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Strengthening Immunization Quality Using Old Survey Data: Analytical Evidence from the 2014 Cameroon Multiple Indicator Cluster Survey (MICS)

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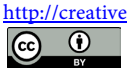

Abstract

Objective: Vaccination coverage in Cameroon remains below targets due to missed opportunities for vaccination (MOV) and delays in timely immunization. This study used data from the 2014 Multiple Indicator Cluster Survey (MICS) to assess vaccination timeliness and MOV, with the goal of proposing a reusable analytic framework for future surveys. **Methods:** Children aged 12 - 35 months with documented vaccination dates were included. Vaccine doses were classified as early, timely, or delayed based on the national immunization schedule. Timeliness-to-completeness with their 95% confidence intervals (IC) measured how many children were protected on time. Missed opportunity for simultaneous vaccines (MOSV) was defined as the failure to receive one or more vaccine due doses during a health system contact. Uncorrected missed opportunity for vaccination (uncorrected MOV) was defined as a child who missed one or more due vaccine doses during a contact and did not subsequently return to receive the missed vaccine(s). All uncorrected MOVs refer to children who failed to receive all due vaccines that were missed during eligible contacts. Analyses included descriptive statistics, meta-analysis of MOV proportions, stratified comparisons, and modeling based on the "All uncorrected MOSV" status with a stepwise logistic regression analyses completed with a decision tree classification. **Results:** Of 1447 children (65.3% of cards ownership), 66.1% (95% CI = 63.6 - 68.5) were fully vaccinated among which only 11.3% (95% CI = 9.4 - 13.5) received vaccines on time. Timeliness was

below 80% for all antigens, from 34.7% (BCG) to 61% (Penta1). Timely and completeness for specific doses ranged from 27% to 52%. MOV for simultaneous vaccines (MOSV) prevalence was 90% (95% CI = 84 - 94) nationally, among which 61% (95% CI = 53 - 69) of children had ALL uncorrected MOSV. MOV was significantly more frequent in rural areas and varied by maternal education, wealth, region, and care use. Dose specific MOV ranged from the lowest of 4% (56/1413) for BCG, to the highest of 53.04% for the yellow fever, to 57.1% for PCV vaccines. A significant difference in MOV between sexes indicates gender-related inequities. **Conclusion:** Although based on an older survey, this study demonstrates a methodology for analyzing vaccination data, encompassing both timeliness and combined timeliness-completeness, as well as missed opportunities for vaccination (MOV). The MOV analysis highlights equity gaps and underscores the importance of community-driven, gender-sensitive strategies to strengthen vaccine delivery. Additionally, the observed association between maternal experience of domestic violence and the occurrence of missed opportunities for simultaneous vaccination warrants further investigation.

Keywords

MICS, Analytics and Insights, Domestic Violence, Vaccination Timeliness, MOV, Children, Health System Performance, Cameroon

1. Background

Vaccination remains one of the most effective public health interventions for reducing childhood morbidity and mortality, especially in low- and middle-income countries [1] [2]. However, achieving high overall coverage is not sufficient; ensuring that children are vaccinated on time and at every eligible opportunity is equally critical to sustaining disease control and elimination [3] [4]. Yet, despite relatively high overall coverage reported in national surveys, challenges such as Missed Opportunities for Vaccination (MOV) and untimely vaccination continue to hinder the full potential of these programs [5] [6].

A missed opportunity for vaccination (MOV) occurs when a person who is eligible for vaccination (with no true contra-indications) has contact with health services but does not receive all of their needed vaccines [3] [5]. MOVs are commonly observed when a person attends health services for curative care due to inadequate integration of curative and preventive services. They may also occur when a person attends for vaccination. If they receive some but not all vaccines for which they are eligible, we use the term missed opportunity for simultaneous vaccination (MOSV) according to established guidelines and literature [7] [8].

Vaccination timeliness, on the other hand, refers to the administration of vaccines within the recommended age range, ensuring optimal immune response and protection when children are most vulnerable [9] [10]. Both concepts are increas-

ingly recognized as key quality indicators of immunization programs and are essential for achieving optimal protection in children during periods of greatest vulnerability [8] [11]. In addition, among those key performance indicators, timeliness-and-completeness is crucial for identifying gaps, preventing outbreaks, and supporting better planning of immunization activities. According to the World Health Organization (WHO), an effective surveillance system requires that reports be submitted on time and in full to enable timely and appropriate public health responses [12] [13].

Although studies focusing on MOV and timeliness have increased globally [14]-[22], relatively few have analyzed these indicators in Cameroon in detail. Notable recent efforts include, the analysis of the 2018 Cameroon Demographic and Health Survey (DHS) which reported an MOSV of 75.1% among children aged 12 - 23 months, with uncorrected MOSV at 67.4%, and the highest rates were seen for the Yellow Fever vaccine [20]. A subnational assessment reported an MOV rate of 23.8%, and linked missed doses to both caregiver-related and systemic factors, including poor health worker practices [17].

However, despite the relevance of these indicators, there has been limited analysis of MOV and timeliness using earlier datasets such as the 2014 Cameroon Multiple Indicator Cluster Survey (MICS). Indeed, MICS surveys offer child-level immunization data, including vaccination dates and card ownership, yet MOV and timeliness remain underreported in official outputs.

MOVs have most often been assessed by studies based at health facilities [6] [17] [21] [23] [24]. Such studies have the advantage of allowing investigation of the causes of MOVs but are limited in their generalizability, since they only include people who visit health facilities, and exclude children who don't seek care, are marginalized, or live in remote areas. By contrast, MOSVs can be assessed by appropriate analyses of household surveys that collect information on dates of each vaccine received, allowing estimation of their impact at the population level on coverage and on median age at vaccination [8] [20] [25] [26]. DHS as well as MICS, offers survey data, and plays a great role in the identification of immunization service quality indicators, standing as a mean of achieving Sustainable Development Goal (SDG) *i.e.* SDG3: Ensure healthy lives and promote well-being for all at all ages, which directly includes immunization, maternal and child health, and disease prevention. Methods for analyzing MOV from survey have been documented and first analyses and demonstration highlighted from some surveys [8] [26] [27].

Although several countries have not yet integrated MOVs (Missed Opportunities for Vaccination) into their programs, this methodology is still not widely adopted.

MOV assessment is not listed among the standard analyses for a vaccination coverage survey but is listed as an additional analysis [8]. Neither DHS nor MICS reports MOV outcomes routinely. Nigeria was a notable exception, having included analyses of missed opportunities for simultaneous vaccination (MOSV) in

its main MICS reports in 2016 and 2021 [7] [26]. Otherwise, analyses of MOV or MOSV using DHS and MICS data have been conducted exclusively through secondary data analysis [28]. This means that the programmatic insights gained from examining MOSVs are typically made available to stakeholders after the release of the main vaccination coverage results. Since 2021, Cameroon has strengthened its commitment to addressing population health needs [25] [29] [30]. In the area of immunization, a key strategy supporting this effort is the triangulation of survey data to better identify children eligible for vaccination and those missed by routine services. MICS data, like DHS and other household survey sources, enable the tracking of performance indicators such as zero-dose status and dropout rates, thereby providing critical evidence to guide immunization planning and program improvement.

