



WHO/UNICEF estimates of national immunization coverage, 1980–2008

Methods:

Background

Information on immunization coverage is used for a variety of purposes: to monitor the performance of immunization services at local, national and international levels; to guide accelerated disease-control initiatives such as polio eradication, measles control, and neonatal tetanus elimination; to identify areas of weak system performance that may require extra resources and focused attention; and as a consideration when deciding whether to introduce a new vaccine. Coverage levels with diphtheria and tetanus toxoid and pertussis vaccine are considered one of the best indicators of health-system performance, and funding agencies frequently consider immunization coverage levels when reviewing applications for financial and technical support. Coverage level with measles vaccine is an indicator of progress towards Millennium Development Goals.

An accurate historical representation of immunization coverage is important to assess trends in immunization system performance, to better establish the relationship between immunization service delivery and disease occurrence, and to provide a framework for setting future goals for coverage achievement.

The WHO/UNICEF review: data, methods and process

In June 2000, WHO and UNICEF conducted a retrospective review of data available on national immunization coverage for the years 1980 to 1999, to determine the most likely true level of immunization coverage. We included data officially reported to WHO and UNICEF by Member States, in addition to data reported in the published and grey literature. Whenever possible we consulted local experts — primarily national Expanded Programme on Immunization (EPI) managers and WHO regional office staff — for additional information regarding the performance of specific local immunization services. Based on the data available, consideration of potential biases, and contributions from local experts we attempted to determine the most likely true level of immunization coverage. Estimates of national immunization coverage were made for bacille Calmette-Guérin (BCG) vaccine, the third dose of diphtheria and tetanus toxoid and pertussis vaccine (DTP3), the third dose of polio vaccine — either oral polio vaccine or inactivated polio vaccine (Pol3) — the first dose of measles vaccine (MCV) and the third dose of hepatitis B vaccine (HepB3). We also made estimates of the proportion of live births protected (PAB) through maternal immunization with at least two doses of tetanus toxoid for countries where the risk of neonatal tetanus is a significant public-health problem. In 2005 estimates of the first dose diphtheria and tetanus toxoid and pertussis vaccine (DTP1) and the third dose of *haemophilus influenzae* type b (Hib3) were added. The retrospective review, completed in October 2001, has been continued annually, and estimates of national immunization coverage are available from 1980 to 2008.

Data, sources and biases

For this review we relied on the following data.

1. Officially reported data by Member States to WHO.
2. The historical database maintained by UNICEF.
3. Published literature — primarily coverage survey results and methods.
4. Unpublished surveys available from ministries of health.

Immunization coverage levels are presented as a percentage of a target population that has been vaccinated. Coverage is usually calculated for each antigen and for the number of doses completed. For example, DTP3 coverage is calculated by dividing the number of children receiving their third dose of DTP by the number of children surviving to their first birthday. The target population chosen varies depending on the countries' policies, the specific vaccine, and the dose for which coverage is being calculated. In most instances the target population is the number of children surviving their first year of life. In general, estimates of immunization coverage are based on two sources of empirical data: reports of vaccinations performed by service providers (administrative data) and surveys containing items on children's vaccination history (coverage surveys). For estimates based on administrative data, service providers (e.g. district health centre, vaccination team, physician) summarize the number of vaccinations given during a time period (usually monthly) and report these data to the local public-health authorities. The data are reviewed and, where necessary,



appropriate action taken. The data are then aggregated and reported to the next administrative level. At the national level these data are aggregated, analysed, and used to determine immunization policy and focus programme activities, and to influence resource allocation.

Surveys are frequently used in conjunction with administrative data; in other instances they constitute the sole source of information on immunization coverage levels. The principle types of surveys are the Expanded Programme on Immunization (EPI) 30-cluster survey, the UNICEF Multiple Indicator Cluster Survey (MICS), and the Demographic and Health Survey (DHS). EPI 30-cluster surveys are frequently conducted by national EPI staff, are designed specifically for measuring immunization coverage, are simple to administer and easy to conduct, but have a precision plus or minus 10% points at 50% coverage. The MICS and DHS are more extensive surveys covering a variety of indicators, have a more rigorous design, and typically have a higher degree of precision, but are more expensive, logistically more complex and the questionnaire is longer and more difficult to administer.

Each of the above methods has advantages and disadvantages. The administrative method provides information on a more timely basis and makes use of routinely recorded data. In addition to giving information on coverage the administrative data can be used to detect and correct problems in service delivery (e.g. vaccine shortage, poor session attendance). Coverage estimates based on this method are sensitive to two major biases; those in the numerator (the number of doses administered), and those in the denominator (the size of the target population). The most frequent numerator bias is introduced when reports on the number of doses administered is not complete. Take the following example. Immunization coverage is being calculated for three areas. Area "A" has an estimated target population of 486 children and 310 were vaccinated. Area "B" has 300 children and 290 were vaccinated. Area "C" has 214 children and 100 were vaccinated. Immunization coverage would be estimated as 70%.

$$\frac{310 + 290 + 100}{486 + 300 + 214} = \frac{700}{1000} = .70 \text{ (or 70\% coverage)}$$

The accuracy of this calculation assumes that data from all areas are reported. However suppose data from one area are not reported. Traditionally one of two procedures has been followed. The first makes the same calculation as above but, because the data for area C are missing, the 100 vaccinations are not included in the calculation.

