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Routine childhood vaccination programme coverage, El Salvador, 2011—In search of timeliness

Eduardo Suárez-Castaneda [a], Lorenzo Pezzoli [b,*], Miguel Elas [a], Rafael Baltrons [c], Elner Osmin Crespin-Elías [d], Oscar A. Rivera Pleitez [d], María Isabel Quintanilla de Campos [d], M. Carolina Danovaro-Holliday [e]

[a] Ministry of Health, El Salvador
[b] Consultant for the Pan American Health Organization, London, UK
[c] Pan American Health Organization, El Salvador
[d] Francisco Gavidia University, El Salvador
[e] Pan American Health Organization, Washington, DC, USA

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ABSTRACT

While assessing immunization programmes, not only vaccination coverage is important, but also timely receipt of vaccines. We estimated both vaccination coverage and timeliness, as well as reasons for non-vaccination, and identified predictors of delayed or missed vaccination, for vaccines of the first two years of age, in El Salvador.

We conducted a cluster survey among children aged 23–59 months. Caregivers were interviewed about the child immunization status and their attitudes towards immunization. Vaccination dates were obtained from children immunization cards at home or at health facilities. We referred to the 2006 vaccination schedule for children below two years: one dose of BCG (Bacillus Calmette-Guérin) at birth; rotavirus at two and four months; three doses of pentavalent – DTP (diphtheria-tetanus-pertussis), hepatitis B, and Haemophilus influenzae type b (Hib) – and of oral poliomyelitis vaccine (polio) at two, four, and six months; first MMR (measles-mumps-rubella) at 12 months; and first boosters of DTP and OPV at 18 months. Timeliness was assessed with Kaplan–Meier analysis; Cox and logistic regression were used to identify predictors of vaccination.

We surveyed 2550 children. Coverage was highest for BCG (991%; 95% CI: 98.8–99.5) and lowest for rotavirus, especially second dose (86.3%; 95% CI: 84.2–88.4). The first doses of MMR and DTP had 991% (95% CI: 98.5–99.6) and 977% (95% CI: 970–985), respectively. Overall coverage was 837% (95% CI: 81.4–86.0); 96.4% (95% CI: 95.4–97.5), excluding rotavirus. However, only 26.7% (95% CI: 24.7–28.8) were vaccinated within the age interval recommended by the Expanded Programme on Immunization. Being employed and using the bus for transport to the health facility were associated with age-inappropriate vaccinations; while living in households with only two residents and in the "Paracentral", "Occidental", and "Oriental" regions was associated with age-appropriate vaccinations. Vaccination coverage was high in El Salvador, but general timeliness and rotavirus uptake could be improved.

1. Introduction

Vaccination coverage is usually calculated from the number of vaccinated individuals (numerator) in a specific target group (denominator), without taking into account time of vaccination, unless age-specific cohorts are defined. However, timely receipt of vaccines has important implications for the success of child immunization programmes, since vaccines administered too late may leave children unnecessarily unprotected, while those administered too early may not be effective [1]. To assess age-appropriate vaccination, the Kaplan–Meier method and the Cox regression, which are survival-analysis techniques used to describe time-to-event data, can be applied [2–6].

El Salvador is on the Pacific coast of Central America. Bordering Honduras and Guatemala, it covers an area of 21,040 km^2 and, with a population of 5,744,113 (2009 census), is one of the most densely populated countries in the world. Administratively, it is divided into five regions, 14 departments, and 262 municipalities. It is considered a lower-middle-income country on the basis of 2009 World Bank Gross National Income per capita [7].

* Corresponding author. Tel.: +44 7527189555; fax: +44 20818 14855.
E-mail addresses: pezz@libero.it, Lorenzo.Pezz@gmail.com (L. Pezzoli).

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In El Salvador, for children younger than two years, the Expanded Programme for Immunization (EPI) includes the following vaccines: Bacillus Calmette-Guérin (BCG) at birth; rotavirus at two and four months; pentavalent – including diphtheria, tetanus, pertussis (DTP), hepatitis B, and *Haemophilus influenzae* type b – and oral poliomyelitis (polio) at two, four, and six months; the first dose of measles, mumps, and rubella (MMR) at 12 months; and booster (b) of DTP and polio at 18 months (2006/2007 schedule). All vaccines included in the EPI schedule are offered to the population free of charge by the government. Like other countries in the region, El Salvador submits annual administrative coverage data to the Pan American Health Organization (PAHO), the regional office of the World Health Organization [8]. Administrative coverage is calculated dividing the number of vaccine doses administered by the number of children in the target age-group. These calculations are affected by data quality issues, both regarding the denominator (e.g., outdated census) and the numerator (e.g., incomplete/incorrect reporting) [9,10], and do not include information on exact age of vaccination, making it impossible to assess timeliness of administration. Especially in low- and middle-income countries, vaccination coverage surveys are used to assess coverage and compare it with administrative data, while answering specific questions to guide programme strategies [11,12].

