Transactions of the Royal Society of Tropical Medicine and Hygiene (2008) **102**, 251—254

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Use of Lot Quality Assurance Sampling (LQAS) to estimate vaccination coverage helps guide future vaccination efforts

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Received 25 July 2007; received in revised form 29 October 2007; accepted 29 October 2007

KEYWORDS
Measles;
Vaccination;
Mass immunisation;
LQAS;
Survey;
Chad

Summary Inadequate evaluation of vaccine coverage after mass vaccination campaigns, such as used in national measles control programmes, can lead to inappropriate public health responses. Overestimation of vaccination coverage may leave populations at risk, whilst underestimation can lead to unnecessary catch-up campaigns. The problem is more complex in large urban areas where vaccination coverage may be heterogeneous and the programme may have to be fine-tuned at the level of geographic subunits. Lack of accurate population figures in many contexts further complicates accurate vaccination coverage estimates. During the evaluation of a mass vaccination campaign carried out in N'Djamena, the capital of Chad, Lot Quality Assurance Sampling was used to estimate vaccination coverage. Using this method, vaccination coverage could be evaluated within smaller geographic areas of the city as well as for the entire city. Despite the lack of accurate population data by neighbourhood, the results of the survey showed heterogeneity of vaccination coverage within the city. These differences would not have been identified using a more traditional method. The results can be used to target areas of low vaccination coverage during follow-up vaccination activities.

1. Introduction

Measles remains a major public health problem in many developing countries and is a principal cause of vaccine-preventable mortality in children under 5 years of age in sub-Saharan Africa. In recent years, the WHO Africa Region has been using Supplemental Immunisation Activi-

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0035-9203/$ — see front matter
doi:10.1016/j.trstmh.2007.10.015

ties, including mass vaccination campaigns, in an effort to control the disease and to decrease measles mortality (Otten et al., 2005). These activities provide an opportunity for unvaccinated children to receive a first dose of vaccine and for previously vaccinated children to receive a second dose.

In early 2005, a measles epidemic was detected in N'Djamena, the capital of Chad. As part of the epidemic control effort, the non-governmental organisation Médecins Sans Frontières, in collaboration with the Ministry of Health, carried out a mass vaccination campaign. The objective of the campaign was to vaccinate 100% of children aged 6—59 months living in the city. Further details of this epidemic can be found elsewhere (Dubray et al., 2007).

During the campaign, some vaccination sites were very busy, whilst at others fewer children than anticipated were seen. It was decided to evaluate the coverage of the campaign by conducting a vaccination coverage survey, with a specific objective of identifying differences in vaccination coverage between neighbourhoods. As a second campaign was planned 5 months later, the idea was to use the results of the survey to better target areas with inadequate vaccination coverage following the first campaign.

Two methods are commonly used to estimate vaccination coverage, the administrative method and surveys using cluster sampling (WHO, 2006). The administrative method compares the number of doses given with the number of children in the target population of the campaign. Accurate population figures are necessary for this method to be reliable. This method can provide information on coverage by geographic area if the population of subareas is available and the origin of the children vaccinated is known. If population figures are inaccurate, this method leads to either an overestimate (Zuber et al., 2003) or underestimate (Huhn et al., 2006). Overestimation can result in part of the population remaining at risk of the disease; underestimation may result in the organisation of unnecessary public health measures, such as follow-up vaccination campaigns. Vaccination coverage surveys using cluster sampling do not require accurate population figures but provide only a global figure for the entire survey area. Vaccination coverage by subarea or neighbourhood cannot be estimated from the results of one survey (Hoshaw-Woodard, 2001).

In our context, neither method adequately responded to our specific question regarding the heterogeneity of vaccine coverage. The population of N'Djamena has more than doubled in the past 15 years with significant in-migration from rural areas of the country. At the time of the last census in 1993 the population was 513 000, whilst current population estimates range from 1.2 million to 1.7 million inhabitants. In addition, the exact proportion of the population under-five is unknown. The city is heterogeneous, with some areas densely populated whilst the outskirts are semirural. Health services are also heterogeneous, with some areas well served and others underserved.

