Title

Unvaccinated children in years of increasing coverage: how many and who are they? Evidence from 96 low- and middle-income countries.

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Abstract

Introduction

While childhood immunisation coverage levels have increased since the 70s, inequities in coverage between and within countries have been widely reported. Unvaccinated children remain undetected by routine monitoring systems and strikingly unreported. The objective of this study was to provide evidence on the magnitude of the problem and to describe predictors associated with unvaccination.

Methods

241 nationally representative household surveys in 96 countries were analysed. Proportions and changes in time of 'unvaccinated' (children having not received a single dose of vaccine), 'partially vaccinated' and 'fully vaccinated' children were estimated. Predictors of unvaccination were explored as well logistic regression methods.

Results

The percentage of unvaccinated children was 9.9% across all surveys. Sixty-six countries had more than one survey: 38 showed statistically significant reductions in the proportion of unvaccinated children between the first and last survey; 10 countries showed increases; and the rest showed no significant changes. However, while eighteen of the 38 countries also improved in terms of partially and fully vaccinated, in the other 20 the proportion of fully vaccinated decreased. The predictors more strongly associated with being unvaccinated were: education of the caregiver, education of caregiver's partner, mother's tetanus toxoid (TT) status, wealth index, and type of family member participation in decision making when the child is ill. Multivariable logistic regression identified the TT status of the mother as the strongest predictors of unvaccinated children. Country-specific summaries were produced and sent to countries.

Conclusion

The number of unvaccinated children is not negligible and their proportion and the predictors of unvaccination have to be drawn from specific surveys. Specific vaccine indicators cannot

properly describe the performance of immunisation programmes in certain situations. Countries immunisation programmes and national and international immunisation stakeholders should also consider monitoring the proportion of unvaccinated children (i.e. those who have received no vaccine at all) and draw specific plans on the determinants of unvaccination.

Introduction

Systematic international efforts to provide immunization against major childhood diseases to all infants began in the late 1970s and early 1980s[1]. Following rapid increases in coverage during the 1980s, global immunization coverage remained stable between 1990 and 2000 at rates close to 80%. Since 2000, increased commitment to immunization at both national and international levels led to a gradual increase in both the availability of new vaccines and in the proportion of children vaccinated[2].

Global achievements, however, mask substantial inter- and intra-country differences[3,4]. In 2009, 23.3 million children under one year of age did not receive the third dose of Diphtheria-Tetanus-Pertussis vaccine (DTP3); 70% of those in 10 countries: Chad, China, Democratic Republic of the Congo, Ethiopia, India, Indonesia, Kenya, Nigeria, Pakistan and Uganda[5].

Routine vaccination monitoring and research on vaccination uptake tend to report on antigen and dose-specific vaccination rates (i.e. the proportion of children in the target population that have been vaccinated with a specific vaccine) either in terms of coverage[6] or timeliness of vaccination[7]. DTP3 is commonly used because it is delivered only in routine vaccination activities and it reflects the capacity of the system to engage infants in three consecutive vaccination events. Coverage expresses the proportion of targeted children who have received vaccines but do not indicate, for example, the ability of the system to deliver multiple-dose vaccines[8]; this is described by measuring coverage of two doses of the same vaccine (e.g. DTP 1 and 3) and better described by drop-out rates (i.e. the proportion of infants having received a dose of a certain vaccine but not a vaccine scheduled for an ulterior age).

A group of children that has been strikingly much less studied is the one of those who have received no doses of any vaccine (‘unvaccinated’)[9]. This is because the proportion of unvaccinated children cannot be captured in the routine reporting system and it can only be assessed in household surveys (these are children who have never been in contact with the health system, where routine data is originated). In 2007 the World Health Organization's (WHO) Strategic Advisory Group of Experts on Immunisation (WHO/SAGE) requested that the WHO's Department of Immunization, Vaccines, and Biologicals undertake a “more detailed analysis of children who have not been reached by immunization services”[10]. The objective of this study was to contribute to the understanding of the factors associated with unvaccinated

children as defined above by providing countries with a digested information pack on the matter.

Methods

The Demographic and Health Surveys (DHS) and the United Nations' Children's Fund (UNICEF) Multiple Indicator Cluster Survey (MICS) are nationally representative, multiple indicator household surveys. In both, probability-based, multi-stage sampling is used to select enumeration areas and households. Mothers of children less than five years of age are interviewed to determine children's immunization status[11,12].

A total of 263 DHS and MICS surveys with individual subjects' responses were accessed. Of the 183 DHS[13] surveys, 17 were excluded: three had no relevant data for this study, six had restricted access at the time of the analysis, three were sub-national and five had no variables related to vaccination status. Of the 80 MICS surveys (44 MICS2[14] and 36 MICS3[15] datasets) five were excluded: four MICS2 and one MICS3 did not contain vaccination data. MICS1 surveys were not used because datasets were not available. A total of 241 surveys (166 DHS and 75 MICS) were included in the analyses. A list of included and excluded surveys is shown in **Table 1** and countries are shown in Figure 1.

Children 12 to 59 months of age were included in the analyses. Twelve months of age was the lower limit because children of that age would have had the opportunity to receive all routine infant vaccines. The upper limit of 59 months was chosen to ensure a sufficiently large sample to make analyses meaningful.

Vaccines considered for the outcome variables were: bacille Calmette-Guérin (BCG), any vaccine containing DTP, oral polio vaccine (OPV) and any vaccine containing measles antigen (MCV).

The outcome variable was vaccination status dichotomised as children not having received any vaccination (‘unvaccinated’) versus children having received at least one dose of any vaccine. A child was labelled as having missing vaccination status if none of the vaccines were documented as either given or not given, and excluded from the analyses; as ‘unvaccinated’ if all documented vaccines were recorded as not given; and as having at least one dose, the remainder. The proportion of unvaccinated children was calculated by dividing the number of unvaccinated children by the total number of children with known vaccination status.

A second variable, ‘at least one dose’, was dichotomised as children having received at least one dose of vaccine but not being fully immunised versus children having received all vaccines. Missing vaccination status was defined and handled as described above. A child was labelled as having had ‘at least one vaccine’ if it had at least one vaccine documented as given but not being fully vaccinated; and as ‘fully vaccinated’ if all eight vaccine doses (1 BCG, 3 DTP, 3 OPV, 1 measles) were documented as given. Unvaccinated children were excluded. This variable provides and indication of the number and proportion of those children who having had the opportunity to have at least one contact with the vaccination programme could not be fully vaccinated (i.e. a dropout-like indicator).

In DHS and MICS, vaccination status is ascertained either by the date of vaccination recorded in the child health card, by having a mark on the card (a certain code is recorded in the dataset) or by the caregiver's recall when the child health card was not available or incomplete. We took into account all vaccinations recorded in cards, regardless of the age at vaccination because the focus of these analyses was the access of children to (vaccination) services rather than correctness of vaccination. Compared to vaccinations recorded in cards, caregivers may forget to report a vaccination that was actually administered and documented[16,17] or conversely, report that a vaccination was given when it was not actually given and not recorded in the card[18]. Recall bias may come into play and cause differences in vaccination rates with those children whose caregivers retained the card[19]. In this study, a vaccination was considered as given if it was documented by either card or caregiver recall.