To complete this picture, quality indicators are also included namely, vaccination timeliness, timeliness and completeness of reporting, and missed opportunities for vaccination (MOVs). Their estimates provide insight into the number of eligible children who remain unvaccinated, as well as the frequency of missed doses. Other MOV-related indicators include visits that resulted in missed opportunities.

However, analyses of timeliness indicators and MOV using MICS data have been largely absent from both peer-reviewed literature and policy reports in Cameroon. This study therefore seeks to fill this gap by conducting a comprehensive analysis of vaccination timeliness and missed opportunities for vaccination using the Cameroon MICS 2014 dataset. By identifying patterns and associated factors, the study aims to apply and illustrate a combination of statistical methods for analyzing vaccination timeliness and missed opportunities for vaccination (MOV) using data from the MICS Cameroon 2014 survey. The objective is to demonstrate how retrospective datasets can be used to develop analytical approaches that inform the interpretation of future survey results and support more effective planning of immunization services in similar settings.

2. Methods

2.1. What Is Known from MICS5 2014

The Multiple Indicator Cluster Survey (MICS 5) of Cameroon was conducted in 2014 by the National Institute of Statistics in collaboration with the Ministry of Public Health, as part of the global MICS program. Technical support was provided by the United Nations Children's Fund (UNICEF) [31]. Based on the standard MICS5 vaccination module and Cameroon's EPI schedule, the following vaccines were assessed in the survey: BCG (Bacillus Calmette-Guérin); Polio vaccines: Oral Polio Vaccine at birth (OPV), Pentavalent vaccine (DTP-HepB-Hib1-3), Pneumococcal Conjugate Vaccine (PCV) (e.g., PCV1-3), Measles-containing vaccines: Measles-Rubella (MR), and vitamin A supplementation administered between 6 and 11 months, and every 6 months. The 2014 MICS reported 67% of children aged 12 to 23 months with vaccination records seen [31].

2.2. Methodological Framework

2.2.1. Data Filtering and Selection Process

We combined datasets from households, women and children to extract all necessary child's characteristics. All children aged 12 to 35 months who were alive at the time of the survey were selected.

Vaccination dates indicating a year of birth later than 2014 were classified as missing and removed from the analysis. Additionally, new categories were created for cases where the recorded vaccination day exceeded 31. In these instances, the vaccination record was typically represented by a check mark, a caregiver's recollection, a "don't know" response, or was simply absent. These details played an important role in calculating missed opportunities for vaccination (MOV), as they helped to identify children with valid vaccination dates (day, month, and year).

2.2.2. Data Analysis

We provided percentage of children with vaccination cards, zero-dose children, and percentage of children in the various sources of vaccination (cards, tick-mark, and recall). Subsequently, we selected children with vaccination cards containing at least one recorded vaccination date; this group served as the denominator for calculating cumulative vaccination coverage, vaccination timeliness indicators, and timely-and-complete indicators. Vaccination timeliness was defined in three distinct categories: early, on time and delay. Early doses are those administered before the minimum age of vaccination; on time administration referred to doses given within the window of opportunity *i.e.*, the child reached the minimum age and was vaccinated before the minimum age and 30.5 days (maximum age); and delayed doses are those provided after the maximum age (**Table S1**).

Vaccination completeness was calculated as the percentage of children who received BCG, OPV0-3, Penta1-3, PCV1-3, measles, and yellow fever. Timely-and-complete indicators were defined as those who were completely vaccinated and received the vaccine on time. The percentage of this indicator was calculated for unique dose, and doses in a series (Penta1-3; OPV1-3, Pcv1-3). identifying how many children were protected on time, which is crucial for early protection against vaccine-preventable diseases. For Penta3, confidence intervals accompanied percentage vaccinated on time for each region.

An overall estimate of MOSV, regardless of characteristics, was calculated, along with an adjusted value (estimated using the traditional random-effects meta-analysis of proportions) [32], and its associated 95% confidence interval. Then, these indicators were stratified by age group, vaccine dose, and other characteristics such as the child's sex, region of origin, place of residence, mother's education level, place of birth of the child, household wealth quintile, and others such as skilled birth attendance and prenatal characteristics. Sub-indicators of MOSV included uncorrected MOSV, and all corrected MOSV computed from the total sample of children who experienced at least one MOV for any vaccine. Uncorrected MOSV refers to the proportion of children who experienced at least one

MOV for any vaccine, and who remained unvaccinated for those missed doses by the time the survey began. In contrast, all corrected MOSV applies to any child who experienced an MOSV and had time to receive all missed vaccine doses before the survey started. Additionally, sub-indicator (that can be deduced from the three others) included "Some BUT not all MOV corrected", which is the proportion of children who experienced at least one MOSV, but did not receive all previously missed doses before the survey commenced [8]. Furthermore, the frequency of missed doses was calculated as recommended by WHO 2018, by assessing the number of vaccination dates where children experienced simultaneous missed opportunities for vaccination (MOV). Additionally, the percentage of vaccination dates with missed doses, as well as the frequency of visits resulting in MOV, were analyzed.

We included variables linked to domestic violence, hypothesizing that mothers facing challenges like missed opportunities for vaccination (MOSV) of their children might also be experiencing mental health issues [33]. To construct the domestic violence score, we applied multiple component analysis (MCA) to a set of ordinal variables capturing women's reported experiences of intimate partner violence, including emotional, physical, and sexual violence (e.g., humiliation, threats, physical assault, forced sexual acts). All variables were coded consistently so that higher values indicated greater exposure to violence. MCA was used to reduce these correlated indicators into a single composite score representing overall intensity of domestic violence. The first principal component, which explained the largest proportion of variance across items, was retained as the violence score. This continuous score was then categorized into quartiles to facilitate interpretation and to allow association with other qualitative variables: higher quartiles indicated increasing levels of exposure to domestic violence. A binary score was also considered by splitting the score using the median value.

An essential indicator highlighted was the proportion of children with uncorrected MOSV, representing the percentage of children who missed one or more vaccines and remained unvaccinated by the time the MICS survey commenced. This indicator is crucial as it reveals the part of the population that vaccination campaigns have not yet reached. Qualitative variables were presented as effective frequency with proportions; quantitative variables were described using median and interquartile range. Pearson Chi-squared test or Fisher exact test were used to compare proportions, and Wilcoxon-Mann-Whitney test for comparing group means.

To better understand the factors contributing to missed opportunities for vaccination, uncorrected MOSV status was used as the dependent variable, with a step-by-step logistic regression guiding the process of variable selection. Independent variables were child, maternal, and household characteristics. Significant predictors identified during this process were then incorporated into a decision tree model [34]. Additionally, interaction effects with the child's sex were evaluated to determine any possible influence before integrating the variables into the

decision tree. This gender-sensitive approach enabled an analysis of whether risk profiles and decision-making pathways differed between boys and girls. This, in turn, helped to identify potential gender-related disparities in vaccination coverage.

