Lives Saved Tool Technical Note
Last updated: 12 November 2020
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Herd Effects of Vaccines

Moderate to high coverage of certain vaccines can reduce the transmission and subsequent morbidity and mortality from their target pathogens. Herd effect is the protection conveyed to unvaccinated or suboptimally vaccinated individuals by population-level vaccination coverage. Within LiST, herd effects are applied as the additional deaths averted by the population-level protection offered by a vaccine after accounting for deaths prevented directly by vaccination. We calculate the direct effect as the number of pathogen-specific deaths averted by the vaccine based on the proportion of the population vaccinated scaled by the efficacy of the vaccine.

Numerous studies have documented reductions in both morbidity and mortality from pathogens exceeding the impact expected due to direct effect alone. This excess reduction can be partially attributable to the protective effect offered to unvaccinated individuals due to reduced pathogen transmission in the population. In a trial setting, the indirect effect of vaccination is assessed by comparing the 1) rates of disease in unvaccinated individuals within a population receiving a vaccine against 2) disease rates in a population without vaccination (either the same population prior to vaccine introduction or a comparable population). However, limited trial data are available. Where available, the measured indirect impact typically reflects high vaccination coverage in the population (due to study design) and the overall size of the study population is limited.

As a result, observational studies tracking rates of disease in a population before and after introduction of a vaccine are often used to assess the herd effect of vaccine. In these observational studies, the vaccination status of individuals is typically unknown. However, population vaccination coverage can often be derived from administrative records or other systems. The overall effect of a vaccine is assessed by comparing rates of disease before and after the vaccine's introduction. The expected direct effect of the vaccine can be modeled based on the vaccine's documented effectiveness and coverage within the population. The indirect effect can then be derived as the difference between the observed overall effect and the expected direct effect in the population. Multiple studies report the necessary information required to calculate indirect effect using this approach. The herd effects utilized in LiST are derived from meta-analyses of these studies.

As population coverage increases, the expected herd effect also increases. This is due to the reduction in pathogen transmission associated with the reduction in the number of susceptible individuals. However, the relationship between vaccination coverage and herd effect is not necessarily linear. At low levels of coverage, the number of vaccinated individuals may not achieve the threshold to reduce transmission in the unvaccinated population. At high coverage levels, transmission may be broken completely well before complete vaccination coverage is achieved.

