

Validity of reported vaccination coverage in 45 countries

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Summary

Background Monitoring and assessment of coverage rates in national health programmes is becoming increasingly important. We aimed to assess the accuracy of officially reported coverage rates of vaccination with diphtheria-tetanus-pertussis vaccine (DTP3), which is commonly used to monitor child health interventions.

Methods We compared officially reported national data for DTP3 coverage with those from the household Demographic and Health Surveys (DHS) in 45 countries between 1990 and 2000. We adjusted survey data to reflect the number of valid vaccinations (ie, those administered in accordance with the schedule recommended by WHO) using a probit model with sample selection. The model predicted the probability of valid vaccinations for children, including those without documented vaccinations, after correcting for bias from differences between the children with and without documented information on vaccination. We then assessed the extent of survey bias and differences between officially reported data and those from DHS estimates.

Findings Our results suggest that officially reported DTP3 coverage is higher than that reported from household surveys. This size of the difference increases with the rate of reported coverage of DTP3. Results of time-trend analysis show that changes in reported coverage are not correlated with changes reported from household surveys.

Interpretation Although reported data might be the most widely available information for assessment of vaccination coverage, their validity for measuring changes in coverage over time is highly questionable. Household surveys can be used to validate data collected by service providers. Strategies for measurement of the coverage of all health interventions should be grounded in careful assessments of the validity of data derived from various sources.

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Introduction

Worldwide interest in the assessment of outcomes of health programmes is growing. For donor-supported initiatives like the Global Alliance for Vaccines and Immunizations (GAVI), which provides aid to strengthen countries' immunisation programmes, and the Global Fund to fight AIDS, Tuberculosis and Malaria, monitoring of results is essential. GAVI gives financial rewards to countries that increase the absolute number of children vaccinated and is testing methodological approaches to improve this process.^{1–3} With an increased focus on the monitoring of outcomes and their important implications for policy and operations, verification of the quality of the estimates used to assess performance of health programmes is necessary.⁴ We address the quality of data used to monitor outcomes of immunisation programmes.

There are two main sources of data used to assess coverage of immunisation programmes worldwide: health service delivery records and household-based surveys.^{5,6} Countries are requested to report their vaccination coverage estimates every year to WHO and the United Nations Children's Fund (UNICEF) using the WHO/UNICEF joint reporting form on vaccine preventable diseases. Here, we refer to data from these forms as officially reported data.^{7,8} Methods and strategies for collection and reporting of these data are specific to each country. The source of data for official reports can include service registries, surveys, or a combination of both. The target population in which vaccination coverage is assessed can also vary between countries, taking into account either yearly number of births, number of infants that survive their first year of life, or the number of children within a specific age range. Further, a country might change its methods for obtaining estimates from year to year.^{3,9} The absence of standardisation in data sources and methods of collection decreases the comparability of officially reported data between countries and over time. Officially reported data tend to be the primary source of information for assessment of vaccination coverage,^{3,8} and thus it is essential to analyse their validity.

Immunisation is also an important model for many other health programmes. There has been much investment in many countries to develop information systems to support programme implementation, monitoring, and evaluation. A careful assessment of the validity of coverage estimates collected from service providers will have important implications for improving the accuracy of health information systems.

The main objective of our analysis is to assess the validity of officially reported vaccination coverage data by comparing them with the best available gold standard. Nationally representative household-based surveys such as the Demographic and Health Surveys (DHS), one of the largest programmes for collection of quantitative data on population, health, and nutrition in the developing

world, can serve as such a gold standard. Use of data from the DHS allows comparative analyses, since the surveys use standardised instruments, training, data collection, and data processing.¹⁰ Results of studies, which have validated DHS methodology and assessed the quality of DHS vaccination data, have shown little evidence of systematic bias.^{11,12} Furthermore, since data compiled through the DHS are generally nationally representative, they capture vaccinations delivered by both the private and public sectors, whereas officially reported data often report only vaccinations given via public programmes.³

Diphtheria-tetanus-pertussis (DTP3) and measles vaccinations are most often used to monitor childhood vaccination coverage rates and trends.^{3,5} We focus on DTP3 and compare the officially reported DTP3 coverage with that from the DHS.

Methods

We used vaccination data from 67 DHS done in 45 countries (panel) from 1990 to 2000. We excluded six surveys because data were not nationally representative, officially reported data were not available

for the corresponding years, or the surveys followed a local calendar system for date-related information.