The findings of a systematic literature review were used to obtain an initial list of potential predictors. Research articles reporting on routine childhood immunization were searched in MEDLINE (from 1966), EMBASE (from 1980), The Cochrane Library (last issue), LILACS (Latin American and Caribbean Centre on Health Science Information; 1982), RHINO literature database; and the following websites: WHO (including WHOLIS; WHO AFRO Vaccine Preventable Diseases; WHO/AFRO, -PAHO, -SEAR, -Europe, -EMRO, -WPRO Immunization), UNICEF, The GAVI Alliance, MEASURE DHS, The World Bank and Children’s Vaccine’s program at PATH; and the sites of immunization programmes of India, China, USA, Nigeria, Indonesia, Brazil, Bangladesh, Pakistan, Ethiopia and RDC. The inclusion criteria were: studies on routine vaccinations in children, reporting quantitative coverage data of at least one vaccine. From the 7,784 studies retrieved, 254 studies were included. Reasons for exclusion were: duplicate reports, newsletters

or editorials, or not focusing on low- and middle-income countries. The initial list of potential predictors included age and sex of the child, housing physical characteristics, ethnicity, religion, socio-economic status, place of residence, wealth, area of residence and access indicators, such as distance to health facilities. These were discussed in meetings with WHO and UNICEF staff to obtain a final list for the analyses.

For these analyses, potential predictor variables were dichotomised (values of the predictors in parentheses; the first term in the parentheses represents the value of the potential predictor for the logistic regression analyses): sex of the child (female versus male), birth order of the child (first birth versus subsequent births; first birth versus the second), level of education of the caregiver (lowest level of education versus all other education levels combined), marital status of caregiver (alone versus in couple), tetanus toxoid (TT) vaccination status of the mother (less than two TT doses versus two or more TT doses in any pregnancy), in case of child's illness, decision making for seeking care or treatment (caregiver does not decide or depends on other partner versus caregiver decides, in conjunction with the partner or alone), sex of the head of the household (female versus male), level of education of the caregiver's partner (lowest level of education versus all other education levels combined), ethnic and religious group (least common group versus rest of the groups), number of household members (above the median versus below the median), number of offspring in the household (above the median versus below the median), offspring dead (above the median versus below the median), area of residence (rural versus urban), radio and television ownership (none versus yes or more than one), wealth index (poorest versus each one of the other four quintiles). **Table 2** shows the potential predictors of the child being unvaccinated included in this study.

Vaccination and predictor variables were thoroughly searched in all surveys, which had different names and code for the same variables, using an algorithm described elsewhere[20].

Statistical analyses were conducted using STATA/IC 10.0 for Windows[21]. Coverage estimates with 95% confidence intervals (CI) were produced using the "svy" STATA command to account for the complex survey designs. Odds ratios (OR) representing the likelihood of being unvaccinated for each potential predictor were obtained by simple and multivariable logistic regression analyses. Logistic regression analyses where conducted in the unique or most recent survey for each country.

Results

1. Numbers and proportions of unvaccinated children

Two hundred and forty-one DHS and MICS surveys were conducted in 96 countries between 1986 and 2007. The total number of children between 12 and 59 months of age in all surveys with known vaccination status was 1,125,574. The overall number of unvaccinated children across all surveys and years was 111,118 (9.9 %) and the median proportion of unvaccinated children was 5.3% (inter-quartile range (IQR) 1.9% to 12.4%). Figure 2 shows the distribution of the number of countries by the proportion of unvaccinated children. In the majority of the surveys (56) less than 5% of children were unvaccinated; in the remaining countries the proportion of unvaccinated children ranged from 5.0% to 28.5%.

The proportions of unvaccinated children by country (unique or most recent survey) with 95% confidence intervals are depicted in Figure 3 , with countries sorted by the magnitude of the proportion (note that the scales of the X axes are different in the three bar charts). The ten countries with the highest proportion of unvaccinated children were Ethiopia (in 2005, 28.5%), Comoros (in 2000, 28.2%), Zimbabwe (in 2005, 27.2%), Lao Peoples' Democratic Republic (in 2000, 26.6%), Southern Sudan (in 2000, 26.3%), Nigeria (in 2003, 22.6%), Niger (in 2006, 19.9%), Madagascar (in 2004, 19.9%), Central African Republic (in 2000, 17.9%) and Chad (in 2004, 16.7%).

For those countries with more than one survey, we estimated changes in the proportion of unvaccinated children and of children with at least one dose of vaccine (Table 3) comparing the earliest and most recent surveys in each country. Forty-eight countries experienced significant changes: ten countries reduced the proportion of unvaccinated children with a median annual change of -0.9% (IQR: -1.4% to -0.4%); and in 38 countries the proportion of unvaccinated children increased with a median change of 0.4% (IQR: 0.2 to 1.4%). 24 countries reduced the proportion of children with at least one dose, in favour of being fully vaccinated. The median annual change was -1% (IQR -1.8% to -0.5%); 24 others increased that proportion (i.e. less fully vaccinated), with a median change of 1.3% (IQR 0.6% to 3%) and 17 others had no significant changes.

The proportion of 'unvaccinated', 'partially vaccinated' and 'fully vaccinated' children can relate to each other in different ways as exemplified using dummy data in Figure 4, where the inner pie represents the baseline proportions arbitrarily set at 33% each, for illustration, and the outer doughnut represents the proportion some time later. In (b), for example, the proportion of unvaccinated children decreases while the proportion of partially vaccinated increases resulting in a smaller proportion of fully vaccinated children (i.e. the improve in unvaccination leads to a worsening of fully vaccination). In the 48 surveys experiencing significant changes over time in the proportion of unvaccinated and partially vaccinated children, 18 improved in both indicators, 20 in only the proportion of unvaccinated, 6 in only the proportion of partially vaccinated (Dominican Republic from 1986 to 2007, Ethiopia from 1992 to 1997, Comoros from 1996 to 2000, Kazakhstan from 1995 to 2006, Liberia from 1986 to 2007 and Mali from 1987 to 2006) and 4 worsened in both (Colombia from 1986 to 2005, Kenya from 1989 to 2003, Uganda from 1988 to 2006 and Zimbabwe from 1988 to 2005) (Table 4).

2. Predictors of unvaccinated children

To ascertain the country-specific population characteristics of unvaccinated children and to identify possible entry points for interventions, we produced two types of summaries: (1) country-specific fact sheets containing the proportions of unvaccinated children for each value of the potential predictor variables and the OR describing the association between the potential predictors and the outcome (unvaccinated); one sheet per survey; and (2) for each predictor, OR for all countries were plotted together to illustrate achievements by country. These results are available from the SAGE / WHO website[22]. The main findings are summarized, below.

The distribution of OR (median and inter-quartile ranges) by predictor across surveys is depicted in Figure 5. The median OR (likelihood of being unvaccinated) was greater among the poorest households (as compared with the richest), children with less educated mothers and mothers' partners, children of mothers unvaccinated against TT, and children of mothers who decide alone regarding the child's care when the child was ill. Predictors that showed no significant differences were the sex of the child, the sex of the head of the household and the number of household members.

No predictor was associated with being unvaccinated in all surveys. For example, wealth index was significantly associated with being unvaccinated in 58 surveys, 68% of those for which this

variable was reported; caregiver's education in 66 (77%) surveys, partners' education in 51 (84%), TT vaccination status in 53 (77%) and mother deciding when a child is ill in 26 (87%) of surveys (note that not all surveys had data for all predictors). See Table 5 for the number of surveys with according to the odds ratios for each predictor.