All MOV and sub-sequent analyses were coded using R version 4.5.0 following VCQI specification guidelines [27] [35].

2.3. Results

2.3.1. Description of the Sample Studied

A detailed flowchart of the selection process is presented in **Figure S1**. In total, 2214 children aged 12 to 35 months were surveyed, of whom 1447 (373 + 1074 = 51.8%) had vaccination records with at least one documented date *i.e.*, 65.3% of card ownership (95% CI = 63.3 - 67.3), suggesting a total of 767 (34.7%) of children never vaccinated (zero-dose) (**Table S1**). In this targeted sample, the sample size varied by antigen from 1115 for yellow fever to 1403 for OPV1, indicating that 2.2% not vaccinated for yellow fever and 0.22% for OPV1 (**Table S2**).

2.3.2. Cumulative Coverage

The cumulative coverage curves presented in **Figure S2** are based exclusively on children whose vaccination cards were seen and included dates, which typically represent the most reliable source of immunization data. As expected, overall coverage levels appear relatively high across most antigens. Birth vaccines such as BCG and OPV0 show a steep and early rise in coverage, indicating that these doses are generally administered on time. However, for multi-dose vaccines such as OPV, PENTA, and PCV, timeliness tends to decline progressively with each additional dose, as reflected by the flattening of the curves.

More striking delays are observed for MCV1 and Yellow Fever vaccines. Although MCV1, expected at 9 months, eventually reaches close to 65% - 70% coverage (**Figure S2**), the gradual slope suggests delays in timely administration. Yellow Fever coverage remains notably lower, with slow uptake and a final coverage under 75% by 12 months. These patterns highlight the importance of considering timeliness in addition to coverage, especially when using high-quality data from children with dated cards. The analysis underscores how even in settings where documentation is available, delayed vaccinations and missed opportunities persist emphasizing the value of integrating timeliness metrics into survey-based assessments.

2.3.3. Timeliness and Completeness Indicators

1) Vaccination timeliness among children 12 to 35 months

Children were receiving vaccine doses as recommended. However, there were instances of both early and delayed doses. Among the children who received the vaccines, on time fell short of the percentage of card ownership, ranging from a high of 61.7% for Penta1 to a low of 34.7% for BCG, suggesting the highest proportion of delayed doses for BCG, reaching 65.3% (**Figure 1**). Timeliness for the third dose of the pentavalent vaccine (Penta3) varied considerably across regions, highlighting

disparities in the continuity of vaccination services. It ranged from as low as 26.8% (95% CI: 20.1 - 34.8) in the Far North region to 75% (95% CI: 53.6 - 71.2) in the Douala region (Figure S3). As Penta3 timeliness is a critical indicator of both service delivery efficiency and adherence to the recommended immunization schedule, these variations suggest systemic challenges in ensuring timely completion of multi-dose vaccines. Poor performance on this indicator may reflect missed opportunities, delayed follow-up, or inequities in access to care.

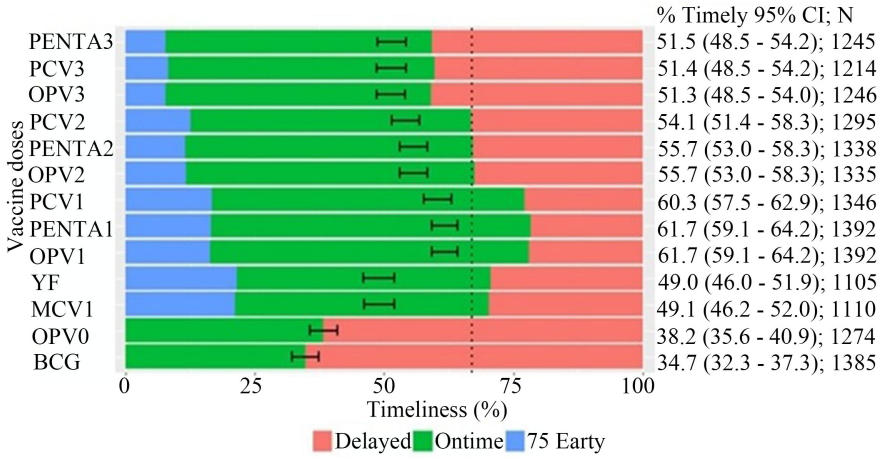

Figure 1. Percentage of children who received vaccine earlier, on time, or vaccination delayed among children aged 12 to 35 months, MICS 2014, Cameroon.

2) Timely and completeness among children aged 12 to 35 months

Among the surveyed children, 66.1% (956/1447) (95% 63.6 - 68.5 CI = 63.6 - 68.5) were completely vaccinated on cards seen of all key vaccines (Table 1), among which only 11.3% (108/956) (95% CI = 9.4 - 13.5) received vaccine on time (Table 1). Among participants with cards seen, 1334 (92.2%) received week-6 vaccine, reflecting high contact rate with health facility after birth (Table 1). Timeliness and completeness for these antigens were generally above 80%. However, when focusing specifically on Penta3, only 56.7% (1255 children) had received the dose, and among them, just 46.1% were both timely and complete. While more than 60% of children received BCG, only 27% received it within the recommended time frame *i.e.*, from birth to less than one week, indicating a significant proportion of delayed BCG administration.

Table 1. Percentage of children fully vaccinated and, who received vaccine on time among children aged 12 to 35 months, MICS 2014, Cameroon.

Vaccines N = 1447*	#children who received the vaccine dose or in the indicated characteristic (%)	n (%) children completely vaccinated and timely in vaccine administration
BCG	1396 (63.0)	377 (27)
Polio 0	1283 (57.9)	387 (30.1)
Polio 1	1403 (63.4)	492 (35)
Polio 2	1347 (60.8)	488 (36.2)

Continued

Polio 3	1256 (56.7)	630 (50)
Penta1	1403 (63.4)	547 (39)
Penta2	1350 (60.9)	630 (47)
Penta3	1255 (56.7)	584 (46.1)
Pneumo 1	1357 (61.3)	548 (40.3)
Pneumo 2	1307 (59.0)	619 (47.4)
Pneumo 3	1224 (55.3)	575 (47)
Measles 1	1119 (50.5)	585 (52.3)
Yellow fever	1115 (50.4)	539 (48.3)
All antigens**	956/1447 (66.1%) (95% CI = 63.6 - 68.5)	108/956 (11.3) (95% CI = 9.4 - 13.5)
Week-6 vaccination++	1334 (92.2)	324 (24.5%)
Zero dose 1+	767 (34.6)	NA
Zero dose 2***	44 (2)	NA
Timely-and-Complete vaccination coverage		
OPV1-3	1230	959 (78)
PENTA1-3	1336	959 (71.5)
PCV1-3	1191	959 (80)

Legend: *the sample of children aged 12 to 35 months who had home-based records, with at least one vaccination date within HBR; **for 12 to 35 months children, those who received, on cards seen, BCG, OPV0-1-3; PENTA1-3, PCV1-3, Measles, and YF; +children who received none of the antigens (among those surveyed; n = 2214); *** children (among those surveyed) who never received penta1; ++ rate of accessibility: frequency of children who received week 6 vaccines: penta1, opv1, pcv1 among card seen and dates. NA: not applicable.

