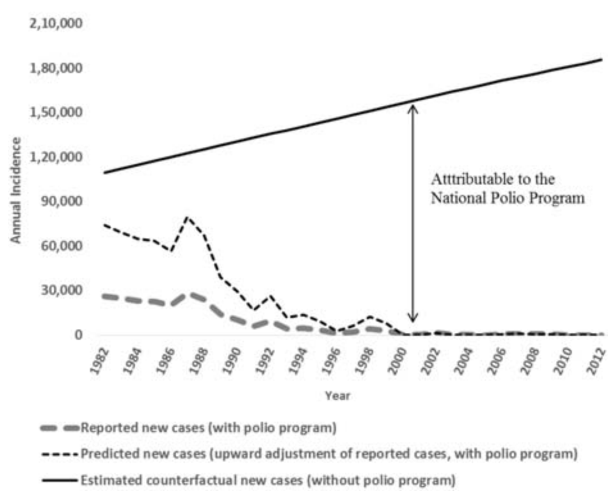

FIG. 1 *Reported, adjusted, and counterfactual incident cases of paralytic polio in India, 1982-2012.*

which is based on a constant pre-vaccine incidence rate and annual estimated population, shows a steady upward trend over time. The gap between the counterfactual series and the estimated series can be attributed to the National Polio Program as the aggregate averted incident cases of polio.

***Table* II** presents the results of our analysis. Our estimates are from an *ex-post* perspective, i.e. no discounting other than in the calculation of DALYs is used. In our base case model which considers a pre-vaccine incidence rate of 15.0 per 100,000 people [19], we estimate that the National Polio Program averted 3.94 million (95% confidence interval [CI]: 3.89–3.99 million) paralytic polio cases, 393,918 polio deaths (95% CI: 388,897-398,939), and 1.48 billion DALYs (95% CI: 1.46-1.50 billion) between 1982 and 2012. Using the VSL approach, total gains in economic productivity from the program are estimated to be $1.71 trillion (INR 76.91 trillion) (95% CI: $1.69-$1.73 trillion [INR 75.93-77.89 trillion]).

If we consider the lower and upper bound value of the sensitivity interval of the pre-vaccine incidence rate (11.25 and 18.75 per 100,000 people, respectively), the total health gain from polio control would be 2.95-–4.93 million incident paralytic polio cases averted, 295,302-492,534 averted deaths and 1.11-1.85 billion DALYs averted. The economic gain using the VSL approach would be $1.28-$2.14 trillion (INR 57.65-96.17 trillion).

If we consider the same pre-vaccine incidence of paralytic polio as in the base case model (15.0 per 100,000 people) but consider the economic value of one DALY to be equal to the GNI per capita in a given year [26,27], the total economic gain from the polio program would be $1.11 trillion (INR 50.13 trillion) (95% CI:

TABLE II ESTIMATED HEALTH AND ECONOMIC BENEFITS OF POLIO ERADICATION IN INDIA, 1982-2012

Scenario		*Estimated benefits*	*95% Confidence Interval*
Base case model (pre-vaccine incidence of 15.0 per 100,000 people)			
Incident paralytic cases averted (million)		3.94	3.89–3.99
Deaths averted		393,918	388,897–398,939
DALYs averted (billion)		1.48	1.46–1.50
Economic gain (VSL method)	2011 US$, trillion	1.71	1.69–1.73
	2011 INR, trillion	76.91	
Economic gain (DALY/GNI per capita method)			
2011 US$, trillion		1.11	1.10–1.13
2011 INR, trillion		50.13	49.50–50.76
Sensitivity analysis (pre-vaccine incidence of 11.25 per 100,000 people)			
Incident paralytic cases averted (million)		2.95	
Deaths averted		295,302	
DALYs averted (billion)		1.11	
Economic gain (VSL method)	2011 US$, trillion	1.28	
	2011 INR, trillion	57.65	
Economic gain (DALY/GNI per capita method)	2011 US$, billion	835.14	
2011 INR, trillion		37.58	
Sensitivity analysis (pre-vaccine incidence of 18.75 per 100,000 people)			
Incident paralytic cases averted (million)		4.93	
Deaths averted		492,534	
DALYs averted (billion)		1.85	
Economic gain (VSL method)			
2011 US$, trillion		2.14	
2011 INR, trillion		96.17	
Economic gain (DALY/GNI per capita method)			
2011 US$, trillion		1.39	
2011 INR, trillion		62.69	

Note: The 95% uncertainty ranges are obtained from a 500 simulation sensitivity analysis varying the incidence rate of polio in the interval 11.25-18.75 per 100,000 people [19]. All economic estimates are in 2011 constant US dollars (US$1 = INR 45).

WHAT IS ALREADY KNOWN?

- Health interventions could not only help avert morbidity and mortality, but they could also substantially increase economic productivity over the productive lifetime of individuals.

WHAT THIS STUDY ADDS?

- We find that the national polio elimination efforts during 1982-2012 in India have brought tremendous health and economic gains.

$1.10-$1.13 trillion [INR 49.50–50.76 trillion]). With this alternative valuation of DALYs, pre-vaccine incidence rates of 11.25 and 18.75 per 100,000 would result in economic gains of $835.14 billion and $1.39 trillion (INR 37.58 and 62.69 trillion), respectively. The estimated health gains of the program would remain unaffected under this alternative approach.