Multivariable logistic regression was performed to account for confounding and effect modification. The independent variables were those having the strongest association with the likelihood of being unvaccinated defined as having the highest median OR in the simple logistic regression: education of the mother, education of mother's partner, TT vaccination status of the mother, decision-making when child is ill and wealth index. Summary results of the multivariable logistic regression are shown in Table 6.

The TT vaccination status of the mother was the predictor with the highest association with being unvaccinated (OR 2.53, IQR 1.60 to 3.85). The OR of the wealth index, using the poorest quintile as reference, increased progressively with the other quintiles from the 'less poor' (OR 1.30, IQR 0.98 to 1.78) up to the 'richest' (OR 2.30, IQR 1.04 to 5.32).

The absolute magnitude of OR for the outcome 'at least one dose' were smaller than their equivalents in the 'unvaccinated' analysis. The highest OR was observed when comparing the poorest with the richest wealth quintile (OR 1.73, IQR 1.12 to 2.66).

Discussion

Despite steady increases in vaccination coverage over the past decade[2], a significant number of children remain unreached by immunization services. In responding to WHO/SAGE[10] we have attempted to provide information on the characteristics of unvaccinated children in a format useful to country immunization programme managers. Fact-sheets were sent to countries as an aid for decision making. In order to retain survey-specific information and to avoid giving the false impression that the described associations are global we have avoided conducting meta-analyses or pooling results.

It is striking that the study of children not having received a single dose of any vaccine has been relatively neglected by research. A number of countries have had more than 20% children receiving no vaccinations, two of them with large numbers of children less then five years of age: Nigeria (25 776 000 children in 2010[23]) and Ethiopia (13 819 000 children in 2010[23]). While the proportion of unvaccinated children is relatively small in the great majority of countries, there remain children who have had not a single contact with the health system resulting in a vaccination.

Reporting on a single indicator, while being a feasible and timely way to assess the performance of immunisation programmes, does not unveil serious events, such as unvaccination, since improvements in the coverage of any sub-set of vaccines do not necessarily entail an increase in fully immunised children or a decrease in the proportion of unvaccinated; the proportion of unvaccinated children can improve while the proportion of fully vaccinated children can be reduced and vice-versa. This has implications for performance-based funding schemes as well as programmatic planning which are often based on a single indicator[24]. Common measures of immunization system performance such as antigen/dose specific coverage, drop-out, proportion of fully immunized and proportion of un-immunized[25,26], while related, are actually independent measures. For example, in Ethiopia DTP3 coverage increased between 2000 and 2005 from 56% to 69% while the proportion of unvaccinated children also increased from 16.7% to 28.5%.

Logistic regression analyses confirm that these children live in the poorest and least well educated families. The analyses showed that predictors that were frequently and strongly associated with being unvaccinated were: limited caregivers' education, limited caregivers'

partners' education, poor TT vaccination status of mothers, poorest household and mothers deciding alone about the care for the ill child. The association with TT could suggest that services are largely accessible to a sector of the population who is willing to use them, or that households may uptake health services as a whole without distinction of services or that TT immunisation has a positive effect in the subsequent uptake of childhood immunisations. However, household surveys have limited data on health services issues, such as range of activities, staff or other resources to reach a conclusion.

Both simple and multivariable methods were used to determine the significance and magnitude of the association between potential predictors and the outcome variables. While multivariable analysis is more explanatory and provides a more precise estimate of the contribution of each individual factor associated to being unvaccinated by controlling for the contributions of other factors included in the model, simple logistic regression may be more useful in directing interventions by targeting population characteristics strongly associated with unvaccination. The 'diagnostic odds ratio' has been suggested as a prevalence-independent diagnostic performance indicator[27], which allows for comparing tests (in our case, for identifying predictors) and for analysing using logistic regression models. Association with predictors was slightly different when considering unvaccinated children or children with at least one but not all doses of vaccine. Similar findings have been reported elsewhere, although the calculations of partially vaccination rates were not identical to those used here[9]. Predictors were strongly associated with the fact of being unvaccinated suggesting that these children belong to more extreme situations.

Addressing some of the identified predictors require substantial resources and time and the impact on vaccination outcomes may not be immediate (e.g. household wealth). However we purposely included other predictors that could be useful in identifying potential interventions, such as ownership of radio or television (TV) in the household. The absence of radio or TV were strongly associated with an increase in the likelihood of being unvaccinated (in the simple and multivariable logistic regression models) and informs the use of mass media interventions to increase coverage[28].

This analysis had several limitations. First, for some children the vaccination status was ascertained by caregiver's recall. A bias may be introduced overall if recall significantly differs

between the different predictor groups. Furthermore, the inclusion of children who received vaccines beyond the correct vaccine schedule will have probably reduced the proportion of unvaccinated children. Therefore, our findings should be seen as a best case scenario. Secondly, data for all potential predictors was not available in all surveys. For example, the predictor 'mother's decision when child is ill' appeared in only 30 surveys[29]. Thirdly, DHS and MICS, in their different waves, were designed in slightly different ways. Although data was harmonised prior to the analyses, some inconsistencies may remain undetected. Forth, not all surveys were recent and findings may no longer be relevant in some rapidly changing countries. Finally, many potential predictors of a child receiving no vaccination are likely to be missed by multiple indicator surveys. More targeted surveys enhanced with qualitative methods are likely to provide a more complete picture of the characteristics and causes of a child being unvaccinated.

Conclusion

While routine vaccination coverage monitoring based on specific vaccines provide a feasible and timely way to ascertain the performance of immunisation programmes, serious events (such as being 'unvaccinated') and inequities may remain unveiled. Countries immunisation programmes and national and international immunisation stakeholders should monitor the proportion of unvaccinated children in addition to coverage for specific vaccines. This should be done periodically or where poor performance is suspected. Nationally representative household surveys provide evidence on those issues and can also be used to ascertain the specific factors that influence access to immunization services. In our analyses several factors emerged as important and the country-specific fact sheets made the findings accessible at country level to consider corrective actions.

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Competing interests

No competing interests declared.

Table 1. Data sets included and excluded in these analyses.

Table 2. Predictors and their values used in these analyses.

Table 3. Proportion of unvaccinated children (over all children with known vaccination status) and of partially vaccinated (over all children with at least one dose of vaccine) and annual changes from the oldest to the most recent surveys for countries with at least two surveys.

Table 4. Number of countries with significant changes in the proportion of unvaccinated and partially vaccinated children.

Table 5. Number of surveys according to the odds ratio categories (less than one, one and more than one) by predictor.

Table 6. Median Odds Ratios and inter-quartile range across surveys for each predictor (multivariable logistic regression) and both outcomes.

Figure 1. Map showing the countries where at least one DHS or one MICS have been conducted.

Figure 2. Number of surveys by proportion of unvaccinated children.

Unique or most recent surveys. (Albania and Moldova 2000 excluded from the graphic, having no unvaccinated children).

Figure 3. Proportion of unvaccinated children 12 to 59 months of age by survey (sorted by proportion).

Note. Data from the unique or most recent survey in each country. Albania 2005 and Moldova 2000 were excluded (no unvaccinated children).