2.4. MOV Indicators

2.4.1. Overall MOV Prevalence and Age Category

Among children with cards seen (12 to 35 months) with at least one vaccination date (1447), 1307 (90.3%, 95% CI = 87% - 92%) experienced one or more MOV for simultaneous vaccines (Table 2). Among those who experienced an MOSV, 12.3% (161/1307) returned to health facilities to receive all previous missed vaccines, before the survey started. In contrary, 759 (759/1307 = 58.1%) did not come back to health facilities to catch-up the previously missed vaccines (Table 2). The proportion of children who remained with previous missed doses not all received (*Some But not all corrected*) was 29.6% (computed as (1307-759-161)/1307), and 95% CI = (27.1; 32.1) (data not tabulated).

In the first year of life (12 to 23 months), 90.9% of children experienced at least one MOV for simultaneous vaccines (MOSV), while 88.5% was found in the second year (24 - 35 months) of life (Table 2). However, there was no significant difference with the prevalence of MOV in the first year of life and the second year

of life (p-value = 0.2). In addition, female children and male children experiences MOV the same as the difference in proportions was not statistically significant (p = 0.2) (Table 2). With regards to this nonexistence of difference, the following results are based on the whole sample.

We adjusted the MOSV prevalence by region using a simple meta-analysis of proportions:90% (95% CI = 84% - 94%) of overall MOV for simultaneous vaccines among which 61% (95% CI = 53% - 69%) were MOSV uncorrected, and only 12%; 95% CI = 8% - 16% had all the MOSV corrected before the survey began (Table 2).

Table 2. Overall MOV prevalence (raw and adjusted) by age category, and regions, and residence; Cameroon MICS, 2014.

		Had MOSV (%)			Had MOSV only uncorrected (%)			Had MOSV all corrected (%)		
Characteristic	**Overall**	**YES**	**NO**		**YES**	**NO**		**YES**	**NO**	
MOV	N = 1447	N = 1307	N = 140	**p**	N = 759	N = 688	**p**	N = 161	N = 1286	**p**
Raw prevalence		(90.3)			(58.07)			(12.3)		
Adjusted prevalence*		90 (95 CI = 84 - 94)			61 (95 CI = 53 - 69)			12; 95 CI = 8 - 16		
Age category (months)				0.2			0.4			0.8
12 to 23	1073	976 (91)	97 (9.0)		560 (57.3)	513 (48)		122 (12.5)	951 (89)	
24 to 35	374	331 (89)	43 (11)		199 (60.1)	175 (47)		39 (11.7)	335 (90)	
Child's sex				>0.9			>0.9			>0.9
1	758	684 (90)	74 (9.8)		397 (58.0)	361 (48)		85 (12.4)	673 (89)	
2	689	623 (90)	66 (9.6)		362 (58.1)	327 (47)		76 (12.2)	613 (89)	
Regions; n				0.005			<0.001			<0.001
Adamaoua	149	140 (94)	9 (6.0)		63 (45)	86 (58)		24 (17.1)	125 (84)	
Centre (No Yaounde)	135	126 (93)	9 (6.7)		72 (57.1)	63 (47)		10 (7.9)	125 (93)	
Douala	128	122 (95)	6 (4.7)		82 (67.2)	46 (36)		5 (4.0)	123 (96)	
East	140	115 (82)	25 (18)		73 (63.4)	67 (48)		19 (16.5)	121 (86)	
Far-North	138	117 (85)	21 (15)		46 (39.3)	92 (67)		30 (25.6)	108 (78)	
Littoral (No Douala)	99	91 (92)	8 (8.1)		66 (72.5)	33 (33)		7 (7.7)	92 (93)	
North	164	143 (87)	21 (13)		77 (53.8)	87 (53)		28 (19.6)	136 (83)	
North-West	112	101 (90)	11 (9.8)		63 (62.3)	49 (44)		11 (10.8)	101 (90)	
West	109	100 (92)	9 (8.3)		64 (64)	45 (41)		7 (7.0)	102 (94)	
South	65	60 (92)	5 (7.7)		31 (51.7)	34 (52)		9 (15)	56 (86)	
South-West	95	87 (92)	8 (8.4)		60 (69)	35 (37)		6 (6.8)	89 (94)	
Yaounde	113	105 (93)	8 (7.1)		62 (59)	51 (45)		5 (4.7)	108 (96)	

Continued

Residence; n			0.15		0.02			<0.001
1 = Urban	718	657 (92)	61 (8.5)	402 (61.1)	316 (44)		57 (8.6)	661 (92)
2 = Rural	729	650 (89)	79 (11)	357 (54.9)	372 (51)		104 (16)	625 (86)
Residence others; n			0.072		0.05			<0.001
1 = Yaounde and Douala	241	227 (94)	14 (5.8)	144 (63.4)	97 (40)		10 (4.4)	231 (96)
2 = Other towns	477	430 (90)	47 (9.9)	258 (60)	219 (46)		47 (11)	430 (90)
3 = Rural areas	729	650 (89)	79 (11)	357 (55)	372 (51)		104 (16)	625 (86)

*adjusted using a meta-analysis of proportions of MOV among regions; p: p-value for the chi-squared test or Fisher Exact test for qualitative variables, and Wilcoxon-Mann-Whitney for group mean comparison; MOSV: MOV for simultaneous vaccines; the sum of MOSV uncorrected and MOSV all corrected, taken away from the Had MOSV is the estimate of the "Some BUT not all corrected".

2.4.2. Overall MOV Raw Prevalence and MICS Variables

1) *Across regions*

MOSV and sub-indicators varied significantly across regions ($p < 0.0001$) (Table 2). Among those who experienced an MOSV in those regions, only uncorrected MOSV was more than a half of those who experienced MOV. Indeed, in the Littoral (without Douala) region were 92% of children had at least one vaccine missed, 72.5% (*i.e.*, 66 children out of 99 who experienced simultaneous MOV) did not correct their MOSV before the survey started (Table 2). Uncorrected MOSV ranged from 39.3% (in the Far North) to 72.5% in Littoral (without Douala), and consequently in very few proportions of previous missed vaccines were administered in Douala (4%) (Table 2). Although MOSV proportions did not differ significantly between place of residence ($p = 0.15$), there was a change in the uncorrected MOSV prevalence across residence place. Indeed, children within the urban area had 61.1% of MOV uncaught, and 55% in the rural areas, and the difference in proportions was highly significant ($p \leq 10^{-6}$) (Table 2). In addition to that, children in the rural area (16%) were more likely to correct their MOV than those in the urban area (8.6%) and the difference was highly significant ($p < 0.001$) (Table 2). When disaggregating place of residence by including Yaoundé and Douala, and other towns as urban areas, we found a significant difference in all MOV indicators (Table 2).