DISCUSSION

Overall, our findings indicate that India accrued large health and economic benefits from investing in polio elimination efforts. We estimate that India averted 3.94 million paralytic cases of polio, 393,918 related deaths, 1.48 billion DALYs, and gained $1.71 trillion (INR 76.91 trillion) in economic productivity between 1982 and 2012 in our base case analysis. In Indian vernacular, one billion is equal to 100 crores and one trillion is equal to one lakh crores. Thus, the National Polio Program contributed much to the economic growth of India, a fact not appreciated by many.

Previous studies have estimated the benefits of polio eradication in various countries under different time horizons and under different polio eradication initiatives. Duintjer-Tebbens and colleagues [15], for instance, estimated the incremental net benefits of the GPEI was $40-$50 billion from 1988 to 2035, which was estimated to prevent eight million paralytic polio cases. Khan and Ehreth [14] estimated the total medical care cost savings from global polio vaccination campaigns was $128 billion (in 2000 USD), which prevented four million paralytic polio cases, 855,000 deaths, and 40 million DALYs from 1970 to 2050. Bart and colleagues [23] estimated a much lower savings from global polio eradication. They estimated that a global eradication initiative would result in savings of $13.6 billion (in 1993 USD) from 1986 to 2040. Thompson and Duintjer-Tebbens [24] estimated the net benefits of the polio elimination program in the United States was $180 billion (net present value in 1955) due to prevented treatment costs alone, including 1.1 million prevented cases of paralytic polio and over 160,000 prevented deaths from 1955 to 2005.

In order to complete eradication of all polio, due to wild and vaccine-derived polioviruses, the GPEI recommends that countries begin introducing at least one dose of inactivated polio vaccine (IPV) into routine immunization by the end of 2015, phasing out the use of OPV in a staggered manner (by serotype) until only IPV is in use without any OPV [28]. Theoretically vaccination will no longer be needed in the future [28]. Phasing out OPV is necessary since it can cause vaccine-associated paralytic polio (VAPP) and evolve into circulating vaccine-derived polio virus (cVDPV), meaning the virus can survive in the community and emerge as wild-like, IPV is required to mitigate the risks of immunodeficiency-related vaccine-derived polio virus (iVDPV) spreading in the community and of cVDPVs causing polio outbreaks. All interventions against vaccine-related polio are together called the “endgame strategy” of polio eradication. India’s endgame strategy started in 2015 by roll out of routine IPV vaccination.

Some researchers postulate that IPV vaccination may be necessary even after the declaration of eradication of polio due to wild and vaccine-derived viruses [29,30]. Since there is such a need for continued IPV vaccination for the foreseeable future, the economic rationale for current polio eradication efforts is less certain [29]. As IPV is costly for poorer countries, the decision to eventually switch to IPV in these countries may not be economically justified, even though it is essential for eradication. Duintjer Tebbens and colleagues [32] argue that continued OPV use indicates that either there will be high costs forever, or a large number of cases forever, which gives credence to long-term health and economic benefits of switching from OPV to IPV. Barrett, *et al*.[33] argue that wealthier countries should subsidize the cost of IPV for poorer countries for several years until the risks from cVDPV has dropped or disappeared. After this, poorer countries would be able to stop vaccination altogether.

There are several limitations to our analysis. First, we may underestimate the benefits of polio elimination for a few reasons. Our analysis starts with 1982, but routine polio immunization was adopted in India beginning in 1978 in a staggered manner. Thus, we may underestimate the benefits of polio elimination by not including 1978-1981 in our calculation. Also, long-term benefits beyond 2012 are not included in our analysis. Another reason for underestimation may be the incidence rate of 15 per 100,000 people that we used in the analysis. There are reports of higher incidence rates, but we used the very conservative data [21].

Second, we assumed a constant polio incidence rate under the counterfactual scenario and did not take into account polio transmission dynamics. Due to lack of data, possible changes in the incidence over time could not be incorporated in our analysis. However, we used a wide sensitivity range to evaluate other incidence scenarios. Third, there is no data on the lifetime cost of polio per patient in India, including treatment costs and productivity losses. Therefore, we refrained from calculating averted treatment costs in our analysis. More robust cost estimates may yield estimated economic benefits different from–likely higher–than those evaluated using the VSL method.

Fourth, due to a lack of data on the programmatic costs of polio elimination in India, we were unable to reliably estimate the cost-effectiveness or benefit-cost ratios of the program. A recent study by Prinja, *et al*. [34] estimated the cost of routine immunization per child in three states of India to be $1.80, and the cost of supplementary immunization for polio (Pulse Polio) to be $28.80 per child. There are two other older studies which estimated the cost of polio immunization in India [35,36]. However, none of them provide long-term cost data during 1982-2012 required for our analysis. Even considering the approximately $2 billion apportioned to the polio elimination program by the Indian government and donor agencies [3], these reported costs pale in comparison to the huge economic gains estimated in our analysis.

Fifth, our results may be somewhat underestimated since we included life expectancy at birth to calculate DALYs and to subsequently compute economic benefits; however, using life expectancy at age three would have been more robust since life expectancy at age three is likely longer than at birth because life expectancy at birth incorporates infant mortality.

Finally, while we assume a counterfactual scenario of no elimination efforts (including no polio immunization), other comparisons are also possible. For example, the supplementary immunization (Pulse Polio) could be compared against a counterfactual scenario of polio immunization as part of a routine universal immunization program. This would be helpful in comparing the incremental costs and benefits of the different components of polio elimination efforts in India.

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