Reported administrative coverage of the third dose of DTP (included in the pentavalent in El Salvador), the vaccine generally used to track immunization progress globally [13], has fluctuated between 89% and 100%, in the period 2005–2011 [14]. In November 2011, we conducted a survey among children aged between 23 and 59 months in El Salvador to assess vaccination coverage, timeliness of vaccination, reasons for non-vaccination, and predictors of delayed or missed vaccination, for the vaccines recommended during the first two years of age.

2. Methods

2.1. Survey design

Between 1 November and 2 December 2011, we conducted a household-based cluster survey [15] among children aged 23–59 months living in El Salvador. We chose this age range so that all participants had the chance of having a complete vaccination schedule including the first booster doses of polio and DTP. To reach regional estimates of coverage with 5% precision and 95% confidence interval (CI), assuming coverage at 80% and a design effect of 2, the minimum sample size required in each region was 510 children, divided in 30 clusters of 17, corresponding to 2550 children in the entire country.

2.2. Sampling in the field

We randomly selected clusters of 17 households from the list of municipalities by region, according to probability proportional to population size (PPS) [16]. In each selected municipality, we randomly selected one locality (i.e., a suburb or a neighbourhood in urban areas or a village in rural areas) by simple random ballot from the list of all localities in the municipality. In the locality, we followed two different procedures to select the first household of each cluster. In urban areas, we numbered the squares in which the locality was divided and selected one randomly; we then numbered the dwellings in the selected square and selected one randomly to start the survey. In rural areas, we selected a sector and then the starting household in the sector from the map of the locality available from the local health facility. We selected the subsequent 16 households, by turning to the right while exiting the household and visiting the adjacent households. Only one eligible child per household was randomly selected for the survey. Households with no eligible children or that appeared permanently vacant were excluded. Households in which it appeared that someone was living, but no one was responding, were scheduled for one revisit at a different time. If we could not complete the cluster in the selected locality, we moved to the closest locality in the same municipality and repeated the procedure to select the remaining households. All simple random selections in the field were done using the table of random numbers.

2.3. Data collection and entry

After obtaining verbal consent, trained surveyors interviewed the caregivers and transcribed information from the immunization cards of the selected children, using a standard questionnaire (available as supplementary online material). We collected information on socio-demographic factors, divided into broad categories: place of residence, demographics, household characteristics, attitudes of the caregiver towards vaccination, and reasons for non-vaccination. If the immunization card was not available, surveyors sought vaccination history from the immunization record available at the local health establishment where the child was vaccinated. Data were entered onto a computerized form designed in SPSS (IBM Corp. 2011, SPSS Statistics, Armonk, NY, USA).

2.4. Outcome measures

We considered as not vaccinated any child without evidence of having received specific vaccinations from the immunization cards or whose caregiver did not present the immunization card and for whom no evidence on vaccination was found in the public immunization record. To assess delays in vaccination, we used the recommended vaccination schedule for children less than two years old in El Salvador in 2006/2007.

We considered three, progressively narrower, definitions of vaccination coverage: (1) general coverage, defined as the proportion of children having received vaccines, independent of their age at vaccination; (2) acceptable timing, defined as having received vaccines scheduled in the first year of life before 365 days of age (except rotavirus vaccine, for which the maximum age was 209 days) or ones scheduled in the second year of life between 355 (except MMR for which the minimum age was set at 270 days) and 729 days of age with an interval of at least 28 days between subsequent doses containing the same antigen; and (3) age-appropriate vaccination, defined as being vaccinated according to the EPI schedule, namely having received BCG between 0 and 30 days of age, two rotavirus vaccines, the first dose starting from 60 and the last one up to 149 days, three pentavalent and polio vaccines, the first dose starting from 60 and the last one up to 209 days, MMR between 365 and 395 days, and DTP1b and polio1b between 450 and 575 days, and with an interval of at least 28 days between subsequent doses containing the same antigen.

2.5. Statistical analysis

We used STATA 10 (StataCorp. 2007, Stata Statistical Software, College Station, TX, USA) for the analysis, applying the "svyset" command for complex survey designs with regional population size and number of eligible children living in the households as survey weights to account for differences in probability of selection. We assumed that data were approximately self-weighted within each cluster selected with PPS. We calculated vaccination coverage estimates with 95% CI. For each vaccine, we estimated the cumulative probability of being vaccinated at age t, by inverse Kaplan–Meier survival function, or $1 - S_{KM}(t)$ [17] and we assessed at what age

Table 1
Vaccination coverage in general, according to acceptable timing, and at the appropriate age in children between 23 and 59 month of age, El Salvador, 2011. $n = 2550$.