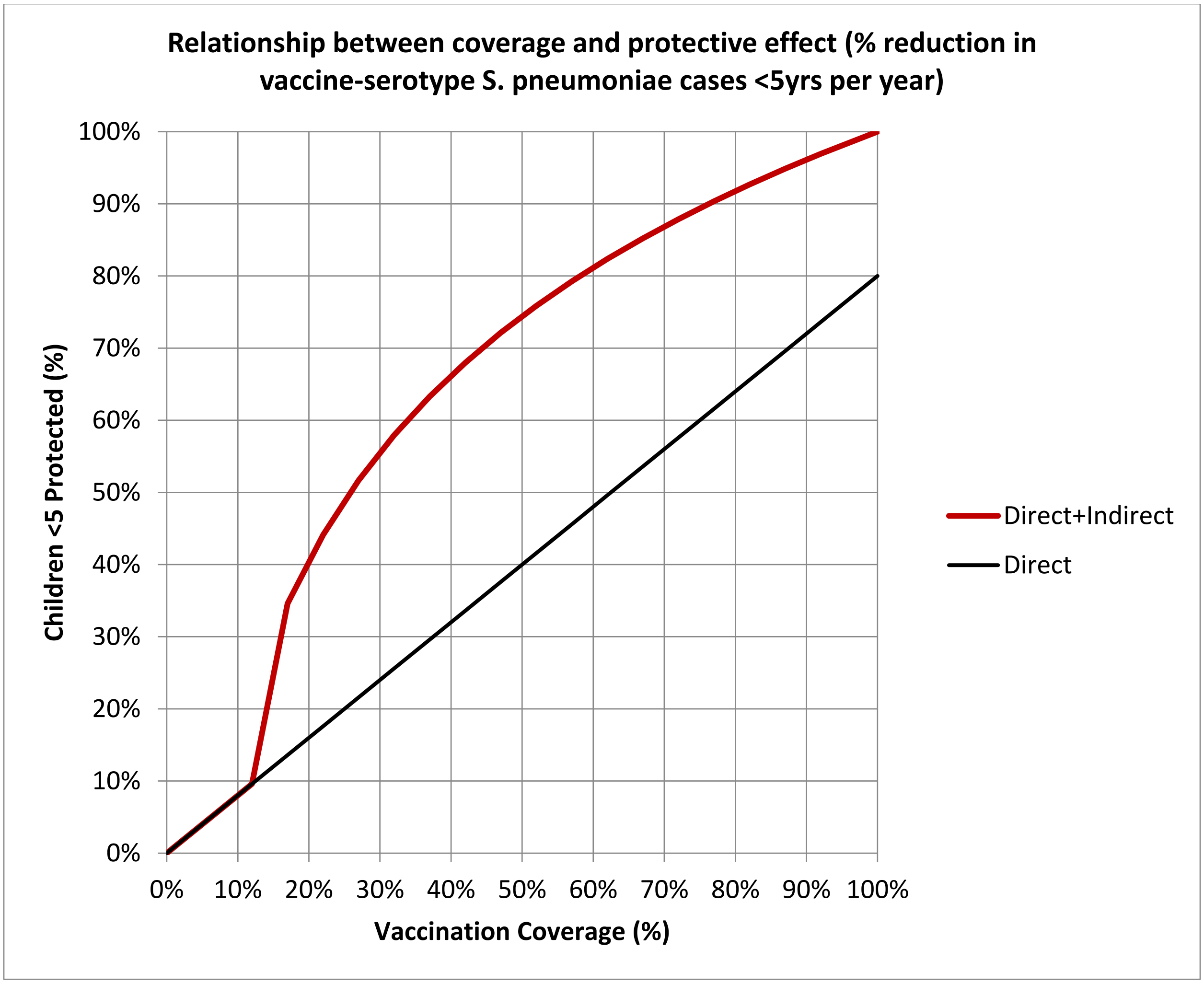
Within the LiST interface, herd effects can be specified in 5% coverage intervals ranging from 0 to 100% coverage. Additionally, the user can specify different herd effects for different age cohorts. We calculated defaults herd effects using the midpoint of each 5% coverage intervals. Herd effects were assumed to be constant across age cohorts >1 month. For each vaccine with demonstrated herd effects, we calculated herd effect as the proportion of the susceptible population protected by vaccination coverage in the population. No estimates of herd effects in children under 1 month are provided due to lack of data on pathogen-specific disease etiology in neonates.

Pneumococcal Conjugate Vaccine (PCV)

We derived the total effect of PCV vaccine over varying levels of vaccination coverage from a report modeling the herd effect of PCV in India (1) based on data from a study in Spain (2). The total effect of vaccination on vaccine serotype S. pneumoniae mortality by coverage was estimated using Formula 1.

$$Total\ Effect = 1 + \ln(coverage)\frac{0.31}{\%\ Sp\ attributable\ to\ vaccine\ serotypes}\ if\ coverage \geq 13$$