The DHS used a two-stage sampling scheme, with selection at the first stage from primary sampling units or clusters, followed by the second stage of random selection of households within each cluster.¹³ From the selected households, all mothers aged 15–49 years were asked to show the interviewer the health cards of children born in the 5 years (or sometimes 3 years) before the survey.¹⁰ The interviewer documented the date each vaccine was received. If no card was presented, the interviewer asked the mother to recall all vaccinations, and if appropriate, the number of doses received, without asking for dates.

For this analysis, we selected the proportion of children receiving DTP3 vaccination as an indicator of vaccination coverage. The numerator was the number of children who received three doses of DTP, in accordance with a modified schedule recommended by WHO.⁷ Since WHO's schedule was not universally followed, we permitted a flexible timetable to allow maximum comparability between nations: three doses of DTP vaccine to be completed by age 12 months, with the first dose administered not earlier than age 1 month and the two subsequent doses at a minimum of 4 weeks apart. We refer to vaccinations given in accordance with this schedule as valid vaccinations.

The denominator of our indicator was the population of children surviving until age 12 months for each birth cohort in the 5 (or sometimes 3) years before the survey. We excluded those children younger than 12 months who had not completed all vaccinations to avoid the drawback of censored observations. We estimated vaccination rates for each cohort in the full calendar year before the survey was done.

Different approaches exist for interpretation of DTP3 coverage rates from survey data. One approach considers only valid vaccinations that are documented with a health card (hereinafter referred to as documented valid vaccination). This method can result in an underestimation of the total valid vaccinations, because undocumented valid vaccinations would not be captured. Cards might not always be seen at the time of interview because of loss, misplacement, storage at health facilities or elsewhere, or other survey-related procedures.¹¹ Another approach considers all vaccinations irrespective of the schedule of administration and the presence of documentation (hereinafter referred to as crude vaccination). Such interpretation, while more inclusive than the use of documented valid vaccination only, also does not reflect the total valid coverage because it does not differentiate between valid and invalid vaccinations.

In response to the limitations of the two aforementioned interpretations, we developed a method for estimating total valid vaccinations from the survey data. A probit model with sample selection (also known as the Heckman probit model) was used to model the probability of a DTP3 vaccination being valid. The model accounts for the differential likelihood that the respondents will have documented vaccination information;^{14,15} ie, the model accounts for the fact that the respondents who do have documented information might be a non-random subsample of all respondents. The model checks for the correlation between the error terms of the equations (not shown here) that are used for predicting the probability of the two events—having had valid immunisation and having documented vaccination information. The presence of a correlation means that the possession of a documented history of vaccination affects

45 countries included in analyses

Bangladesh
Benin
Bolivia
Brazil
Burkina Faso
Cameroon
Central African Republic
Chad
Columbia
Comoros
Dominican Republic
Egypt
Eritrea
Ghana
Guatemala
Guinea
Haiti
India
Indonesia
Ivory Coast
Kazakhstan
Kenya
Kyrgyzstan
Madagascar
Malawi
Mali
Morocco
Mozambique
Namibia
Nicaragua
Niger
Nigeria
Pakistan
Paraguay
Peru
Philippines
Rwanda
Senegal
Tanzania
Turkey
Uganda
Uzbekistan
Yemen
Zambia
Zimbabwe

the prediction of the validity of vaccination. In such a case, the model corrects for systematic differences between the two groups of respondents so that predicted probabilities for respondents do not have a selection bias.¹⁶

For the four surveys in which sample selection did not bias the probability of valid vaccination, we used a probit model without a sample selection to model the probability of a DTP3 vaccination being valid in children with documented information of vaccination.

Several investigators have assessed the effects of sociodemographic factors on vaccination status.^{17–21} Drawing from the results of such work, we tested for an association between several mother, child, and household-related variables and having documented information on vaccination and between the variables and the validity of vaccination. The factors that showed statistically significant association were used to model the probability of having a documented vaccination (the probability of inclusion in the sample from which the probabilities of valid vaccinations were estimated), and the probability of valid vaccinations in children with documented vaccinations. The predicted probability of valid vaccination with adjustment for sample selection was then applied to children with undocumented vaccination status. Total valid DTP3 vaccination coverage rates were constructed from the sum of the predicted and documented valid vaccinations. All rates were weighted at the cluster level to allow the DHS sampling design.