Vaccine	General[d]		Acceptable timing[e]		Age-appropriate[f]		Administrative coverage 2005–2008–2011[g] (%)
	n	% (95% CI)	*n*	% (95% CI)	*n*	% (95% CI)	
BCG[h]	2528	99.1 (98.8–99.5)	2516	98.6 (98.1–99.1)	2307	90.0 (88.7–91.3)[c]	84–99–91
Rota[i] 1	2391	93.7 (92.2–95.2)	2324	91.0 (89.4–92.5)	1723	66.7 (64.5–69.0)	
Rota 2	2213	86.3 (84.2–88.4)	2105	82.0 (79.8–84.3)	1660	64.6 (62.2–67.0)	
Penta[j] 1	2548	99.9 (99.8–100.0)	2482	97.4 (96.7–98.1)	2120	82.7 (81.1–84.3)	
Penta 2	2548	99.9 (99.7–100.0)	2496	97.9 (97.2–98.5)	2150	84.0 (82.2–85.8)	
Penta 3	2541	99.6 (99.3–99.9)	2418	94.8 (93.9–95.7)	1963	76.7 (74.5–78.9)	89–98–89
Polio[k] 1	2547	99.9 (99.7–100.0)	2494	97.8 (97.2–98.4)	2144	83.6 (82.0–85.2)	
Polio 2	2544	99.7 (99.5–100.0)	2504	98.1 (97.5–98.7)	2172	84.9 (83.1–86.7)	
Polio 3	2540	99.5 (99.2–99.8)	2444	95.9 (95.0–96.7)	1988	77.8 (75.5–80.1)	89–98–89
All first year vaccinations[a]	2192	85.5 (83.4–87.6)	1966	76.9 (74.5–79.2)	1202	46.6 (44.3–49.0)	
MMR[l] 1	2527	99.1 (98.5–99.6)	2433	95.0 (94.0–96.1)	1807	71.0 (69.0–73.0)	99–95–90
Polio 1b	2502	98.1 (97.3–98.8)	2293	89.6 (88.0–91.2)	1713	66.7 (64.3–69.2)	
DTP[m] 1b	2496	97.7 (97.0–98.5)	2230	87.0 (85.4–88.6)	1679	65.3 (62.8–67.7)	
All second year vaccinations[b]	2484	97.3 (96.4–98.2)	2146	83.6 (81.7–85.4)	1245	48.8 (46.5–51.0)	
Complete	2149	83.7 (81.4–86.0)	2041	66.8 (64.1–69.6)	693	26.7 (24.7–28.8)	

[a] Vaccinations scheduled during the first year of life: one dose of BCG, two of rota, and three of polio and penta.
[b] Vaccinations scheduled during the second year of life: first MMR, first polio and DTP boosters.
[c] The definition used considers doses given within the first month of age, but BCG is strongly recommended at birth; the number of children who received BCG within the first three days of life was 1799 (i.e., 70.2%; 95% CI: 681–724).
[d] Number of doses/total children sampled.
[e] First year vaccinations 365 days of age (except rotavirus, for which the maximum age was 209 days); second year vaccination between 355 (except MMR for which the minimum age was set at 270 days) and 729 days of age; with an interval of at least 28 days between subsequent doses containing the same antigen.
[f] BCG between 0 and 30 days of age, two rotavirus vaccinations between 60 and 149 days, three pentavalent and polio vaccines between 60 and 209 days, MMR between 365 and 395 days, and DTP1b and polio1b between 450 and 575 days; with an interval of at least 28 days between subsequent doses containing the same antigen.
[g] *Source*: http://ais.paho.org/phip/viz./im_coveragebycountry.asp.
[h] Bacillus Calmette-Guérin.
[i] Rotavirus vaccine.
[j] Pentavalent vaccine – including diphtheria, tetanus, pertussis, hepatitis B, and Haemophilus influenzae type b.
[k] Oral poliomyelitis vaccine.
[l] Measles, mumps, and rubella vaccine.
[m] Diphtheria, tetanus, pertussis.

90% and 95% (two thresholds commonly used to assess vaccination programmes) of children were vaccinated [18,19]. We computed reasons for non vaccination for each vaccine and aggregated them. Setting date of birth as origin time, date of vaccination as failure time, and date of the survey as exit time ("stset" command), we applied Cox regression analysis to take into account time of vaccination while assessing which independent variables had an effect on the coverage of five vaccines given at different times along the schedule: BCG, rotavirus 2, pentavalent 3, MMR, and DTP 1b. In unvaccinated children, the time to the next eligible dose was censored at the date of survey. All the independent variables significantly associated with the outcome at univariable analysis were included initially in a multivariable model; the final model was reached using backward selection with a cut-off level at $p < 0.05$ for including the variable in the model. This conservative cut-off level was chosen to minimize the likelihood of finding significant associations by chance, given the high number of variables examined. The resultant hazard ratios (HR) should be interpreted as age- and vaccination-specific rate ratios [2]. For analysis purposes, months were considered as having 30 days. We also conducted an analysis of risk factors for non-age-appropriate vaccination, limiting the analysis to the group of children who had received all vaccines (i.e., with a complete vaccination schedule) ($N = 2149$). Using age-appropriate complete vaccination as main outcome, we calculated odds ratios (OR) both with univariable and multivariable (logistic regression) models using a step-down approach like the one described for the Cox regression.