This gives an estimate of 60% coverage.

$$\frac{310 + 290}{486 + 300 + 214} = \frac{600}{1000} = .60 \text{ (or 60\% coverage)}$$

This procedure, in effect, assumes that there has been no vaccination in areas from which data are not available (zero doses administered), and so most likely underestimates true coverage.

The second procedure is to exclude from the denominator areas for which vaccination data have not been reported.

Applying this method to the example above we estimate a coverage of 76%.

$$\frac{310 + 290}{486 + 300} = \frac{600}{786} = .76 \text{ (or 76\% coverage)}$$

This procedure may produce a bias that leads to either over or underestimation of coverage depending on the number of children vaccinated in the area for which the data were not reported. In general, however, one would expect that areas performing well are more likely to report, resulting in an overestimation of true coverage.

The biases described above occur when intermediate sites fail to report. A similar bias can occur when the data collection/reporting system excludes part of the population. The most common example is when a significant proportion of vaccinations are performed in the private sector and are not reported to the public-health authorities. If the denominator is derived from the total population and the numerator is based only on children receiving vaccination in the public sector, this will lead to an underestimation of the actual coverage.

Biased estimates of coverage can also be the result of an inaccurate denominator — the size of the target group. An overestimate of the denominator will bias coverage low while an underestimate will inflate the estimate of coverage.



This bias can most readily be seen when coverage is high and the denominator has been underestimated. In this case immunization coverage estimates can exceed 100%. Errors in estimating the denominator can result from population projections based on outdated censuses, poor population projections, or sudden shifts in population.

Estimates based on surveys also have advantages and disadvantages. The principal advantages of surveys are that an estimate of immunization coverage can be obtained if the denominator is unknown, and that vaccinations given by the private sector can be included. The principle disadvantage of surveys is that they provide information on the previous birth year's cohort (making it difficult to use for timely programme intervention). In addition, the survey methodology may provide a wider than desired confidence interval, interviewers may be poorly trained, and the implementation and supervision may be weak. In some instances the length or complexity of the questionnaire may compromise the accuracy of the responses. Finally, as with any survey, the results may be inappropriately generalized beyond the population represented in the survey.

Methods

In general we have tried to distinguish between situations where the data accurately reflect immunization system performance and those where the data are likely to be compromised and present a misleading view of immunization coverage. While the estimates with the exception of PAB are not the result of a formal modelling exercise, we have nevertheless applied a series of principles.

1. Evidence based: We have made no ad hoc adjustment to reported data; in some instances data for a country was available from a single source, usually the national reports to WHO. In these instances, in the absence of data from an alternative source, those data were used for the WHO/UNICEF estimate.
2. Country-specific: Each country was reviewed individually, and data were not "borrowed" from other countries. There was no attempt to group countries based on income, development levels, population size or geographic location. The resulting estimates are based only on data from that country.
3. Consistent patterns and trends: In cases where no data are available for a given year for a country and antigen, we have considered data from earlier and later years and interpolated to estimate coverage for the missing year. In cases where data sources are mixed and show large variation, we have attempted to identify the most likely estimate in consideration of the possible biases in the data.
4. Local knowledge incorporated: We have consulted with local experts and have attempted to put the data in the context of local events, both those occurring in the immunization system (e.g. vaccine shortage for parts of the year, donor withdrawal, etc.) and more widely occurring events (e.g. international incidences, civil unrest, heightened political commitment to immunization, etc.).
5. No averaging: In the event that multiple data points are available for a given country and antigen, we have not automatically taken an average of the data points. Rather we have considered the potential biases in each of the sources and attempted to construct a consistent pattern over time.
6. No smoothing: Immunization coverage levels vary over time, and while there are frequently general trends, we have not attempted to fit the data points to curve using smoothing techniques.
7. No 100% coverage: While it is theoretically possible to immunize 100% of the target population, especially in small countries, in reality a true immunization level of 100% is unlikely. In the review we occasionally encountered coverage levels in excess of 100%. These levels are most likely to be the result of a systematic error ascertainment of the numerator or the denominator, a mid-year change in target age groups, or inclusion of children outside the target age group in the numerator. We have chosen to represent the highest level of coverage as 99%.
8. PAB coverage has been estimated using a mathematical model. PAB is the proportion of births in a given year that can be considered as having been protected against tetanus as a result of maternal immunization. In this model, annual cohorts of women are followed from infancy through their life. A proportion receive DTP in infancy (estimated based on the WHO-UNICEF estimates of DTP3 coverage). In addition some of these women also receive TT through routine services when they are pregnant and may also receive TT during SIAs. The model also adjusts reported data, taking into account coverage patterns in other years, and/or results available through surveys. The duration of protection is then calculated, based on WHO estimates of the duration of protection by doses ever received. A further description of the model can be found in: Griffiths U., Wolfson L., Quddus A.,