Survey data are not impervious to systematic errors. Our methods do not account for potential recall bias because of memory lapses or event omission. Current evidence on the quality of data from maternal recall is not straightforward. Some results suggest low accuracy of mothers' recall of vaccinations.^{22–24} Others, however, indicate high levels of accuracy, with between 83% and 98% of vaccinations recalled correctly by mothers.^{25–27}

To check for any potentially serious bias, we compared DTP3 vaccination rates for countries that had data available from two consecutive surveys done 3 years apart, which allowed for a comparison of 95% CI for the coverage rate for the same birth cohort from two sources that were different only with respect to the period of mothers' recall.

Such surveys with overlapping cohort data were available for Bangladesh, Indonesia, and Tanzania. We also compared the differences between the officially reported and total valid immunisation rates from DHS to see if recall bias was having an effect.

Countries generally reported vaccination rates per calendar year,²⁸ whereas we estimated total valid rates from the DHS by birth cohort. To allow comparison of the two rates, we adjusted the officially reported rates to simulate a cohort-based schedule, assuming uniform distribution of births and DTP3 vaccinations across the calendar year. Based on DTP3 vaccination schedule, we assumed that children younger than age 3 months would not be able to complete their vaccinations. Therefore, in any calendar year the birth cohort from the previous year would receive 3/12 (25%) more DTP3 vaccinations than the birth cohort of the same calendar year. We therefore attributed, to a given birth cohort, 4·5/12 (37·5%) of DTP3 vaccinations from the same calendar year and 7·5/12 (62·5%) of vaccinations from the following calendar year.

We compared cohort-specific rates cited in the two data sources using simple ordinary least squares regression. We also did time-trend analysis for officially reported and DHS coverage data for countries that had two surveys done at least 3 years apart. All statistical procedures were done with STATA version 7.

Role of the funding source

The survey data used in the analysis were obtained from a secondary source, Macro International, compiled under financial support of the United States Agency for International Development.

Results

The total valid DTP3 rates range from 11% to 77% between countries (figure 1). Total valid vaccination rates by birth cohort were between the crude rates, which ranged from 17% to 92%, and documented valid rates, which range from 2% to 74%. The large variation in vaccination coverage was not surprising in view of the wide differences between countries in sociodemographic characteristics and degrees of health system development. For example, the

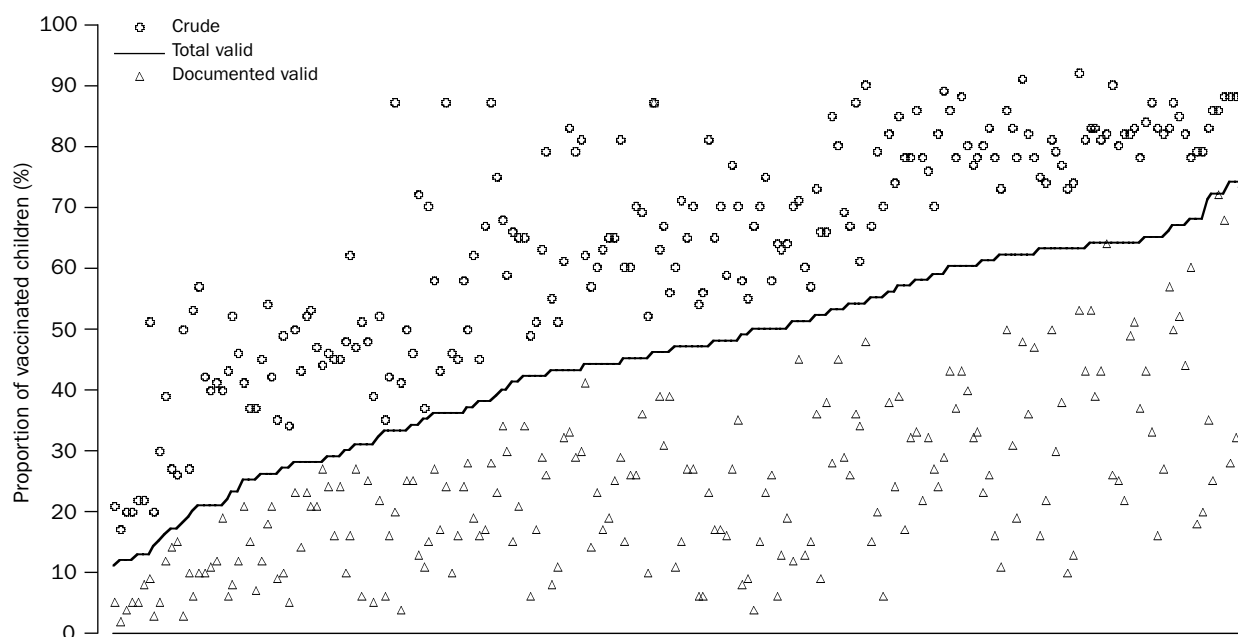


Figure 1: DTP3 vaccination rates by birth cohort (1985–98) from the DHS for 45 countries

Data are sorted by total valid vaccination rate. Data recorded for several cohorts per year per country.