2.6. Ethical considerations

Participation was voluntary and informed consent was obtained before the interview. The survey was conducted as part of the standard procedure to evaluate the activities of the Ministry of Health. Thus, it was considered to be non-research by PAHO's institutional review board (IRB) and was exempted from ethics committee approval.

3. Results

3.1. Sample description

Overall, we interviewed the caregivers of 2550 children born between 4 November 2006 and 12 December 2009 distributed in 85 clusters. No caregiver refused participation, but three clusters could not be accessed and were replaced.

3.2. Vaccination status

No children completely unvaccinated were found. In general, coverage was highest for BCG and lowest for the rotavirus vaccine, especially the second dose. Complete coverage with all vaccines examined was 83.7% (95% CI: 81.4–86.0) in general, 66.8% (95% CI: 64.1–69.6) according to "acceptable timing", and 26.7% (95% CI: 24.7–28.8) at the appropriate age (Table 1). Excluding the rotavirus vaccine, complete general coverage was 964% (95% CI: 95.4–97.5).

By one month of age, 88.5% of children had received BCG (90% by 11 months and 95% by 21 months); by five months, 66.3% had received rotavirus 2 (90% and 95% coverage were never reached for this vaccine); and by seven months 78.7% had received pentavalent 3 (90% by 81 months and 95% by 10.4 months) and 79.1% polio 3 (90% by 81 months and 95% by 99 months) (Fig. 1). By 13 months of age, 75.3% were vaccinated with MMR (90% by 153 months and 95% by 221 months); by 19 months, 30.9% were vaccinated with DTP 1b (90% by 229 months, while 95% coverage was never reached) and 70.0% with polio 1b (90% by 227 months, while 95% coverage was never reached) (Fig. 2).

For 2407 children (94.4%), data was obtained from a vaccination card and for the rest from the vaccination record at a health facility;

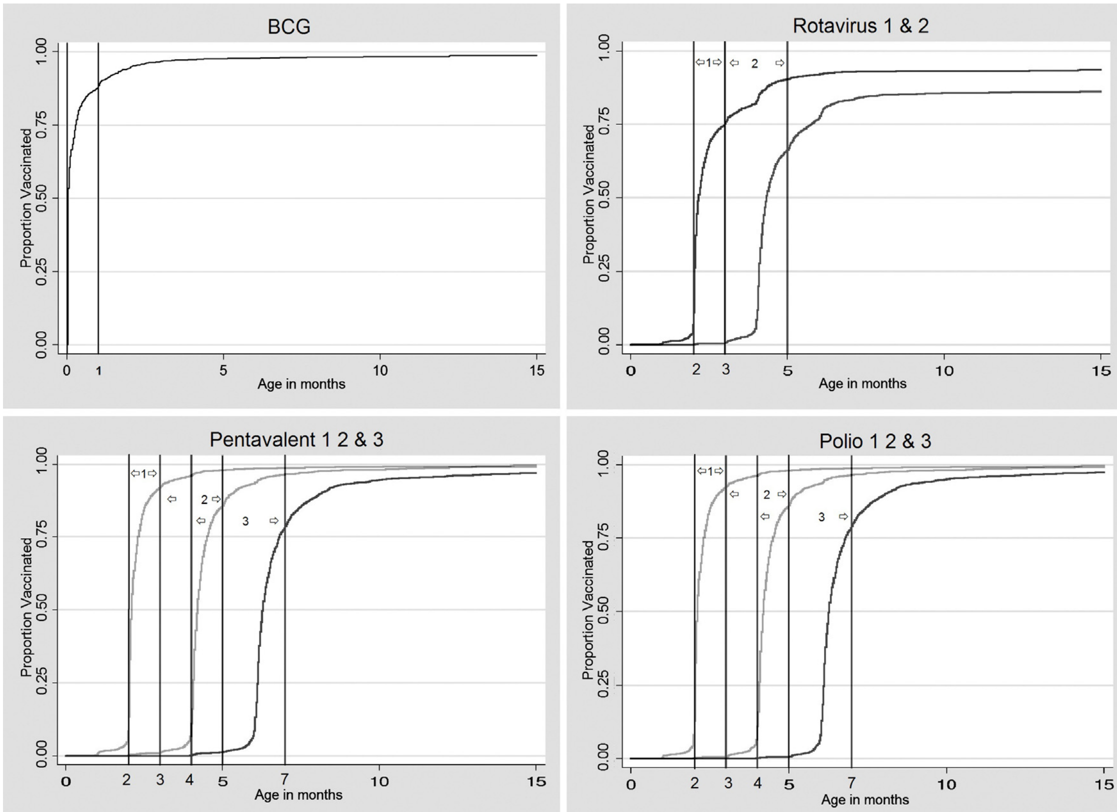

Fig. 1. Inverse Kaplan–Meier curves showing the proportion of children vaccinated with each dose of the vaccinations scheduled for the first year of life, El Salvador, 2011. For each dose two reference lines are drawn to mark the age-appropriate intervals for vaccination, these are also pointed out in the graph by two arrows indicating each specific dose when more than one vaccine is displayed. BCG: Bacillus Calmette-Guérin; Polio: oral poliomyelitis vaccine.