Because of the range in population figures, administrative estimates for citywide campaign vaccination coverage, based on the vaccination of 175 470 children and the extremes of the population estimates of 191 643 and 272 000 children between 6 months and 5 years of age, were as low as 65% and as high as 92%. Furthermore, vaccination teams and experienced supervisors, based on the daily volume of children at each vaccination site, suspected that neither of these values was accurate. They also suspected vaccination coverage was heterogeneous, but had neither an idea of the origin of children at each site nor whether children visited the vaccination sites closest to their homes.

2. Materials and methods

It was decided that Lot Quality Assurance Sampling (LQAS) would be the most appropriate evaluation method in this context as it has been used successfully in past evaluations of vaccination coverage (Dubray et al., 2006; Tawfik et al., 2001). LQAS provides both a citywide estimate and estimates for geographic subunits. The limitation of the method is that a specific estimate for each subunit cannot be evaluated, but they are classified as having 'acceptable' or 'unacceptable' vaccination coverage based on upper and lower cut-offs defined for the specific survey (Hoshaw-Woodard, 2001).

The city was divided into 25 non-overlapping lots based on administrative neighbourhoods with well known boundaries. When necessary, neighbourhoods were regrouped to create lots of equivalent population size and homogeneity. A lower threshold of 70% vaccination coverage below which a lot was considered to have 'unacceptable' vaccination coverage and an upper threshold of 85% above which a lot was considered to have 'acceptable' vaccination coverage were selected. In neighbourhoods with vaccination coverage >85% the campaign was considered a success, whilst in neighbourhoods with vaccination coverage <70% the population was considered to be still at risk for measles and in need of particular attention during the follow-up campaign. Using these thresholds, sample size and threshold values were calculated using cumulative binomial probabilities (Sample LQ v1.10; Brixton Health, London, UK) using $\alpha = 0.05$ and $\beta = 0.10$. The sample size per lot was calculated as 65 and, if less than 13 unvaccinated children were identified, the lot was classified as having 'acceptable' vaccine coverage (>85%), otherwise the lot was classified as having 'unacceptable' vaccination coverage (<70%). As we wished to calculate an average vaccination coverage for the city as well as determining whether each lot had 'acceptable' or 'unacceptable' coverage, information was collected for all 65 children in each lot.

To select households within each of the 25 lots, a systematic sampling plan was developed. A central location in each lot, such as an intersection or health centre, was predetermined by the supervision team. From this point, teams randomly selected a direction by spinning a pen and the closest compound in that direction was selected as the starting household for the lot. From this point, every fourth compound on the right was included in the survey. If multiple households were found in one compound, teams numbered all the households and then selected one household using a random number table.

Oral informed consent was obtained before beginning the interview. The objectives of the survey were explained to potential respondents who were free to refuse participation before or at any time during the survey. Information on age, sex and vaccination status before and after the campaign from one 6—59-month-old child per family was obtained from the head of the household. In households with multiple children in this age group, one child was randomly selected

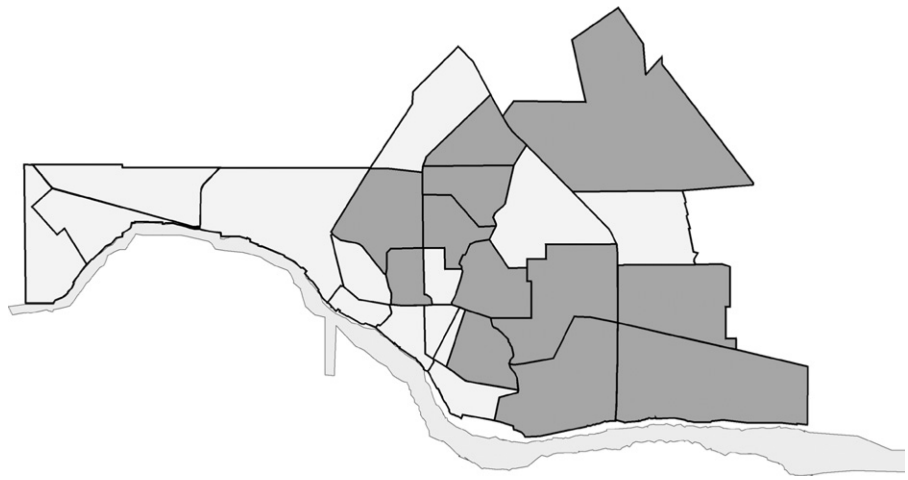

Figure 1 Estimated vaccination coverage using card confirmation by lot. Lots with 'acceptable' coverage are shown in dark grey.

and the information was collected. Vaccination status was collected based on card confirmation (card) or, if no card was available, by oral history (history).