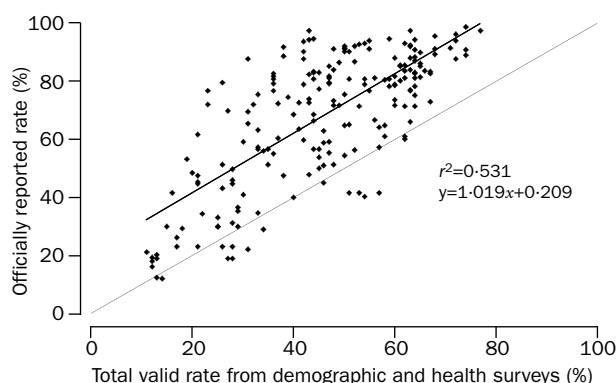


Figure 2: **DTP3 vaccination rates by birth cohort (1985–98) for 41 countries by data source**

Bold line shows line of best fit. Thin line is line of equivalence.

rate of secondary education in mothers ranged from 3% to 99%.

Figure 1 shows that large differences exist between estimates of crude and documented valid vaccination coverage, in some countries as high as 65 percentage points. Much of the disparity between these two rates was attributable to whether the verification of DTP3 vaccination was mainly based on mothers' recall or health cards. There did not seem to be a consistent pattern with respect to the size of the difference between the total valid and crude rates or between total valid and documented valid estimates.

Results of our analyses pointed to systematically high officially reported DTP3 coverage rates, as compared with total valid estimates from the DHS. As figure 2 shows, 90.7% of the DTP3 rates by birth cohort from officially reported data are above the equivalence line; 55.4% of these data points were at least 20 percentage points higher (with 75.5% at least 10 percentage points higher). In accordance with the observed trend, an officially reported coverage of 20.9% would be expected from an estimate of 0% total valid coverage from the DHS (95% CI 14.4–27.4; $r^2=0.531$). We did note a few exceptions (7% of cohorts), where officially reported estimates were 1–16% lower than DHS estimates.

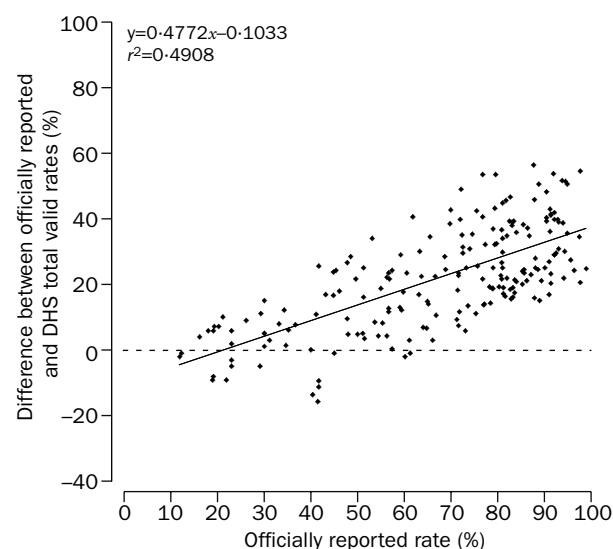


Figure 3: **Differences in DTP3 vaccination rates by birth cohorts for 45 countries (1985–98) by data source**

Bold line shows line of best fit.

Officially reported DTP3 rates were compared with crude rates from the DHS. Although the difference was smaller than that between officially reported and total valid DTP3 rates, our results (data not shown) suggested that an officially reported coverage of 16.3% could be expected at a crude coverage rate of 0% from the DHS (7.5–25.3; $r^2=0.408$). Part of this difference in the pattern of over-reporting could be attributable to the fact that crude vaccination rates, like officially reported rates, might not take into consideration adherence to the recommended schedule for vaccine administration.

We assessed the relation between officially reported estimates with the difference between these and total valid vaccination estimates from the DHS. Figure 3 shows that with each percentage point increase in officially reported DTP3 rates, the degree of over-reporting increased on average by 48% (41.1–54.7; $r^2=0.49$). In other words, the higher the officially reported DTP3 rates, the greater the size of the difference between this rate and that from DHS estimates.