two children were excluded as no written record of their vaccination status could be found, though for both, the caregivers reported that the children had received vaccines. The most frequent reason for non-vaccination was that there was no vaccine at the health facility (especially for not having received the rotavirus vaccine), followed by not having time to attend the health facility, the decision to postpone vaccination, being unaware that the child needed the vaccine, and not wanting to wait because the health facility was overcrowded (Table 2).

3.3. *Factors associated with vaccination status and with being vaccinated at the appropriate age*

In the completely vaccinated cohort ($N = 2149$), age-appropriate vaccination was more likely if the child was living in the "Occidental", "Paracentral", or "Oriental" regions or in a household with only two residents and the caregiver had achieved secondary education. It was less likely in children whose parents were employed or had to get the bus to take them to vaccination (Table 3). Also the 14 children surveyed who belonged to the indigenous ethnic group were less likely to receive age-appropriate vaccination.

Being vaccinated in the private sector was a positive predictor of vaccination for four (BCG, rotavirus 2, pentavalent 3, and DTP 1b) of the five vaccines assessed. Also the year of birth was often associated with vaccination, although no clear trend was identifiable (Table 4). Children living in the urban area, travelling to the health centre by taxi, whose caregiver had achieved secondary education and was also the person interviewed were more likely to have received BCG. With regards to rotavirus 2, children living in the "Oriental" region, being born in 2009, and who were male were less likely to be vaccinated; while children whose caregiver was married and was also their parent were more likely to be vaccinated.

4. Discussion

We evaluated coverage of the routine childhood vaccination programme in El Salvador for all vaccines given routinely (excluding seasonal influenza) during the first two years of life. Rotavirus was the vaccine with the lowest coverage, while BCG had the highest. The majority of children had a complete vaccination status, but few were vaccinated at the recommended age. We identified that the employment level, the size of the household, the mode of transport to the health facility, and the region of residence all had an effect on timely vaccination. These results provide useful directions for the immunization programme in El Salvador.

Vaccination coverage was in general high, but less than one third of children received all vaccines at the appropriate age. Particularly in a setting with good access to vaccines, the implication of delay in receipt of vaccines is that a pool of children with incomplete or delayed vaccination is at unnecessary risk of vaccine preventable infectious diseases [20]. Not surprisingly, the education level of caregivers was positively associated to age-appropriate vaccination, although no clear trend was identifiable. Also it is not surprising that caregivers with jobs or who have to take care of big families would have fewer opportunities to vaccinate children on-time. The fact that travelling to the health centre by bus was associated with untimely vaccination may be explained by the fact that caregivers who have to rely on the bus to take children to vaccination may have fewer opportunities to really be on schedule, or may be a proxy for other unmeasured socio-demographic characteristics, as is belonging to the indigenous ethnic group. The

Table 2
Reported reasons for not being vaccinated, children between 23 and 59 month of age, El Salvador, 2011.

Reason	BCG		Rota 1 + 2		Penta 1 + 2 + 3		OPV 1 + 2 + 3		MMR		DTP 1b		OPV 1b		All	
	N	%	*n*	%	*n*	%	*n*	%	*n*	%	*N*	%	*n*	%	*N*	%
There was no vaccine at the health facility	4	31	372	80					1	5	9	17	7	15	393	63
Did not have time	2	15	20	4	2	25	2	14	4	21	8	15	5	11	43	7
Decided to postpone vaccination			6	1	1	13			3	16	17	33	14	30	41	7
Was not aware that the child needed this vaccination	3	23	17	4			1	7	3	16	6	12	7	15	37	6
The health facility was overcrowded (did not want to wait)	1	8	15	3			1	7	2	11	4	8	5	11	28	5
Was not visited by the health promoter	1	8	8	2	1	13	3	21	1	5	2	4	3	6	19	3
The schedule of the health facility is incompatible with working hours	1	8	8	2					1	5	1	2	1	2	12	2
Fear of adverse events following immunization			2	0	1	13	3	21	1	5	2	4	2	4	11	2
Was not attended at the health facility (was referred to another day)			1	0	3	38	3	21			1	2	1	2	9	1
The child was sick when the vaccine was due (they did not take him/her to the health facility)			3	1					1	5	2	4	2	4	8	1
Health facility is too far			5	1											5	1
Does not know where to get vaccination			3	1					2	11					5	1
The health facility was closed			4	1											4	1
The doctor/nurse has contraindicated the vaccine	1	8	1	0											2	0
Travel to the health facility is too expensive			1												1	0
Considers vaccination not important			0				1	7							1	0