Figure 4. Four different scenarios of change in the proportion of unvaccinated, partially vaccinated and fully vaccinated children.

Inner pie: baseline proportions of unvaccinated, partially vaccinated and fully vaccinated children, arbitrarily set at 33% each; in the outer doughnut, the hypothetical situations some time later on.

Figure 5. Distribution of OR by predictor, sorted by median OR.

Notes. Data from the unique or most recent survey in each country. Mid lines in boxes: median; lateral extremes in boxes: 20^{th} and 75^{th} percentiles; dots: individual surveys.

Authorship statement

XBC, KB and AB designed the study. XBC conducted the analyses. XBC, KB and AB interpreted the results. XBC wrote the initial draft of the manuscript and XBC, KB and AB worked out several versions.

Xavier Bosch-Capblanch, Basel, 21st September 2011.

Table 1. Data sets included and excluded in these analyses.

	Country	Year
	DHS - Included	
1	Armenia	2000
2	Armenia	2005
3	Azerbaijan	2006
4	Bangladesh	1994
5	Bangladesh	1996
6	Bangladesh	2000
7	Bangladesh	2004
8	Bangladesh	2007
9	Benin	1996
10	Benin	2001
11	Benin	2006
12	Bolivia	1989
13	Bolivia	1994
14	Bolivia	1998
15	Bolivia	2003
16	Brazil	1986
17	Brazil	1996
18	Burkina Faso	1993
19	Burkina Faso	1999
20	Burkina Faso	2003
21	Burundi	1987
22	Cameroon	1991
23	Cameroon	1998
24	Cameroon	2004
25	Central African Republic	1994
26	Chad	1997
27	Chad	2004
28	Colombia	1986
29	Colombia	1990
30	Colombia	1995
31	Colombia	2000
32	Colombia	2005

	Country	Year
33	Comoros	1996
34	Congo	2005
35	Congo DR	2007
36	Côte D'Ivoire	1994
37	Côte D'Ivoire	1999
38	Dominican Republic	1986
39	Dominican Republic	1991
40	Dominican Republic	1996
41	Dominican Republic	1999
42	Dominican Republic	2002
43	Dominican Republic	2007
44	Egypt	1988
45	Egypt	1992
46	Egypt	1995
47	Egypt	2000
48	Egypt	2003
49	Egypt	2005
50	Ethiopia	1992
51	Ethiopia	1997
52	Gabon	2000
53	Ghana	1988
54	Ghana	1993
55	Ghana	1998
56	Ghana	2003
57	Guatemala	1987
58	Guatemala	1995
59	Guatemala	1999
60	Guinea	1999
61	Guinea	2005
62	Haiti	1994
63	Haiti	2000
64	Haiti	2006
65	Honduras	2006

	Country	Year
66	India	1993
67	India	1999
68	India	2006
69	Indonesia	1991
70	Indonesia	1994
71	Indonesia	1997
72	Indonesia	2002
73	Indonesia	2007
74	Jordan	1990
75	Jordan	1997
76	Jordan	2002
77	Jordan	2007
78	Kazakhstan	1995
79	Kazakhstan	1999
80	Kenya	1989
81	Kenya	1993
82	Kenya	1998
83	Kenya	2003
84	Kyrgyzstan	1997
85	Lesotho	2004
86	Liberia	1986
87	Liberia	2007
88	Madagascar	1992
89	Madagascar	1997
90	Madagascar	2004
91	Malawi	1992
92	Malawi	2000
93	Malawi	2004
94	Mali	1987
95	Mali	1996
96	Mali	2001
97	Mali	2006
98	Mexico	1987

	Country	Year
99	Morocco	1987
100	Morocco	1992
101	Morocco	2003
102	Morocco	2005
103	Mozambique	1997
104	Mozambique	2003
105	Namibia	1992
106	Namibia	2000
107	Namibia	2007
108	Nepal	2052
109	Nepal	2057
110	Nepal	2063
111	Nicaragua	1998
112	Nicaragua	2001
113	Niger	1992
114	Niger	1998
115	Niger	2006
116	Nigeria	1990
117	Nigeria	1999
118	Nigeria	2003
119	Pakistan	1991
120	Pakistan	2006
121	Paraguay	1990
122	Peru	1986
123	Peru	1991
124	Peru	1996
125	Peru	2000
126	Peru	2004
127	Philippines	1993
128	Philippines	1998
129	Philippines	2003
130	Rwanda	1992
131	Rwanda	2000

	Country	Year
132	Rwanda	2005
133	Senegal	1986
134	Senegal	1993
135	Senegal	2005
136	South Africa	1998
137	Sri Lanka	1987
138	Sudan	1990
139	Swaziland	2006
140	Tanzania	1991
141	Tanzania	1996
142	Tanzania	1999
143	Tanzania	2004
144	Thailand	1987
145	Togo	1998
146	Trinidad and Tobago	1987
147	Tunisia	1988
148	Turkey	1993
149	Turkey	1998
150	Turkey	2004
151	Uganda	1988
152	Uganda	1995
153	Uganda	2001
154	Uganda	2006
155	Uzbekistan	1996
156	Viet Nam	1997
157	Viet Nam	2002
158	Yemen	1991
159	Zambia	1992
160	Zambia	1996
161	Zambia	2002
162	Zambia	2007
163	Zimbabwe	1988
164	Zimbabwe	1994

	Country	Year
165	Zimbabwe	1999
166	Zimbabwe	2005
	DHS - Excluded	
167	Brazil	1991
168	Dominican Republic (special DHS)	2007
169	Ecuador	1987
170	Indonesia	1987
171	Nigeria (Ondo State)	1986
172	Senegal	1997
173	Togo	1988
174	Ukraine	2007
	MICS 2 - Included	
1	Albania	2000
2	Angola	2001
3	Azerbaijan	2000
4	Bosnia and Herzegovina	2000
5	Bolivia	2000
6	Burundi	2000
7	Cameroon	2000
8	Chad	2000
9	Côte D'Ivoire	2000
10	Comoros	2000
11	Congo DR	2001
12	Dominican Republic	2000
13	Equatorial Guinea	2000
14	Gambia	2000
15	Guinea-Bissau	2000
16	Guyana	2000
17	Iraq	2000
18	Kenya	2000
19	Lesotho	2000
20	Lao PDR	2000

	Country	Year
21	Madagascar	2000
22	Mongolia	2000
23	Myanmar	2000
24	Moldova	2000
25	Niger	2000
26	Central African Republic	2000
27	Rwanda	2000
28	Sierra Leone	2000
29	Sudan North	2000
30	Sudan South	2000
31	Sao Tome and Principe	2000
32	Suriname	2000
33	Swaziland	2000
34	Tajikistan	2000
35	Togo	2000
36	Trinidad and Tobago	2000
37	Uzbekistan	2000
38	Venezuela	2000
39	Viet Nam	2015
40	Zambia	1999
	MICS-2 Excluded	
41	Indonesia	2000
42	Jamaica	Unknown
43	Philippines	2000
44	Senegal	2000
	MICS-3 Included	
1	Albania	2005
2	Bangladesh	2006
3	Belarus	2005
4	Belize	2006
5	Bosnia and Herzegovina	2006
6	Burkina Faso	2006
7	Burundi	2005

	Country	Year
8	Cameroon	2006
9	Cuba	2006
10	Gambia	2006
11	Georgia	2005
12	Ghana	2006
13	Guinea-Bissau	2006
14	Guyana	2006
15	Iraq	2006
16	Côte D'Ivoire	2006
17	Jamaica	2005
18	Kazakhstan	2006
19	Kyrgyzstan	2005
20	Macedonia	2005
21	Malawi	2006
22	Mauritania	2007
23	Mongolia	2005
24	Montenegro	2005
25	Serbia	2005
26	Sierra Leone	2005
27	Somalia	2006
28	Syrian Arab Republic	2006
29	Tajikistan	2005
30	Thailand	2549
31	Togo	2006
32	Trinidad and Tobago	2006
33	Uzbekistan	2006
34	Viet Nam	2006
35	Yemen	2006
	MICS 3 - Excluded	
36	Ukraine	2005

Table 2

Table 2. Predictors and their values used in these analyses.