2) *Regarding mother's education*

In the same as the MOSV prevalence was significantly different across mother's education, there was also a significant increase in the prevalence of uncorrected MOSV while moving from mothers with no education to those in the highest education ($p < 0.001$) (Table 3). In contrast, proportion of children with all corrected MOSV decreased significantly from the highest education level to below. Indeed, half of the children who experienced at least one MOSV at the lowest education level had their MOSV all corrected before the survey started (Table 3). Similar results were found in the household head education level (Table 3), as well

as for the wealth index. Indeed, MOV for simultaneous vaccine increased with the wealth index ($p < 0.001$). There was a difference in proportion of MOSV among children whose mothers experienced more than four prenatal consultations than those below ($p < 0.001$) (Table 3).

Table 3. Overall raw MOV prevalence by household and child's characteristics; Cameroon MICS, 2014.

		Had MOSV (%)			Had MOSV only uncorrected (%)			Had MOSV all corrected (%)		
Characteristics	**Overall**	**YES**	**NO**		**YES**	**NO**		**YES**	**NO**	
	N = 1447	N = 1307	N = 140	**p**	N = 759	N = 688	**p**	N = 161	N = 1286	**p**
Education*				<0.001			<0.001			<0.001
Never	274	229 (84)	45 (16)		111 (48.4)	163 (59)		56 (24.4)	218 (80)	
Primary	557	503 (90)	54 (9.7)		275 (54.6)	282 (51)		63 (12.5)	494 (89)	
Secondary	554	518 (94)	36 (6.5)		329 (63.5)	225 (41)		39 (7.5)	515 (93)	
High	62	57 (92)	5 (8.1)		44 (77.2)	18 (29)		3 (5.2)	59 (95)	
Wealth index				<0.001			0.002			<0.001
Very poor	198	164 (83)	34 (17)		80 (48.7)	118 (60)		38 (23.1)	160 (81)	
Secondary	327	291 (89)	36 (11)		158 (54.3)	169 (52)		52 (17.8)	275 (84)	
Middle	299	264 (88)	35 (12)		153 (58)	146 (49)		26 (9.8)	273 (91)	
Rich	345	323 (94)	22 (6.4)		190 (58.8)	155 (45)		30 (9.2)	315 (91)	
Richest	278	265 (95)	13 (4.7)		178 (67.2)	100 (36)		15 (5.6)	263 (95)	
Education**				0.047			<0.001			0.0001
Never	249	213 (86)	36 (14)		97 (45.5)	152 (61)		44 (20.6)	205 (82)	
Primary	575	518 (90)	57 (9.9)		295 (56.9)	280 (49)		60 (11.6)	515 (90)	
Secondary	517	476 (92)	41 (7.9)		294 (61.7)	223 (43)		53 (11.1)	464 (90)	
High	101	95 (94)	6 (5.9)		71 (74.7)	30 (30)		4 (4.2)	97 (96)	
Missing	5	5	0 (0)		2 (40)	3 (60)		0 (0)	5	
Place of delivery				0.03			0.06			<0.001
Respondent's home	378	332 (88)	46 (12)		163 (49.1)	215 (57)		68 (20.4)	310 (82)	
Other home	43	33 (77)	10 (23)		19 (57.5)	24 (56)		4 (12.1)	39 (91)	
Public hospital	342	315 (92)	27 (7.9)		191 (60.6)	151 (44)		24 (7.6)	318 (93)	
Public health center (CSI/CS/PMI/Dispensary)	264	240 (91)	24 (9.1)		144 (60)	120 (45)		31 (13)	233 (88)	
District Medical Center (CMA)	35	30 (86)	5 (14)		16 (53.3)	19 (54)		7 (23.3)	28 (80)	
Other public medical facility	6	6	0 (0)		3 (50)	3 (50)		0 (0)	6	
Private non-religious hospital	45	42 (93)	3 (6.7)		24 (57.1)	21 (47)		4 (9.5)	41 (91)	
Private faith-based hospital	105	96 (91)	9 (8.6)		62 (64.6)	43 (41)		10 (10.4)	95 (90)	
Private non-religious clinic	54	51 (94)	3 (5.6)		33 (64.7)	21 (39)		3 (5.8)	51 (94)	
Faith-based/missionary health center or dispensary	138	131 (95)	7 (5.1)		87 (66.4)	51 (37)		8 (6.1)	130 (94)	

Continued

Medical office/private practice	6	6	0 (0)	4 (66.6)	2 (33)	0 (0)	6	
Other private medical facility	12	10 (83)	2 (17)	6 (60)	6 (50)	1 (0.1)	11 (92)	
Don't Know	7	4 (57)	3 (43)	0 (0)	7	1 (25)	6 (86)	
Missing	12	11 (92)	1 (8.3)	7 (63.6)	5 (42)	0 (0)	12	
Mode of delivery			0.5		0.3			0.4
1 = Cesarian	45	43 (96)	2 (4.4)	30 (69.8)	15 (33)	2 (4.6)	43 (96)	
2 = No cesarian	965	887 (92)	78 (8.1)	543 (61.2)	422 (44)	86 (9.7)	879 (91)	
9	9	8 (89)	1 (11)	4 (50)	5 (56)	0 (0)	9	
Unknown	428	369	59	182	246	73	355	
Skilled birth attendance			0.5		0.5			0.001
Medecins	216	200 (93)	16 (7.4)	119 (59.5)	97 (45)	15 (7.5)	201 (93)	
Nurse/Midwife	727	669 (92)	58 (8.0)	405 (60.5)	322 (44)	61 (9.1)	666 (92)	
Assistant nurse	325	305 (94)	20 (6.2)	190 (62.3)	135 (42)	36 (11.8)	289 (89)	
Nursing aide/Auxiliary nurse	78	68 (87)	10 (13)	45 (66.1)	33 (42)	8 (11.7)	70 (90)	
Traditional birth attendant	109	90 (83)	19 (17)	48 (53.3)	61 (56)	21 (23.3)	88 (81)	
Community health worker	13	12 (92)	1 (7.7)	9 (75)	4 (31)	1 (8.3)	12 (92)	
Prenatal consultation			<0.001		0.17			0.08
More than 4 = 0	677	639 (94)	38 (5.6)	392 (61.3)	285 (42)	63 (9.8)	614 (91)	
Less 4 = 1	637	562 (88)	75 (12)	322 (57.3)	315 (49)	74 (13.1)	563 (88)	
NA	133	106	27	45	88	22.6	109	

*Mother's education level; **Head of Household education level; NA: missing responses; p: p-value for the chi-squared test or Fisher Exact test for qualitative variables, and Wilcoxon-Mann-Whitney for group mean comparison; MOSV: MOV for simultaneous vaccines; the sum of MOSV uncorrected and MOSV all corrected, taken away from the Had MOSV is the estimate of the "Some BUT not all corrected".