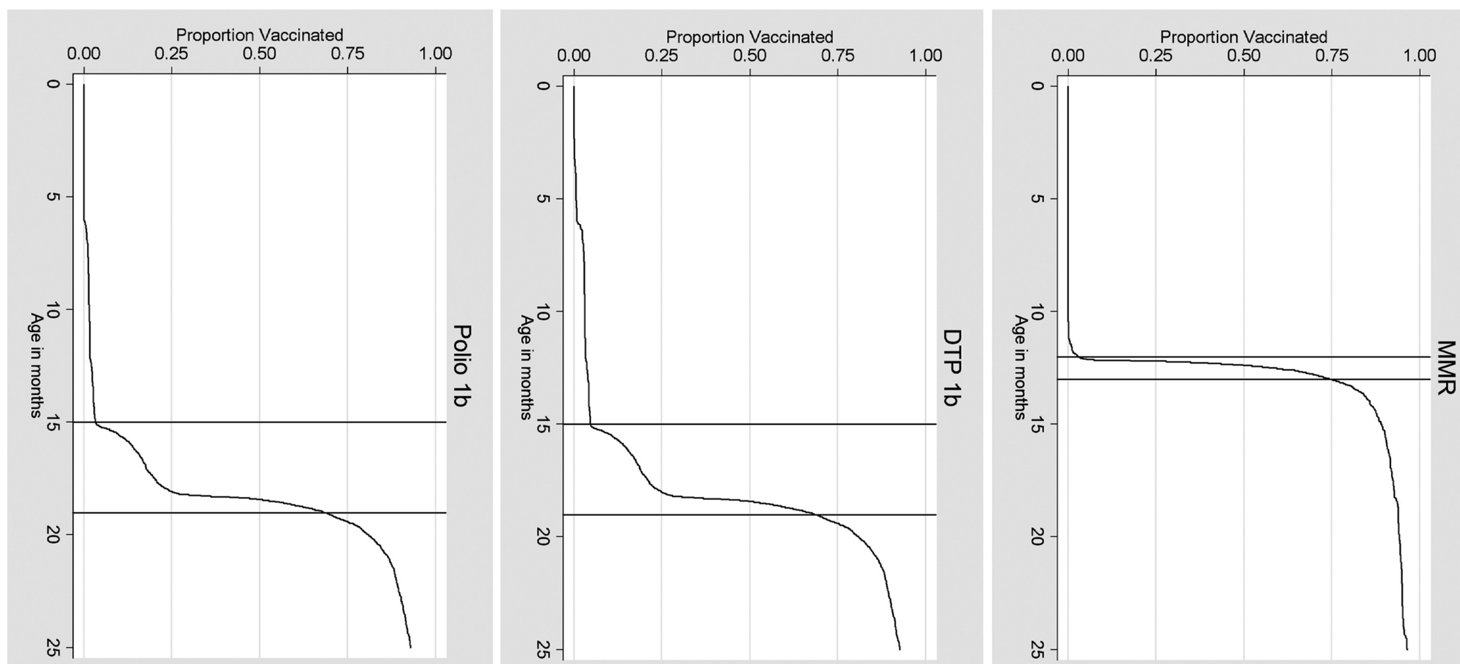

Fig. 2. Inverse Kaplan–Meier curves showing the proportion of children vaccinated with each dose of the vaccinations scheduled for the second year of life, El Salvador, 2011. For each dose two reference lines are drawn to mark the age-appropriate intervals for vaccination. MMR: measles, mumps, and rubella vaccine; DTP: diphtheria, tetanus, pertussis; 1b: first booster dose.

three regions where age-appropriate vaccination was more likely are predominantly rural. In El Salvador rural areas, a higher proportion of health service delivery is done by outreach strategy and more health promoters go door-to-door to offer vaccinations, compared with urban areas. This may have facilitated a timelier access to vaccination, compared with the other two regions, where the largest cities are located. The second dose of rotavirus vaccination

Table 3
Analysis of the predicting factors for age-appropriate vaccination among children who had received all vaccines ($N = 2149$) using logistic regression, children 23–59 months old, El Salvador, 2011.