Ten teams, composed of one woman and one man, carried out the survey. None of the survey team members had participated in the vaccination campaign. The teams received 2 days of training, including half a day of practical training in the field.

3. Results

The survey was conducted from 20—25 June 2005, 1 month after the mass vaccination campaign. In total, 1624 children were included in the survey, 65 children in each of 25 lots (1 child was excluded as he was outside the age range). The sex ratio (M/F) of the children included was 1.18. Fifty-four heads of households (3%) refused to participate in the survey.

Before the campaign, all 25 lots were classified as having 'unacceptable' vaccination coverage (<70%) by card confirmation. Considering both card confirmation and history, 1 of the 25 lots had 'acceptable' vaccination coverage. Following the campaign, using vaccination card as proof of vaccination, all 25 lots were still classified as 'unacceptable'. Considering both card and history, 13 of 25 lots exceeded the upper threshold and had 'acceptable' vaccination coverage (Figure 1).

Citywide vaccination coverage (a weighted average) before the campaign was 7.6% (95% CI 6.3—8.9%) by card and 33.0% (95% CI 30.9—35.1%) considering card confirmation and history. After the campaign, citywide vaccination coverage was 53.0% (95% CI 50.6—55.4%) by vaccination card and 80.6% (95% CI 78.6—82.6%) including history of vaccination.

4. Discussion

Following a mass campaign in N'Djamena, Chad, we were able to identify within-city differences in vaccination coverage as well as a citywide estimate using LQAS. Using a more traditional method, only the citywide coverage estimate would have been available, not allowing geographic variations and therefore neighbourhoods still at risk of outbreaks to be identified. LQAS does not require knowledge of accurate population figures and, although potentially more time consuming than a single survey using cluster sampling owing to the larger sample size (we sampled 1624 children whereas the sample size for a cluster survey with low precision would have been 210 children) (Singh et al., 1996), field implementation is equal for the two methods. Whilst specific vaccination coverage figures for each neighbourhood cannot be easily estimated using LQAS, the thresholds allow appropriate public health decisions to be made. In this case, information on whether vaccination coverage was 'acceptable' or 'unacceptable' for each of the 25 lots was available for planning the next campaign. Surveys in individual lots can be used to monitor vaccination coverage in areas identified as having 'unacceptable' vaccination coverage. This type of follow-up requires few children to be surveyed (maximum 65 in our example) and in practice samples may be even smaller as the survey can be stopped once the threshold is passed, in our example once 13 unvaccinated children have been identified (Hoshaw-Woodard, 2001; Tawfik et al., 2001).

Whilst LQAS may require a larger initial investment than administrative or cluster survey methods owing to larger sample sizes, it may be more cost effective in the long run by providing more detailed information and enabling better decision-making for the allocation of limited resources.

Authors' contributions: KPA, RFG and JPG participated in the conception and design of the study, interpretation of data, drafting the paper and revising it critically for substantial intellectual content; FF participated in the conception and design of the study and interpretation of data, and revising the paper critically for substantial intellectual content; KDN participated in the conception of the study and revised the paper critically for substantial intellectual content. KPA and RFG had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. All authors read and approved the final manuscript. KPA and RFG are guarantors of the paper.

Acknowledgements: The authors would like to thank the Médecins Sans Frontières (MSF) teams in N'Djamena, Chad, at the time of this study for their logistical and administrative support. Particular mention to M.C. Ferir (MSF—Brussels) who was instrumental in the realisation of this survey.

Funding: Médecins Sans Frontières—Belgium (1090 Brussels, Belgium) and France (Paris, 75011, France).

Conflicts of interest: None declared.

Ethical approval: Ministry of Health, N'Djamena, Chad.

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