Younus M., Hafiz R.. Incremental cost-effectiveness of supplementary immunization activities to prevent neo-natal tetanus in Pakistan. *Bulletin of the World Health Organization* 2004; 82:643-651

Process

Update national reports: The first step was to review and update data officially reported by Member States through the WHO regional offices to ensure that WHO databases correctly reflect national data. In some cases data available to international organizations — principally WHO and UNICEF in this instance — may differ. Requests to the countries for information may be made at different times and it is possible that the national authorities have updated their estimate between the times of the requests. Alternatively, the source of data within the country may differ. The criteria for accepting data differs from agency to agency. WHO-reported data are considered official reports by WHO Member States. On some occasions UNICEF may take survey data rather than reports based on administrative data. WHO and UNICEF are working to harmonize the data collection from countries at the international level.

Search the literature: Secondly, we searched for and abstracted information on immunization coverage from a variety of additional sources. The Demographic and Health Surveys (DHS), the UNICEF Multiple Indicator Surveys (MICS) and nationally conducted coverage surveys, constitute the majority of these findings. In addition, we searched the published scientific literature and requested information on other studies from national authorities.

Where possible we consulted with national and regional experts to seek more in-depth knowledge regarding the functioning of the immunization system. These consultations have proved invaluable for a fuller understanding of the functioning of the specific national systems.

Draft estimates: Draft estimates of the most likely coverage for each year and antigen were made based on the data and methods described above. The estimates were based on an appraisal of individual data points, patterns and trends in the data, and information on local circumstances affecting service delivery. In instances where alternative data were not available, estimates were based solely on officially reported data. In general we have tried to distinguish whether the data accurately reflect immunization system performance, or whether the data are compromised and present a misleading view of coverage achievements. We did not attempt to construct a statistical or mathematical model to estimate coverage.

Review by national authorities: An essential part of this review has been the consultation and collaboration with national authorities. The draft estimates were sent to each national authority for their review, comment, and contribution. This collaboration prior to the public release of the final estimates is important not only to inform national authorities of the results of the review before its general release, but also to take advantage of local expertise and knowledge.

Revise draft estimates: The draft estimates were revised based on comments received from the national authorities.

External review: The methods and findings were reviewed by a group of external experts with broad experience in immunization systems and survey methodology. The group supported the methods and recommended a series of future activities.

Dissemination of results: The estimates and supporting data are available on

http://www.who.int/immunization_monitoring/routine/immunization_coverage/en/index4.html

and

<http://www.childinfo.org/areas/immunization/database.php>

and may be freely reproduced.

The methods described here have been published in the *Bulletin of the World Health Organization* and can be accessed on line at <http://www.who.int/bulletin/volumes/87/7/08-053819.pdf>

Burton A, Monash R, Lautenbach B, Gacic-Dobo M, Neill M, Karimov R, Wolfson L, Jones G, Birmingham M. WHO and UNICEF estimates of national infant immunization coverage: methods and processes. *Bulletin of the World Health Organization* 2009; 87:535-541.



Estimating global and regional vaccine coverage

Estimation of global and regional vaccine coverage is based on reports from WHO Member States. When coverage figures have not been reported, i.e. the vaccine is routinely scheduled but no figure was reported to WHO-HQ, a statistical method has been used to estimate the most likely coverage, and this estimate is used in the global and regional calculations. There are three types of missing data.

Type A: Missing prior to the first-ever reported coverage. In these instances, we assume that coverage is 0%.

Type B: Missing between two years where coverage was reported. In these instances the coverage estimate is a linear interpolation of the two reported coverage rates.

Type C: Missing after the last reported coverage value. If coverage has ceased to be reported, we assumed that coverage in the years following the last report will remain at the same level as was last reported.

Statistical estimates of coverage are used only when the country Ministry of Health has not reported coverage data.

Global and regional coverage is then calculated using the estimated and reported coverage figures together with estimates of the target population sized from the *World Population Prospects: the 2008 revision*. Population Division, Department of Economic and Social Affairs, United Nations, New York, 2009. The formula for aggregating coverage for a region (and globally) is:

$$\% \text{ Coverage} = \frac{\sum ((\% \text{ reported or estimated national coverage}) (\text{size of target population}))}{\sum (\text{size of target population})}$$

For HepB3, DTP1, DTP3, Hib3, MCV, POL3 and YF, the size of the target population is the national annual number of infants surviving their first year of life. For TT2+ the national annual number of births is used as a surrogate for the number of pregnant women. Priority countries for neonatal tetanus (NT) elimination and developing countries where tetanus is in the national immunization schedule for childbearing-age women are included in the TT2+ global and regional estimates. The size of the target population for BCG is the national annual number of births in countries that recommend BCG. For yellow fever, only those countries at risk for yellow fever are included in the yellow fever global and regional coverage summaries.