Variables[a]	n[c]	%[d]	OR (95% CI)	Adjusted[b] OR (95% CI)
Geographic characteristics				
Region:				
"Central"	432	20.1	1	1
"Metropolitana"	425	19.8	1.20 (0.87–1.66)	1.25 (0.89–1.73)
"Occidental"	444	20.7	1.35 (0.94–1.93)	1.49 (1.05–2.13)
"Oriental"	406	18.9	1.51 (1.08–2.11)	1.58 (1.13–2.21)
"Paracentral"	442	20.6	1.69 (1.13–2.51)	1.67 (1.12–2.51)
Socio-demographic characteristics				
Belongs to indigenous ethnic group:				
No	2135	99.4	1	1
Yes	14	0.6	0.14 (0.09–0.20)	0.15 (0.08–0.27)
Characteristics of the household				
Nr of residents:				
2	26	1.2	3.11 (1.40–6.93)	2.87 (1.26–6.55)
Between 3 and 5	1338	62.3	1	1
Between 6 and 9	657	30.6	0.92 (0.73–1.16)	0.92 (0.73–1.15)
10 or more	128	5.96	0.66 (0.41–1.07)	0.64 (0.39–1.07)
Characteristics of the caregiver				
Education level:				
No formal education	193	90	1	1
Primary (1st to 6th grade)	735	34.2	1.25 (0.81–1.93)	1.19 (0.77–1.84)
Secondary (7th to 9th grade)	592	27.6	1.67 (1.05–2.65)	1.70 (1.08–2.68)
Baccalaureate	489	22.8	1.42 (0.89–2.26)	1.53 (0.97–2.41)
Higher (technical)	37	17.2	0.95 (0.38–2.37)	1.17 (0.47–2.90)
Higher (university)	103	47.9	1.40 (0.78–2.52)	5.28 (0.72–3.88)
Employment:				
Housewife	1454	67.7	1	1
Unemployed	36	17	1.04 (0.52–2.09)	0.94 (0.47–1.88)
Employed	654	30.4	0.72 (0.58–0.90)	0.67 (0.53–0.84)
Retired	5	0.2	5.39 (0.58–5.05)	5.28 (0.72–3.88)
Immunization services				
Travels to the health centre:				
By foot	1116	51.9	1	1
By bus	692	32.2	0.72 (0.58–0.89)	0.70 (0.56–0.87)
By taxi	46	2.1	0.90 (0.42–1.94)	0.93 (0.45–1.90)
With private vehicle	165	7.7	0.70 (0.50–0.99)	0.75 (0.53–1.07)
Other	130	6.05	1.13 (0.71–1.81)	1.23 (0.76–1.99)

[a] Only variables significantly associated with the outcome are reported.
[b] Adjusted for all other variables reported in the column.
[c] Number of respondents reporting the variable.
[d] Proportion of respondents reporting the variable over the entire group ($N = 2149$).

is the only one of the series for which coverage is significantly below 90%, no matter the definition used. Several factors may explain this. This vaccination was only introduced in October 2006, and steady supply across the whole country may have taken time. Furthermore, it was not recommended in children older than seven months because of a potentially increased risk of intussusception [7,21,22], which also may have contributed to low coverage. Notably, El Salvador experienced a shortage of this vaccine between July and October 2009 [8]. This is consistent with the fact that being born in 2009 was a negative predictor for receiving the second rotavirus vaccine and the most frequently reported reason for non-vaccination was that the vaccine was not in stock.

In absolute terms, BCG presented the highest coverage levels, but less than 90% of children received it within the first month of age. Polio and pentavalent (or DTP) had comparable levels of high coverage. However, less than 80% of children received the third dose of pentavalent at seven months of age and 95% coverage was only achieved after ten months. General vaccination coverage with MMR was almost 100%, which is a very positive result and reflects regional efforts to maintain the Americas measles- and rubella-free [23,24]. When considering only doses given with "acceptable timing", MMR coverage was close to 95%, the threshold believed to confer measles herd immunity [25]. However, 95% coverage was achieved at approximately 22 months of age, which is nine months later than the recommended time frame.

In general, administrative coverage figures [14] were lower than those estimated with this survey. This may indicate that the denominators used to calculate administrative coverage are overestimated and should be revised, or that not all vaccine doses are counted, as may be the case with doses given in the private sector or the social security, or both.

In terms of factors associated with being vaccinated with the different vaccines, we were reassured to notice that coverage was generally satisfactory across all the country, with no important regional variations. Receiving vaccinations from the private sector was a positive predictor for most vaccines examined. This may indicate that individuals who have to pay for vaccination are more willing to vaccinate children, or it may be a proxy for a better socio-economic status, which is traditionally a determinant of vaccination [5,26,27].

As seen elsewhere, coverage estimates varied considerably depending on the definitions used [17]. Having three definitions of vaccination coverage was useful to understand how general coverage gives only part of the picture when assessing routine vaccination programmes. At the time of writing, a standard definition of acceptable timing of vaccination has not been developed

Table 4
The Cox proportional hazard ratios from multivariable analyses for receiving five different vaccines each vaccination, children 23–59 months old, El Salvador, 2011 (N = 2550).