3) *Regarding place of birth and prenatal consultation*

Regarding child's place of birth, the highest proportion of children who corrected their MOV was found in CMA and significant difference was found between all places of birth ($p < 0.001$) (Table 3). Among children who experienced an MOV, we found significant difference in proportion of those who caught their vaccines with the highest proportion for children born traditional birth attendant (Table 3). Indeed, there was 94% of MOV in children from four prenatal consultation against 88% in the opposite. In addition, uncorrected MOV differed slightly of 7% among those from less than four prenatal consultations than the opposite group, and this difference was highly significant ($p = 0.007$) (Table 3).

4) *MOV with delayed dose, mother's age, domestic violence, vaccination contacts*

According to delayed vaccination, and far as Penta 3 is concerned, we found significant difference between MOV uncorrected between those who delayed Penta 3 dose and those who did not $p < 0.001$) (Table S3). For the mother's social

life indicator like domestic violence, we found an increase of proportions with the increase of violence scores. Indeed, MOV prevalence was more pronounced in the highest quartile score, and the differences were significant (p = 0.034) (Table S3). This indicates that children born to mothers affected by domestic violence are less likely to update their vaccination status, as they are more prone to experiencing missed opportunities for vaccination (MOV) for any vaccine.

Moreover, 93% (657/710) of children who had vitamin A contact six months before the survey started, experienced MOV for simultaneous vaccines. Following mother's age category found in the MICS dataset, there was no significant difference of MOV proportions across ae category (p > 0.05) (Table S2). In contrary, we used different coding of age category and found that children born to mother less than 25 years old were more likely to return to health facility (p < 0.001) (Table S3). Religion and vitamin A contact had significant difference in the proportions of MOV (Table S2). Indeed, children who never had vitamin contact had 0.88 probability of experiencing an MOV (Table S3).

2.4.3. MOV by Dose and Percentage of Vaccination Dates with MOV

Among children who were eligible for a dose, MOV occurred in 4% to 57% of them (Table 4). Indeed, MOV for Pneumococcal-conjugate-vaccine (PCV1) at 6-week was 57.1% following by the yellow fever with 53% of children who experienced an MOV among 939 eligible children in the sample. Among them, more than 90% (465/498) did not have chance to be vaccinated from previous missed dose before the survey commenced. Birth doses revealed 52.87% of MOV for OPV0. In the same line, more than 85% of children left without receiving them before the survey. Among those who experienced MOV for Penta3, *i.e.*, 287 (23.7%), 160 (55.8%) did not come back to the health facility to receive previous missed vaccines (Table 4).

Table 4. Prevalence of dose-based Missed Opportunities for Vaccination (MOV) among children aged 12 to 35 months, Cameroon MICS 2014.

	Vaccine doses	Eligible children*	# Had MOV	% Had MOV	# Had Uncorrected MOV	% Had Uncorrected MOV	# Had corrected MOV	% Had corrected MOV
Birth doses	BCG	1413	56	3.96	50	89.29	6	10.71
	OPV0	1411	746	52.87	652	87.4	81	10.86
6-week doses	OPV1	1402	103	7.35	99	96.12	4	3.88
	PENTA1	1387	570	41.1	529	92.81	41	7.19
	PCV1	1392	795	57.11	99	12.45	68	8.55
10-week doses	OPV2	1321	106	8.02	80	75.47	26	24.53
	PENTA2	1323	271	20.48	162	59.78	109	40.22
	PCV2	1281	360	28.1	80	22.22	167	46.39
14-week doses	OPV3	1214	174	14.33	119	68.39	55	31.61
	PENTA3	1211	287	23.7	160	55.75	127	44.25
	PCV3	1286	389	30.25	119	30.59	215	55.27

Continued

9-months doses	MCV1	894	49	5.48	43	87.76	6	12.24
	YF	939	498	53.04	465	93.37	33	6.63

*Number of children who had at least one vaccination visit when they were eligible for the dose, meaning they reached the required age and the required minimum time had elapsed since earlier doses in the series; BCG (Bacillus Calmette-Guérin); Polio vaccines: Oral Polio Vaccine at birth (OPV), Pentavalent vaccine (DTP-HepB-Hib1-3), Pneumococcal Conjugate Vaccine (PCV) (e.g., PCV1-3), Measles-containing vaccines: Measles-Rubella (MR or MCV1); YF: yellow fever.

The percentage of vaccination visits resulting in an MOV varied by dose, ranging from 4.6% for BCG to 47.4% for the yellow fever vaccine (Table S4). For Penta 3, around 21% of vaccination visits led to MOV, while 26% of visits resulted in missed opportunities for the third dose of the Pneumococcal Conjugate Vaccine (PCV). Overall, out of 6535 vaccination visits, 44.24% included at least one missed vaccine dose. Additionally, the frequency of missed doses was approximately one for every 1.56 visits to the health facility (Table S4).

2.4.4. Logistic Regression and Decision Tree

1) Association between variables and All uncorrected MOSV

Given the differences observed in Table 2, Table 3, and Table S3, results from the logistic regression identified the variable related to the total number of vaccination dates, as being strongly correlated with uncorrected MOSV, along with the delayed dose status of Penta3, and the regions of Far-North and South, to which we added the variable child's sex. These variables were used to construct the decision tree shown in Figure S4, although only vaccination status emerged as the sole classification variable. Additionally, we included the sex variable through logistic regression among those selected in the final model.

The decision tree (Figure S4) revealed that the number of vaccination contacts is a strong predictor missed opportunities for simultaneous vaccination uncorrected. Among children with fewer than 5 contacts, 73% had uncaught MOV, meaning they never received the previous missed doses, while only 27% eventually caught up. This group accounted for 31% of the sample. In contrast, among those with 5 or more contacts, only 36% had MOSV uncorrected, and 64% were vaccinated later after experiencing previous missed doses. These children represented 69% of the total sample (Figure S4). This pattern demonstrates that children with fewer contacts are significantly more likely to remain unvaccinated, highlighting the importance of maintaining consistent engagement with immunization services through sensitization on the importance of vaccination attending. Strategies to improve follow-up and ensure repeated contact could play a key role in reducing persistent missed opportunities, and vitamin A contact could be alternatives.

2) Interaction between child's sex and variables

Overall (for boys and girls), children with fewer than five vaccination dates were less likely to have uncorrected (MOSV compared to those with more than five contacts (OR = 0.29; 95% CI = 0.22 - 0.39) (Table 5). Furthermore, children residing in the Far-North region faced an increased risk of experiencing an MOSV, with an

odds ratio of 1.86 compared to those in the Adamaoua region, and this result was statistically significant (p = 0.03). Similarly, children in Littoral (excluding Douala) and South-West regions demonstrated comparable risks, as their odds ratios were above 1 and the 95% confidence intervals did not include 1 (Table 5).