Variable description	Predictor value	Reference value
Sex of the child	Female	Male
Level of education of the mother	Least educated	Not least educated
Marital status of the mother	Alone	In couple
Tetanus toxoid (TT) vaccination status of the mother	Less than 2 TT doses	2 or more TT doses
Mother's decision when child ill	Mother does not decide alone	Mother decides alone
Sex of the head of the household	Female	Male
Least educated	Not least educated	
Above median	Below median	
Number of offspring in the household	Above median	Below median
Number of offspring dead	Above median	Below median
Birth order of the child.	First birth	Younger
	First birth	2nd born
Area of residence	Rural	Urban
Radio ownership	No radio in the household	Radio in the household
Television ownership	No TV in the household	TV in the household
Religion	Minority groups	Majority group
Ethnic group	Minority groups	Majority group
Wealth index	Poorest quintile	2nd quintile
	Poorest quintile	3rd quintile
	Poorest quintile	4th quintile
	Poorest quintile	5th quintile

Table 3. Proportion of unvaccinated children (over all children with known vaccination status) and of partially vaccinated (over all children with at least one dose of vaccine) and annual changes from the oldest to the most recent surveys for countries with at least two surveys.

Country name[a]	Oldest and most recent		Unvaccinated		Annual change		Partially vaccinated		Annual change	
	Year 1	Year 2	Year 1	Year 2	%		Year 1	Year 2	%	
Albania	2000	2005	15.5%	0.0%	-3.1%	ns	70.7%	68.8%	-0.4%	ns
Armenia	2000	2005	6.8%	1.9%	-1.0%	s	12.5%	61.9%	9.9%	s
Azerbaijan	2000	2006	10.2%	12.4%	0.4%	ns	81.5%	59.4%	-3.7%	ns
Bosnia and Herzegovina	2000	2006	4.8%	1.2%	-0.6%	s	19.8%	38.8%	3.2%	s
Bangladesh	1994	2007	13.1%	2.6%	-0.8%	s	29.1%	14.8%	-1.1%	s
Burkina Faso	1993	2006	18.1%	0.6%	-1.3%	s	49.5%	42.1%	-0.6%	s
Burundi	1987	2005	0.3%	0.4%	0.0%	ns	43.7%	63.5%	1.1%	ns
Benin	1996	2006	14.5%	8.1%	-0.6%	s	36.8%	50.4%	1.4%	s
Bolivia	1989	2003	10.8%	3.2%	-0.5%	s	64.0%	35.4%	-2.0%	s
Brazil	1986	1996	5.4%	2.0%	-0.3%	s	37.2%	20.7%	-1.6%	s
Congo DR	2001	2007	77.3%	16.6%	-10.1%	s	67.9%	62.9%	-0.8%	s
Central African Republic	1994	2000	16.2%	17.9%	0.3%	ns	55.2%	67.5%	2.1%	ns
Côte d'Ivoire	1994	2006	17.5%	1.2%	-1.4%	s	54.7%	45.5%	-0.8%	s
Cameroon	1991	2006	23.0%	4.6%	-1.2%	s	52.8%	59.6%	0.4%	s
Colombia	1986	2005	0.0%	1.2%	0.1%	s	24.8%	37.5%	0.7%	s
Dominican Republic	1986	2007	0.8%	4.7%	0.2%	s	93.6%	38.7%	-2.6%	s
Egypt	1988	2005	14.2%	0.2%	-0.8%	s	35.1%	14.9%	-1.2%	s
Ethiopia	1992	1997	16.7%	28.5%	2.3%	s	80.3%	78.3%	-0.4%	s
Ghana	1988	2006	1.8%	0.3%	-0.1%	s	54.1%	36.6%	-1.0%	s
Gambia	2000	2006	4.4%	0.3%	-0.7%	s	26.8%	30.7%	0.6%	s
Guinea	1999	2005	24.2%	15.2%	-1.5%	s	63.1%	56.6%	-1.1%	s
Guatemala	1987	1999	12.4%	5.1%	-0.6%	s	55.8%	35.1%	-1.7%	s
Guinea-Bissau	2000	2006	8.8%	1.5%	-1.2%	ns	40.2%	52.3%	2.0%	ns
Guyana	2000	2006	1.9%	0.6%	-0.2%	s	13.5%	55.3%	7.0%	s
Haiti	1994	2006	14.9%	10.3%	-0.4%	ns	56.8%	51.4%	-0.4%	ns
Indonesia	1991	2007	32.0%	9.6%	-1.4%	s	36.3%	36.5%	0.0%	s
India	1993	2006	36.5%	6.7%	-2.3%	s	47.9%	52.8%	0.4%	s
Iraq	2000	2006	2.1%	1.6%	-0.1%	ns	32.8%	67.6%	5.8%	ns
Jordan	1990	2007	4.4%	0.6%	-0.2%	s	82.5%	18.5%	-3.8%	s
Kenya	1989	2003	0.4%	6.1%	0.4%	s	27.4%	43.2%	1.1%	s
Kyrgyzstan	1997	2005	0.3%	1.0%	0.1%	ns	30.6%	99.7%	8.6%	ns
Comoros	1996	2000	6.4%	28.2%	5.4%	s	37.8%	23.6%	-3.5%	s
Kazakhstan	1995	2006	0.0%	0.1%	0.0%	s	67.6%	18.4%	-4.5%	s
Liberia	1986	2007	3.5%	12.8%	0.4%	s	77.1%	65.0%	-0.6%	s
Lesotho	2000	2004	8.9%	4.3%	-1.2%	s	19.7%	31.4%	2.9%	s
Morocco	1987	2005	15.4%	0.1%	-0.9%	s	35.9%	38.5%	0.1%	s
Madagascar	1992	2004	20.1%	19.9%	0.0%	ns	41.6%	32.3%	-0.8%	ns