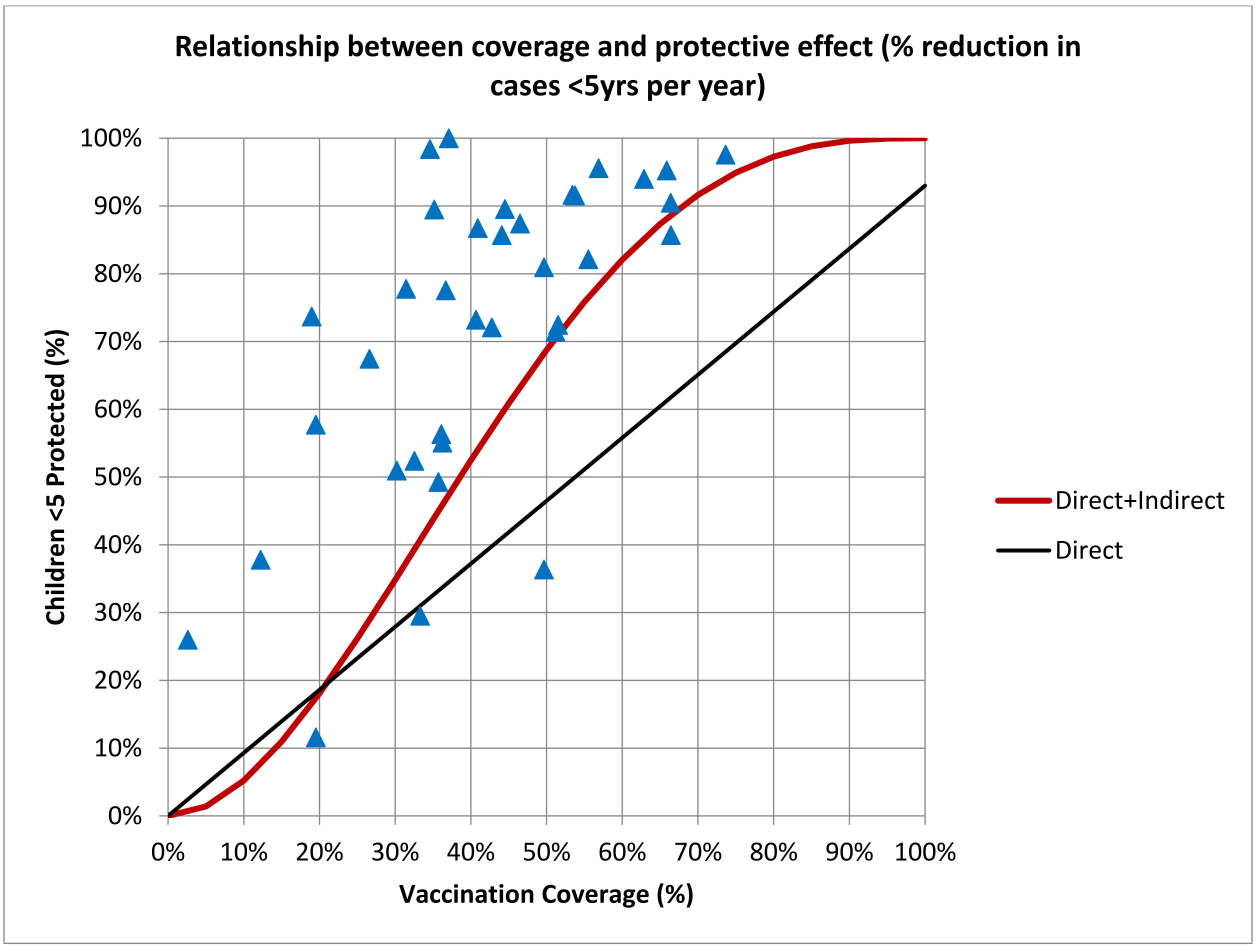
Fig 1. Total (direct + indirect) effect and direct effect of PCV on vaccine-serotype S. pneumoniae cases in children under 5 by population vaccination coverage


Relationship between coverage and protective effect (% reduction in vaccine-serotype S. pneumoniae cases <5yrs per year)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Children <5 Protected (%)
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Vaccination Coverage (%)
Direct+Indirect
Direct

Hemophilus Influenzae B (Hib)

We estimated the total effect of Hib vaccine by vaccination coverage using an unpublished systematic review on the herd effect of Hib (3). The total effect of vaccination on Hib mortality was conservatively estimated as beta function with an alpha=2 and beta = 3. The expected herd effect of Hib was constant across countries.

Fig 2. Total and direct effect of Hib vaccine on *H. influenzae B* cases in children under 5 by population vaccination coverage