Table 5. Uncorrected MOSV and its association with variables across child's sex in Cameroon MICS, 2014.

	Overall; 12 - 35 m N = 1232*	Boys; n (%)	Girls; n (%)	95% Confidence Intervals			95% Confidence Intervals Boys				95% Confidence Intervals Girls			
All Uncorrected MOSV	705	370 (52)	335 (48)											
Regression terms				**Overall Odds ratios (OR)**	**Low**	**High**	**p-value**	**Odds ratios (OR)**	**Low**	**High**	**p-value**	**Odds ratios (OR)**	**Low**	**High**	**p-value**
Adamaoua	108	56 (52)	52 (48)	1.00											
Centre (No Yaounde)	124	70 (56)	54 (44)	1.54	0.89	2.66	0.12	**2.11**	**0.95**	**4.69**	0.07	1.25	0.56	2.77	0.59
Douala	125	51 (41)	74 (59)	1.52	0.87	2.64	0.14	**2.35**	**1.01**	**5.62**	0.05	1.30	0.62	2.75	0.49
Far-North	107	54 (50)	53 (50)	**1.86**	**1.06**	**3.30**	**0.03**								
East	88	44 (50)	44 (50)	1.00	0.55	1.81	0.99								
Littoral (No Douala)	95	57 (60)	38 (40)	**1.87**	**1.03**	**3.42**	**0.04**	1.57	0.70	3.53	0.27	**3.13**	**1.22**	**8.69**	**0.02**
North	133	85 (64)	48 (36)	1.08	0.63	1.84	0.78								
North-West	104	55 (53)	49 (47)	1.26	0.71	2.23	0.43								
West	102	48 (47)	54 (53)	1.44	0.82	2.57	0.21	**2.26**	**0.96**	**5.43**	0.06				
South	58	29 (50)	29 (50)	1.13	0.57	2.21	0.73								
South-West	81	42 (52)	39 (48)	**1.95**	**1.05**	**3.68**	**0.04**					**2.74**	**1.09**	**7.31**	**0.04**
Yaounde	107	56 (52)	51 (48)	1.09	0.62	1.92	0.75								
Total vaccination dates (more than 5)	934	486 (52)	448 (48)	1											
Less than 5	298	161 (54)	137 (46)	**0.29**	**0.22**	**0.39**	**$<10^{-6}$**	**0.29**	**0.20**	**0.44**	**$<10^{-6}$**	**0.28**	**0.18**	**0.43**	**$<10^{-3}$**
Delayed Penta3/NO	848	435 (51)	413 (49)	**1**											
Delayed Penta3/YES	384	212 (55)	172 (45)	**0.68**	**0.52**	**0.89**	**$<10^{-6}$**	**0.54**	**0.37**	**0.77**	**$<10^{-6}$**	0.86	0.58	1.30	0.48

*The regression with interaction was ran on 1232 participants out of 1447, because missing values on variables were not allowed in the modelling process. Indeed, these are the variables that were retained during the Stepwise regression analysis, which required complete data in the estimation process.

Notably, girls were found to be at higher risk of experiencing uncorrected MOSV in Littoral (excluding Douala) (p = 0.02) (Table 5). Additionally, while children receiving Penta3 doses very late exhibited a significantly reduced risk of uncaught vaccines (p < 0.001), this effect was notably significant only among boys

($p < 0.001$) (Table 5).

3. Discussion

This study highlights the value of examining vaccination timeliness, completeness, and missed opportunities for vaccination (MOV) together to gain a comprehensive understanding of immunization program performance and quality. While completeness measures whether a child eventually receives all vaccines, timeliness assesses whether these are administered at the appropriate ages, and MOV reflects systemic inefficiencies, when eligible children interact with health services but do not receive due vaccines. With new MICS surveys planned soon, it is essential to have methodological benchmarks, which justify the importance of this work, as it can help guide the development of future survey reports. Though not intended to guide current decisions, the methodology can be adapted to recent surveys and facility-based studies, enhancing the evaluation of immunization strategies in similar settings. Through a survey conducted in Cameroon more than ten years ago, we developed a statistical analysis plan aimed at generating estimates on missed opportunities for vaccination (MOV), to fill the critical knowledge gap on MOV in the country.

Only 65.3% of children had vaccination cards with dates, well below the WHO benchmark of ≥90% for quality monitoring [36] [37]. By 2018, this had improved to 75.2% [38]. Complete vaccination coverage in 2014 was just 66.1%, compared to 70.4% in 2018 [20]. Coverage dropped significantly around the 6 - 14 weeks visits and again at 9 months, especially for yellow fever and measles vaccines. Timeliness rates were below 80%, with only 46.1% of children receiving Penta3 on time. BCG and birth-dose polio were particularly delayed. Vaccination at week 14, particularly Penta3, is an indicator of good vaccination coverage, and this appears to be strongly dependent on the level of access to health facilities after a child's birth, which is also reflected by Penta1 coverage.

MOV prevalence was alarmingly high in 2014: nine out of ten children experienced MOSV. By 2018, this had improved, with three out of four children affected [20], *i.e.*, a statistically significant reduction ($p < 0.001$). Specific antigens were disproportionately affected by MOV: it ranged from 53.04% (for yellow fever) to 57.1% for PCV1. Many children failed to catch up with previous missed doses. For instance, over 75% of oral polio doses were still overdue at the time of the survey. The 2018 DHS similarly reported high MOV for yellow fever (91.1%) and lower levels for oral polio vaccine [20]. Uncorrected MOSV in 2014 and 2018 were 61%, and 67%, respectively; highly above a pooled estimate of 15% [6% - 24%] of uncorrected MOSV in Africa [28].

These figures suggest that from 2014 to 2023, many children remained un- or under-protected against preventable diseases, contributing to recent epidemic resurgences. Despite relatively high coverage for BCG (93%) and Penta1 (81%) in 2023, other antigens remained below 85% especially, yellow fever and MCV1 coverage ranged between 67% and 71% [1] [39]. Even for BCG, delays were common,

undermining its effectiveness [17]. These trends reflect persistent challenges in follow-up, access, and system responsiveness.

In addition to known predictors like maternal education, socioeconomic status, and residence [22] [40], this study found that regional residence, delays in Penta3, and the total number of recorded vaccination dates, as significant predictors of a child remaining unvaccinated over time after missing doses. Importantly, stratified analysis revealed gender-based differences, suggesting the need for regional and sex-specific targeting.