Mali	1987	2006	0.7%	15.7%	0.8%	s	83.9%	50.6%	-1.8%	s
Mongolia	2000	2005	4.6%	0.1%	-0.9%	s	12.6%	31.6%	3.8%	s
Malawi	1992	2006	8.8%	0.5%	-0.6%	s	21.7%	45.5%	1.7%	s
Mozambique	1997	2003	23.6%	13.2%	-1.7%	ns	39.4%	34.6%	-0.8%	ns
Namibia	1992	2007	9.2%	3.2%	-0.4%	s	40.7%	37.2%	-0.2%	s
Niger	1992	2006	59.1%	19.9%	-2.8%	s	60.4%	69.6%	0.7%	s
Nigeria	1990	2003	43.4%	22.6%	-1.6%	s	49.7%	82.9%	2.6%	s
Nicaragua	1998	2001	2.0%	2.7%	0.2%	ns	19.3%	28.5%	3.1%	ns
Nepal	2052	2063	19.8%	2.2%	-1.6%	s	44.1%	15.8%	-2.6%	s
Peru	1986	2004	0.3%	0.6%	0.0%	ns	56.8%	40.1%	-0.9%	ns
Philippines	1993	2003	10.8%	8.2%	-0.3%	s	23.9%	22.7%	-0.1%	s
Pakistan	1991	2006	31.8%	6.0%	-1.7%	s	50.0%	43.4%	-0.4%	s
Rwanda	1992	2005	7.1%	2.8%	-0.3%	s	15.3%	23.0%	0.6%	s
Sierra Leone	2000	2005	12.0%	1.4%	-2.1%	s	59.9%	58.8%	-0.2%	s
Senegal	1986	2005	3.4%	5.2%	0.1%	ns	71.3%	41.0%	-1.6%	ns
Swaziland	2000	2006	2.3%	3.3%	0.2%	ns	27.7%	22.7%	-0.8%	ns
Chad	1997	2004	46.6%	17.0%	-4.2%	s	76.6%	85.5%	1.3%	s
Togo	1998	2006	13.6%	3.5%	-1.3%	s	61.8%	55.5%	-0.8%	s
Thailand	1987	2549	0.0%	0.1%	0.0%	ns	55.9%	17.6%	-0.1%	ns
Tajikistan	2000	2005	5.2%	0.9%	-0.9%	s	18.3%	97.5%	15.8%	s
Turkey	1993	2004	6.5%	2.1%	-0.4%	s	28.9%	44.1%	1.4%	s
Tanzania	1991	2004	8.6%	4.4%	-0.3%	s	26.9%	24.7%	-0.2%	s
Uganda	1988	2006	0.2%	5.3%	0.3%	s	48.6%	54.0%	0.3%	s
Uzbekistan	1996	2006	0.0%	0.0%	0.0%	ns	19.4%	99.7%	8.0%	ns
Viet Nam	1997	2006	2.9%	1.0%	-0.2%	s	43.3%	74.5%	3.5%	s
Yemen	1991	2006	30.6%	10.9%	-1.3%	s	36.1%	81.0%	3.0%	s
Zambia	1992	2007	8.4%	6.3%	-0.1%	ns	30.5%	31.9%	0.1%	ns
Zimbabwe	1988	2005	0.9%	27.2%	1.5%	s	12.8%	32.3%	1.1%	s

a: Trinidad and Tobago excluded due to errors in the original dataset. ns: confidence intervals overlap; s: confidence intervals do not overlap. Confidence intervals not shown.

Table 4. Number of countries with significant changes in the proportion of unvaccinated and partially vaccinated children.

	Partially vaccinated[a]		
Unvaccinated	Better	Worse	**Totals**
Better	18(a)	20(b)	**38**
Worse	6(c)	4(d)	**10**
Totals	**24**	**24**	**48**

a: Letters in parenthesis are related to Figure 4.

Table 5. Number of surveys according to the odds ratio values (less than one, one and more than one) by predictor.

Predictor (reference value)	Simple regression						Total number surveys
	<1		=1		>1		
	N	%	N	%	N	%	
Birth order – 1st born (versus 2nd born)	0	0%	39	63%	23	37%	62
Birth order – 1st born (versus youngest)	2	3%	28	45%	32	52%	62
Education – Last educated	0	0%	20	23%	66	77%	86
Education partner – Lest educated	1	2%	9	15%	51	84%	61
Ethnic – Minority groups	10	21%	20	42%	18	38%	48
Household members –More members	6	8%	45	58%	27	35%	78
Marital status - Alone	5	6%	70	79%	14	16%	89
Radio – No	1	1%	21	30%	49	69%	71
Religion – Minority groups	9	16%	29	51%	19	33%	57
Sex – Female	2	2%	85	92%	5	5%	92
Sex head household – Female	11	19%	41	71%	6	10%	58
Sons and daughters dead – More deaths	2	3%	21	33%	41	64%	64
Sons and daughters in household – More	3	3%	53	62%	30	35%	86
Television – No	0	0%	31	39%	49	61%	80
Tetanus before birth – No	0	0%	16	23%	53	77%	69
Wealth index – Poorest (versus less poor)	5	6%	45	53%	35	41%	85
Wealth index – Poorest (versus moderately poor)	6	7%	33	39%	46	54%	85
Wealth index – Poorest (versus rich)	3	3%	29	34%	54	63%	86
Wealth index – Poorest (versus richest)	3	4%	24	28%	58	68%	85
Child ill decide – No decides alone	0	0%	4	13%	26	87%	30
Residence – Rural	6	7%	37	43%	43	50%	86

<1 and >1: indicates odds ratios below and above 1, respectively, with confidence intervals not containing the value 1; =1: indicates odds ratios with confidence intervals containing the value 1. The last column has the total number of surveys with data available for each predictor suitable for logistic regression analyses.

Table 6. Median odds ratios and inter-quartile ranges across surveys for each predictor (multivariable logistic regression) and both outcomes.

	Unvaccinated			At least one dose		
	Median	IQR		Median	IQR	
Education caregiver - least educated	1.87	1.33	2.87	1.31	1.05	1.67
Education partner - least educated	1.61	1.16	2.52	1.17	1.00	1.44
Tetanus before birth - No	2.53	1.60	3.85	1.36	1.08	1.72
Child ill decision - decides alone	2.19	1.49	3.13	1.33	1.16	1.61
Wealth – poorest (versus 'less poor')	1.30	0.98	1.78	1.20	0.99	1.51
Wealth - poorest (versus 'moderately poor')	1.79	1.00	2.73	1.34	1.00	1.77
Wealth - poorest (versus 'rich')	1.82	1.00	3.09	1.58	1.09	1.95
Wealth - ' poorest (versus richest')	2.30	1.04	5.32	1.73	1.12	2.66