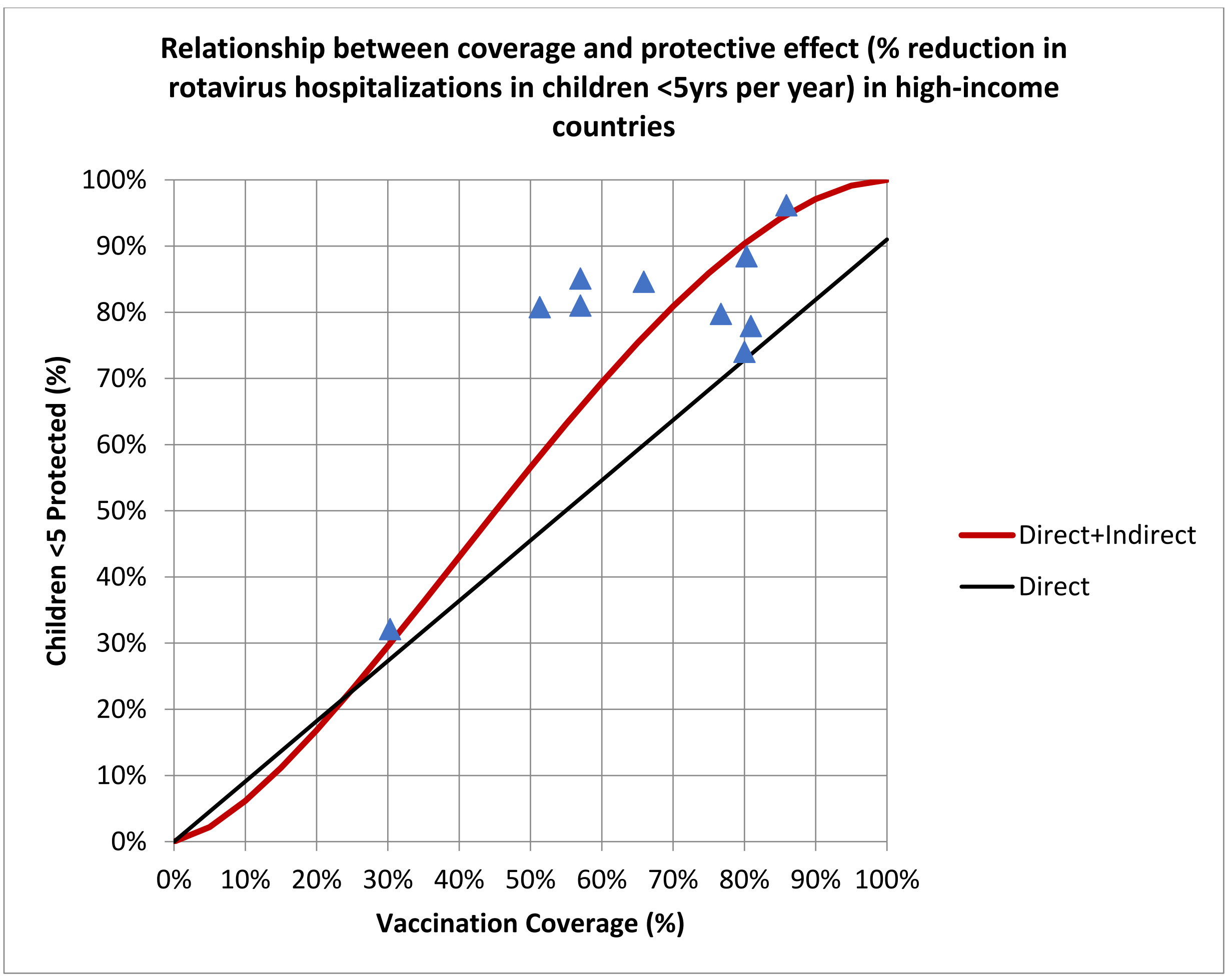
*Blue triangles represent individual study data points of the observed total effect and underlying population vaccination coverage

Rotavirus Vaccine

We derived the total effect of rotavirus vaccine over varying levels of vaccination coverage from a systematic review on the herd effect of rotavirus vaccine (4). The total effect of vaccination on rotavirus mortality by coverage was estimated as beta function with an alpha=1.5 and beta=1.8. The total effect was then scaled by the regional efficacy of rotavirus vaccine (5) relative to the efficacy of rotavirus vaccine in high-income settings.

MDG/SDG Region	Vaccine Efficacy	Ratio
Sub-Saharan Africa	0.461	0.509
Southern Asia, Southeast Asia, Oceania	0.5	0.552
East Asia and Western Pacific	0.884	0.976
Latin America and the Caribbean	0.796	0.878
Developed Countries, North Africa, Central Asia, Western Asia	0.906	1