If differences between officially reported rates of vaccinations and DHS estimates increased from the youngest to the oldest cohort, we would suspect a systematic internal bias in the DHS. However, our results did not show any significant difference between cohorts (results not shown).

A comparison of coverage rates for the same cohort with overlapping data from two consecutive surveys did not indicate a recall bias in any of the three countries for which these data existed. Significant differences in the coverage figures reported for the same cohort would suggest bias; figure 4 shows that the rates from the two sources consistently fell within the 95% CI. Thus, any potential differences in rates due to recall were within the DHS sampling error range. However, availability of more surveys with overlapping cohort-based data might have allowed this analysis greater robustness.

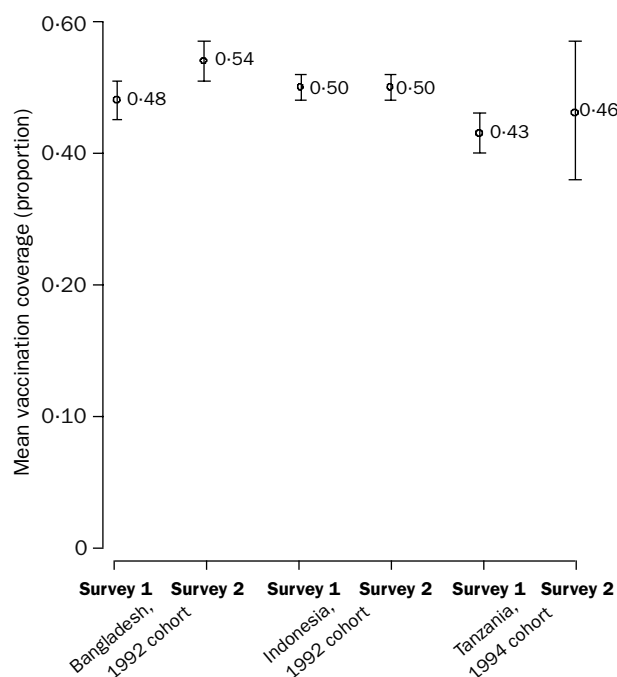


Figure 4: **Comparison of total valid DTP3 vaccination rates for overlapping birth cohorts across two successive DHS surveys in three countries**

Bars show 95% CI.

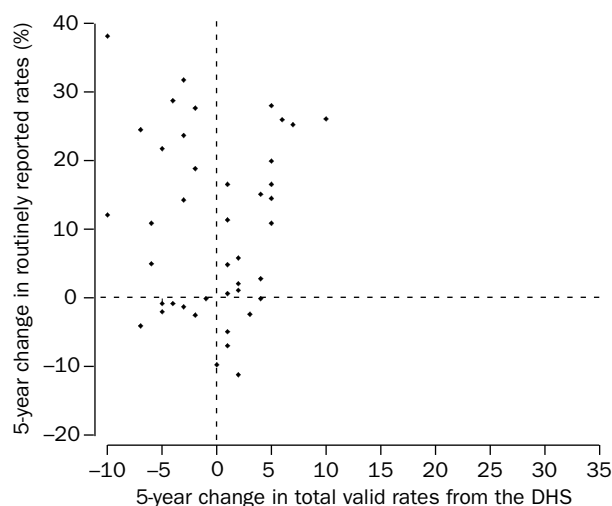


Figure 5: **Quinquennial change in coverage rates for DPT3 for 16 countries by birth cohort**

There was no strong pattern in the comparison of changes over 5-year periods between officially reported DTP3 coverage rates and the DHS rates (figure 5). We would expect that if officially reported data are reflective of those from the gold standard DHS, then changes over time would be similar for both sources. The analysis showed a weak relation between changes seen in officially reported rates and the corresponding DHS estimates (coefficient 0.21, $r^2=0.02$).

Discussion

Our results show that officially reported data could be misleading in assessment of changes in vaccinations over time.

Rates of DTP3 coverage as reported via WHO/UNICEF joint reporting form on vaccine preventable diseases are higher than those derived from a household survey, the DHS. Officially reported rates of vaccination coverage are highly informative if they are low. However, if reported coverage is high, total valid coverage in the population might, in fact, be rather low. More disturbingly, changes in official coverage are not at all correlated with changes in the total valid rates of coverage in the population. What can explain these huge differences in reported vaccination rates?