Figure 1
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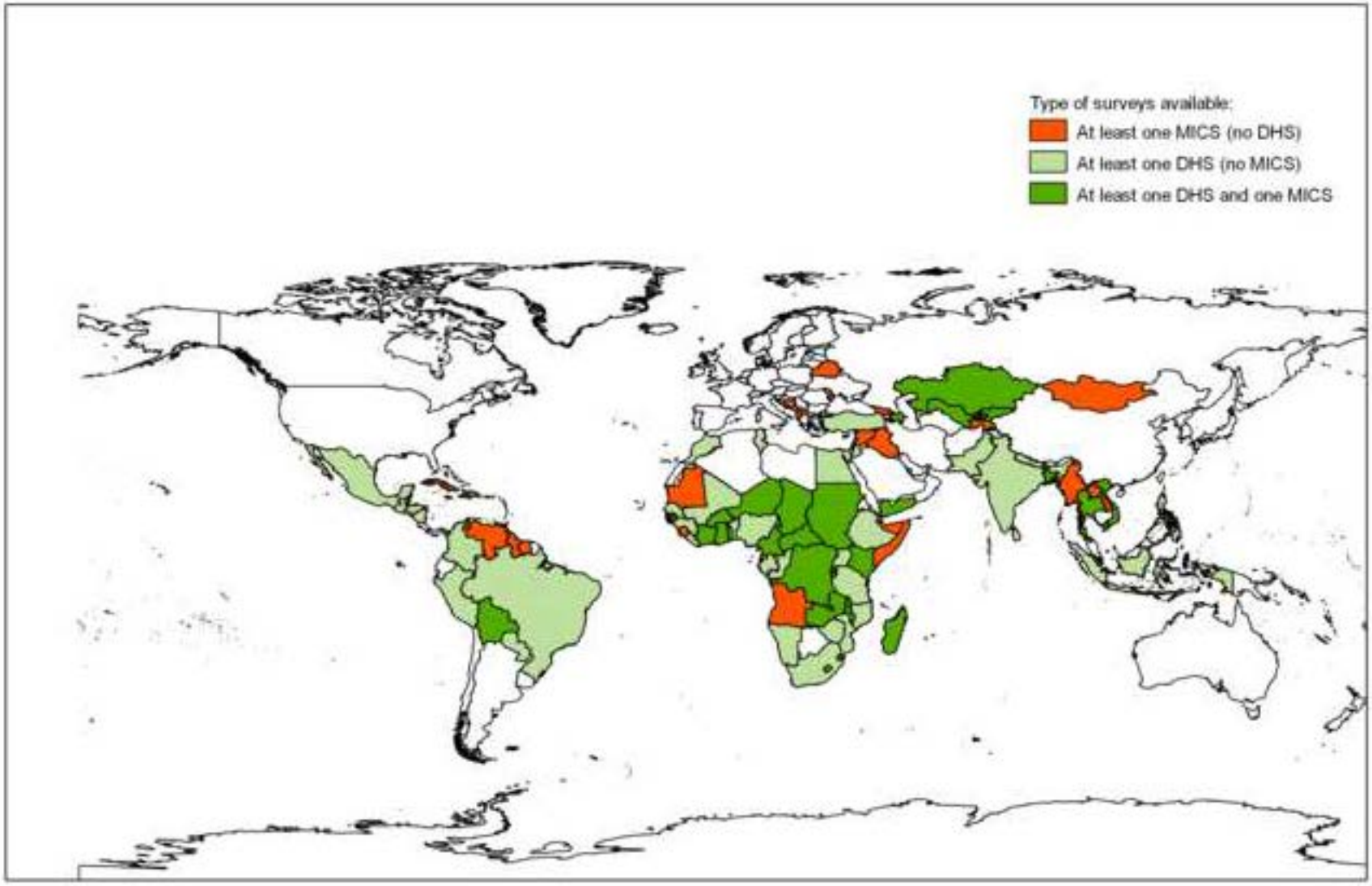

Figure 2
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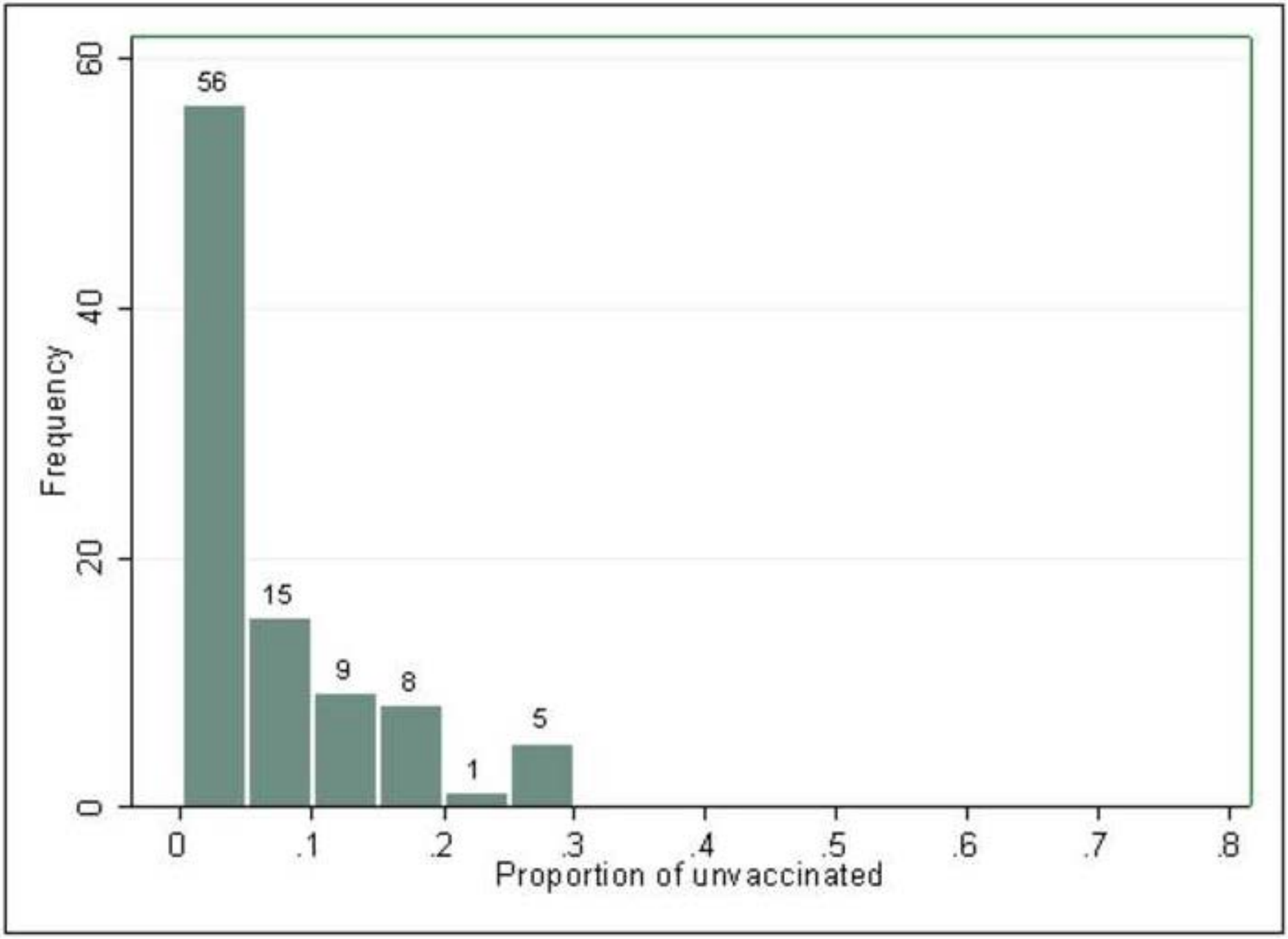