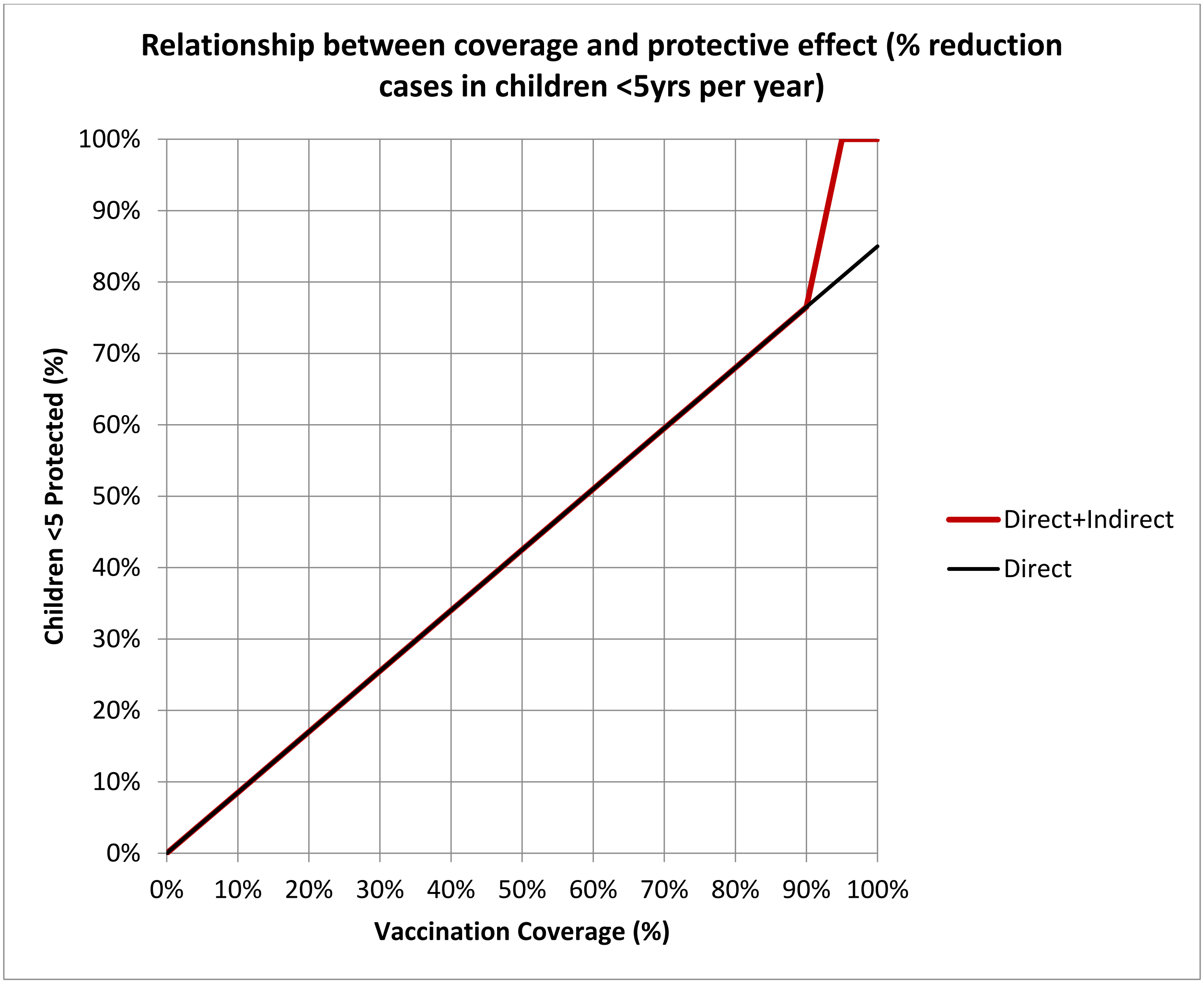
Fig 3. Total and direct effect of rotavirus vaccine on rotavirus hospitalizations in children under 5 by population vaccination coverage in high-income countries



* Blue triangles represent individual study data points of the observed total effect and underlying population vaccination coverage

Measles Vaccine

Due to measles high R_0, high vaccination coverage is required to achieve herd immunity. According to the WHO measles vaccination, vaccination coverage of 92-95% is required to prevent measles outbreaks (6). We incorporate the herd effect of measles as a linear increase in indirect effect from 0 to 100% protection of susceptibles as coverage increases from 90 to 95% coverage.



Other Vaccines

We do not include default herd effect values for any other vaccines. There is insufficient data to estimate the herd effect of the meningococcal A vaccine despite some evidence of reduced carriage among unvaccinated children. There is also a lack of data suggesting an indirect effect of DPT on pertussis transmission. Adolescents and adults are the most common source of pertussis transmission to children. Pertussis immunity wanes 5 to 10 years after vaccination, offering little protection for unvaccinated children against transmission from older age groups. All other vaccines included in LiST have little to no impact on child mortality and similarly no effect on mortality tied to their indirect effects.