Socio-demographic variables	n	%	BCG[a]	Rota 2[a]	Penta 3[a]	MMR[a]	DTP1b[a]
Place of residence							
Lives in "Metropolitana" region	504	19.8				0.85 (0.75–0.96)	
Lives in "Occidental" region	511	20.0				1.12 (1.00–1.26)	
Lives in "Oriental" region	512	20.1		0.82 (0.70–0.98)			
Lives in "Paracentral" region	511	20.0					1.31 (1.11–1.53)
Lives in urban area	1194	46.8	1.09 (1.02–1.18)				0.85 (0.76–0.95)
Child							
Born in 2006	55	2.2	1.33 (1.11–1.60)		1.53 (1.13–2.09)		
Born in 2007	806	31.6				0.83 (0.74–0.91)	0.83 (0.73–0.93)
Born in 2008	877	34.4	1.26 (1.16–1.36)		1.18 (1.08–1.29)		
Born in 2009	812	31.8		0.88 (0.80–0.97)		1.13 (1.03–1.25)	1.17 (1.07–1.27)
Male	1328	52.1		0.86 (0.79–0.94)			
Interviewee							
Is also the caregiver	2084	81.7	1.20 (1.08–1.33)				
Parent of the child	2426	95.1		1.12 (1.01–1.24)	1.13 (1.03–1.25)		
Mother of the child	1293	53.3					1.15 (1.06–1.26)
Caregiver							
Married	2044	80.2		1.14 (1.04–1.25)			1.12 (1.02–1.23)
No formal education	232	9.1			0.82 (0.71–0.94)		
Secondary education (7th-9th grade)	695	27.3	1.12 (1.03–1.22)		1.13 (1.03–1.24)		
University education	117	4.6			1.24 (1.04–1.47)		
Attitudes and practices towards immunization							
Vaccinated in the private sector	33	1.29	1.47 (1.22–1.76)	1.60 (1.13–2.26)	1.94 (1.35–2.80)		1.59 (1.14–2.22)
Travels to the health centre by taxi	59	2.3	1.18 (1.02–1.38)				

[a] Adjusted for all the other variables reported in the column.

by PAHO. Our definition was based on expert consultation and a review of the literature [28–31]. The use of survival analysis techniques enables comparisons with other cohorts where the definitions of "risk periods" for vaccination differ from ours [32]. The Kaplan–Meier method was useful to visualize the increase in coverage over time. The use of Cox regression was useful to estimate predictors of vaccination adjusting for age at vaccination. Even though it was technically possible [33], we did not use Cox regression to determine the contributions of socio-demographic variables on complete vaccination coverage, preferring to analyze five different vaccines separately.

Our operational limitations are linked to replacements during the survey. We replaced three clusters because we did not get the authorization to access a private residential area, the "maras", local delinquent groups, forbid us to access the locality, or the locality was geographically inaccessible. It is impossible to say how this selection bias affected our results. Presumably, an overestimation of coverage may have been produced if these are localities in general inaccessible also by health professionals. Two children who did not have a vaccination card or a vaccination record in the health system were also substituted. This was due to an erroneous interpretation from the surveyors, and may have produced a slight overestimation of vaccination coverage; though, we were reassured that in both cases their caregivers claimed that they were regularly vaccinated. Another possible limitation was that only live children were included in the survey. This may have also resulted in an overestimation of vaccination coverage, if children who were dead at the time of the survey were also less likely to have been vaccinated. A methodological limitation was that we did not check for interactions in our multivariable statistical models given the great number of variables under study. Having said that, the associations found may not require to be explained further by looking at possible interactions. Also, certain factors were significantly associated with vaccination but were only reported by a few respondents (e.g., only 33 children in our sample were vaccinated privately and 14 belonged to an indigenous ethnic group). It is difficult to explain these associations, which may be due to chance, and their impact on coverage nationally may be negligible. Finally, the wide age range (23–59 months) used for the survey may have introduced bias with regards to coverage estimates stratified by year of birth. However, we believe that this bias was minimal since we avoided using estimates by year of birth, apart from when we applied the Cox regression model, automatically adjusted for age.

In conclusion, vaccination coverage was high in El Salvador, although children were rarely vaccinated at the recommended age. A major objective of any immunization programme is not only to increase coverage rates but also to achieve the highest levels of protection against preventable diseases at the youngest possible age. In this sense, assessing when children were vaccinated proved as important as assessing whether they were. Health care workers should put extra effort in ensuring age-appropriate vaccination and the importance of adhering to the recommended schedule to prevent infectious diseases should be explained to caregivers. Special efforts need to be directed towards vaccination against rotavirus in order to raise coverage of this vaccine. Future studies could examine more specifically attitudes or practices towards vaccination, specific populations (e.g., indigenous communities, communities with high crime rates or low socio-economic groups), or coverage of vaccines not included in this evaluation (e.g., influenza) to compare them with the routine programme.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.vaccine.2013.11.072.

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