Figure 3

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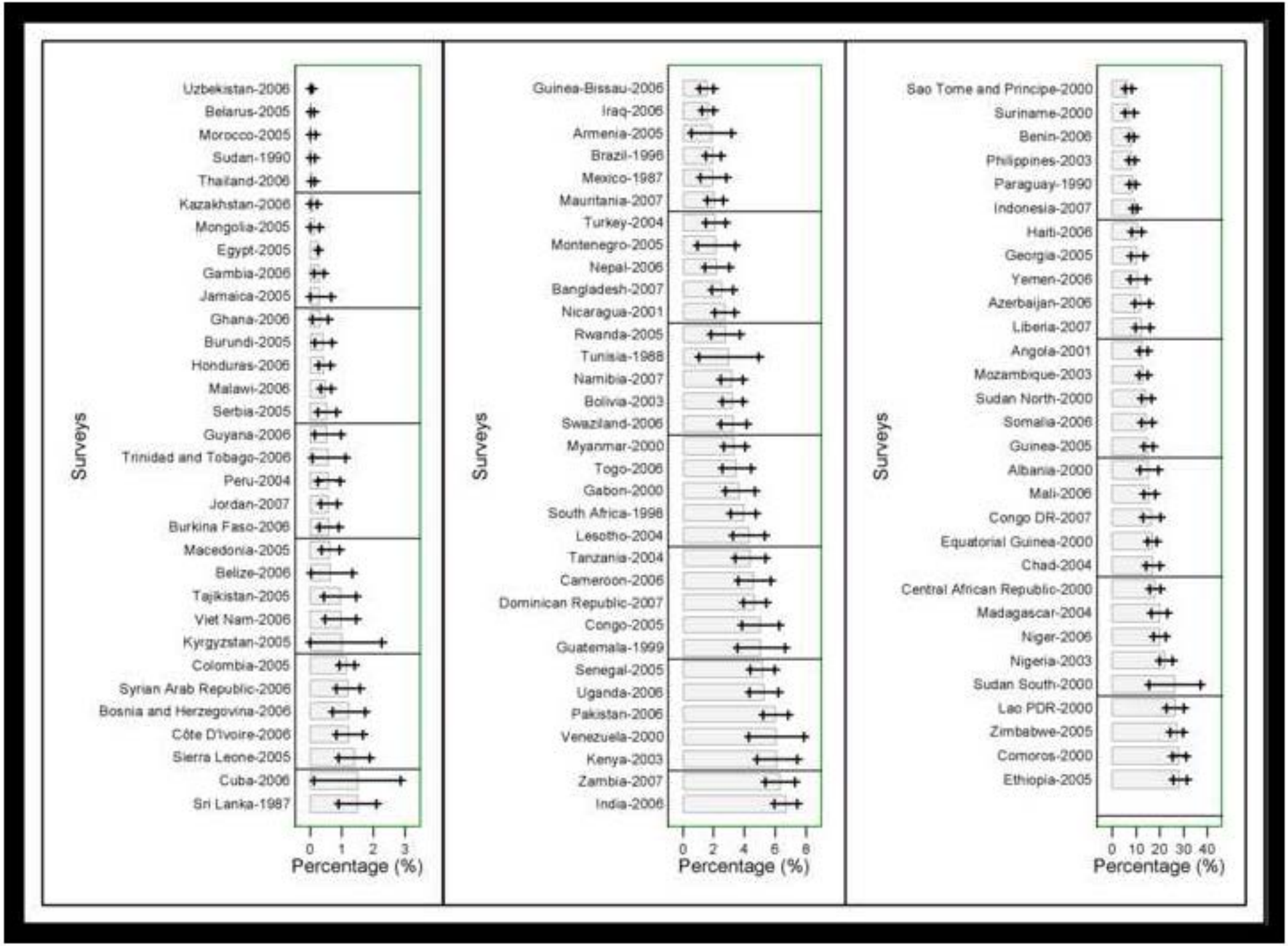

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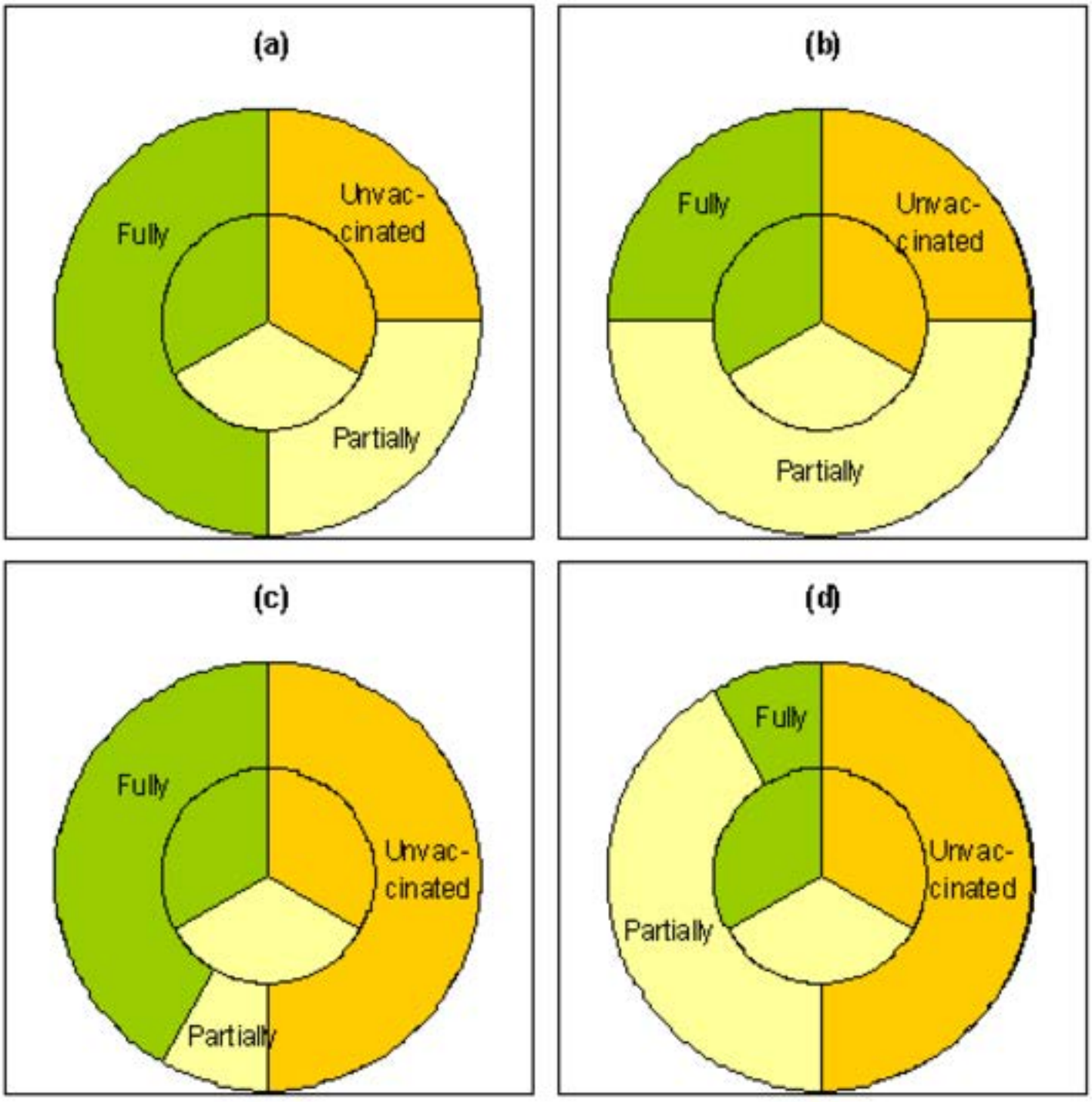

Figure 5
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