Four main factors probably account for most of the difference. First, information collected through service providers often records all vaccinations not just those that have been delivered in accordance with the recommended schedule. In other words, service providers tend to report on crude coverage rather than total valid coverage, despite total valid coverage being the more relevant variable for policymakers. However, there is a substantial difference even between crude coverage and the officially reported data. Second, officially reported vaccination coverage data in most countries only incorporated vaccinations delivered in public sector providers. Vaccinations given by non-governmental organisations or other private providers are not included. This should, in principle, bias official reports to report low rather than high rates. Third, weak information systems can lead to the transmission of inaccurate information from the periphery to the centre in many health systems. Fourth, where vaccination coverage is related to financial or non-monetary incentives for health workers or supervisors, figures might, in some cases, be intentionally inflated.

	Verification factor (95% CI)
Ivory Coast	87% (66–108)
Kenya	40% (13–67)
Liberia	60% (37–84)
Mali	75% (30–119)
Pakistan	67% (44–90)
Tanzania	57% (35–79)
Uganda	71% (57–85)

DTP3 verification factors for seven countries from DQA's

More analysis is needed to understand the relative importance of these four factors to the difference between officially reported and gold standard assessments of vaccination coverage. One important initiative sponsored by GAVI and WHO is a series of Data Quality Audits (DQAs). DQA verifies the number of reported vaccinations per country. A verification factor is calculated on the basis of the proportion of reported DTP3 vaccinations during the previous year that could be verified. The verification factor in seven countries, where the first series of DQAs have been done, ranged from 40% to 87% (table). Workers from the DQA pointed to several weaknesses in information systems, including low timeliness and completeness of reporting, inconsistent computer filing procedures, dual reporting systems, absence of written policies, poor data storage, insufficient analysis and feedback, and confusion in use of denominator.³ Because of the limited number of DQAs done to present (eight countries in 2000 and 12 in 2001), unavailability of the official reports from the last series of DQAs, and no time overlap between DQAs and the data analysed in our study, we could not validate our findings with those of the audits.

Assessment of the extent to which variation in the methods for compiling officially reported coverage rates could explain differences between them and the DHS estimates would have been useful. However, such analysis was not possible because the WHO/UNICEF joint reporting forms for vaccine preventable diseases that we had did not specify the source of officially reported coverage rates.

A promising avenue for further analysis would be to identify factors that predict or explain the difference between coverage as assessed by service delivery registries and household surveys. Factors such as the presence and size of incentive payments linked to vaccination rates, or the extent of vertical or horizontal management of immunisation programmes would be potential factors to include in a multivariate analysis. Studies of these factors could provide clues as to how information collected from service providers can be used as an input to valid and reliable assessments of vaccination coverage.

Our findings support the WHO recommendation that all national programmes monitor coverage of vaccination periodically through household surveys.²⁹ Experience has shown that household surveys have the advantage of capturing activities within the public sector and the private sector. Like many studies that assess the extent of maternal recall bias,^{22–27} our analysis of the quality of vaccination data obtained in the DHS suggests high reliability of survey findings, thus lending support to household surveys as a potential method of validation for routine data. Surveys that could collect comprehensive information about coverage of critical health interventions and other important aspects of health system performance—eg, WHO's World Health Survey—can produce substantial economies of scale and lower marginal costs of data collection. It will be to the

detriment of health programme monitoring and health system performance assessment if, in efforts to strengthen national health information systems, such surveys are not judged to be an essential source of information to be gathered in addition to that from service delivery records.

We believe that these findings have implications for efforts to gather information on the coverage of other health interventions. Worldwide, the effort to obtain valid and reliable information on vaccination coverage to support programme implementation and monitoring has been one of the most comprehensive and wide reaching in public health. However, despite impressive investment in these efforts, changes in coverage based largely on data collected from public sector service providers is not correlated with changes in coverage detected in household surveys. This absence of information on reported changes means that efforts to expand the scope of information on the coverage of health interventions must be based on careful validation studies. Coverage of health interventions is essential information for decision-makers; methods developed to monitor coverage for other interventions should be based on strategies that are likely to be valid.

Contributors

C Murray, B Shengelia, and M Thieren had the original idea for the study. C Murray, B Shengelia, A Tandon, and S Moussavi designed the statistical analysis. N Gupta compiled survey data. N Gupta and S Moussavi analysed and managed data and wrote the first draft of the manuscript. All authors participated in the interpretation of results, and reviewed and approved the final version.

Conflict of interest statement

None declared.

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