We found an apparent relationship between maternal exposure to domestic violence and MOV. The WHO recognizes domestic violence as a major mental health risk, often leading to post-traumatic stress disorder, which affects approximately 63.8% of women [41]-[43]. We observed that the likelihood of MOSV increased significantly with the level of domestic violence faced by the mother. First, according to current literature, children born to mothers facing post-partum mental health are more likely to be under vaccinated. Studies in high-income settings have shown that maternal mental illness is linked to lower childhood vaccination uptake and reduced adherence to recommended schedules, with children of mothers with common mental disorders having lower odds of being vaccinated at later ages compared to children of mothers without mental health conditions [44]. Third, intimate partner violence (IPV) and associated distress can impair caregiver capacity to manage complex schedules, prioritize preventive care, or navigate barriers such as travel, time constraints, and social isolation. This reduced capability can increase the risk of *uncorrected MOV*, where missed vaccines are not later caught up. Conceptually, IPV contributes both to psychosocial stress and structural constraints that jointly undermine optimal vaccination behavior. Second, violence and its psychological sequelae may undermine maternal health-seeking behavior, diminishing engagement with preventive services even when contact with health systems occurs. For example, cross-sectional analyses indicate that IPV can contribute to reduced utilization of maternal and child health services such as antenatal care and institutional delivery, which are key platforms for ensuring timely vaccination. To address these interlinked risks, it is essential to develop and deploy tools that simultaneously track vaccination status and underlying social vulnerability factors, such as maternal exposure to domestic violence and mental distress. Integrating these dimensions into routine monitoring systems can enable earlier identification of children at risk of uncorrected MOV and support targeted, proactive interventions to sustain high and equitable vaccination coverage.

4. Strengths and Limitations

This study contributes an analytical framework that can guide expansion of survey modules to cover vaccination timing, caregiver mental health, and card availability. As far as card availability is concerned, results from MOV only infer to the sample of children with cards possession, reason why the study design was not accounted

for [27]. However, we conducted regression analyses and compared results between weighted and unweighted estimates, but the direction of the effect did not change (**Table S5**). We did not cover all relevant indicators, which should be addressed in future MICS rounds. These include time-to-correct MOSV, predictors of MOV, equity assessments using MOV indicators, and models of intersectional analysis. Beyond individual and household factors, structural and contextual barriers play a critical role. Understanding why previous missed vaccines are not caught up can uncover health system delivery gaps and inform more effective, equitable strategies [45]-[48].

Regression analyses identified the total number of vaccination contacts as a key predictor of uncorrected MOSV. This indicates that, within our dataset, the model primarily distinguishes between children who followed the recommended vaccination schedule and those who failed to attend the expected number of visits. This implies that failure to return to the health facility is a critical driver of uncorrected MOSV. It underscores the need to understand barriers to follow-up, especially around the 9-month milestone, and tailor interventions accordingly.

5. Programmatic and Survey Implications

Findings from the analysis of missed opportunities for vaccination (MOV) can help improve the targeting of future immunization strategies and surveys. Specifically, results can guide the prioritization of deeper or more frequent data collection efforts in high-risk subgroups, including rural populations, low-income households, mothers with low education levels, and children attending health facility types with a high prevalence of MOSV [49]. Attention should also be given to children with only uncorrected MOSV, those who did not eventually catch up on their missed doses, as well as those born to caregivers facing mental health challenges.

Data disaggregated by district supports equity-focused interventions. Identifying common ages for delay can optimize survey design and clarify definitions of early, timely, and delayed doses for each antigen in the national immunization schedule. Household survey-based MOV assessment remains challenging, but investment in training and standardization is key. Future surveys should include health provider KAP modules to examine service quality drivers. Integrating service delivery components (e.g., growth monitoring, family planning, maternal mental health) into survey tools offers a fuller picture of system performance. Linking mental health and immunization is especially important in the post-partum period [42] [50]. Tracking MOV and timeliness over time helps refine indicators beyond coverage rates. This aligns with WHO and UNICEF recommendations to include MOV in national monitoring [51]. Such integration improves funding proposals, aligns with the Immunization Agenda 2030 (IA2030) goals, and enhances national strategy. MOV analysis disaggregated by sex, region, maternal education, and facility type exposes equity gaps. Intersectional analyses can guide gender-sensitive, context-specific strategies to reduce barriers to immun-

ization.

6. Conclusion

Though based on MICS 2014, this study presents a lasting analytical model for addressing current immunization challenges. It provides essential insights into vaccination system performance and quality, enabling future survey refinement and evidence-based planning. Incorporating timeliness and MOV into national data systems strengthens immunization strategies and equity, improving program responsiveness and impact.

Contributions to the Literature

- Analysis of Cameroon's MICS 2014 reveals a very high prevalence of missed opportunities for vaccination (MOV), exposing critical immunization gaps not captured by standard coverage indicators;
- Uncorrected MOV disproportionately affects rural populations, poorer households, and children of less-educated mothers, highlighting persistent population health inequities;
- Vaccination timeliness and MOV indicators provide essential complementary metrics for public health monitoring and immunization policy;
- Leveraging existing survey data offers a cost-effective approach to inform equity-oriented immunization planning and outbreak prevention in low-resource settings.

Authors' Contributions

The first author has an interest in the secondary use of survey databases. SWY was trained on the use of the WHO survey manual; ZF came up with the idea; SWY developed the work plan, ran the data selection process, implementation of MOV guidelines in R, and wrote the manuscript.

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Ethical Considerations

Not required.

Data Availability

The data used in this study come from the 2014 Cameroon Multiple Indicator Cluster Survey (MICS). Access to the data was granted following a formal request submitted and approved through the official MICS website (https://mics.unicef.org). Data used are publicly available upon request and fully anonymized, in accordance with UNICEF's data use policies. Ethical approval was not required for this study, as it is based on secondary data that are publicly available and fully anony-

mized, containing no identifiable personal information.

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Conflicts of Interest

None declared.

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Supplements

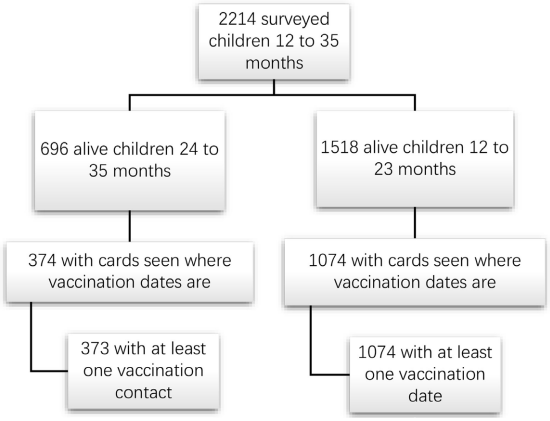


Figure S1. Flow chart of the participants from MICS 2014, Cameroon.

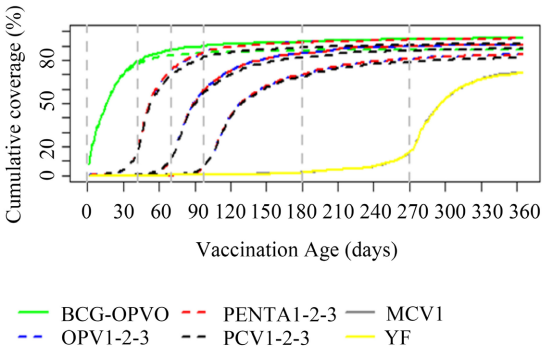
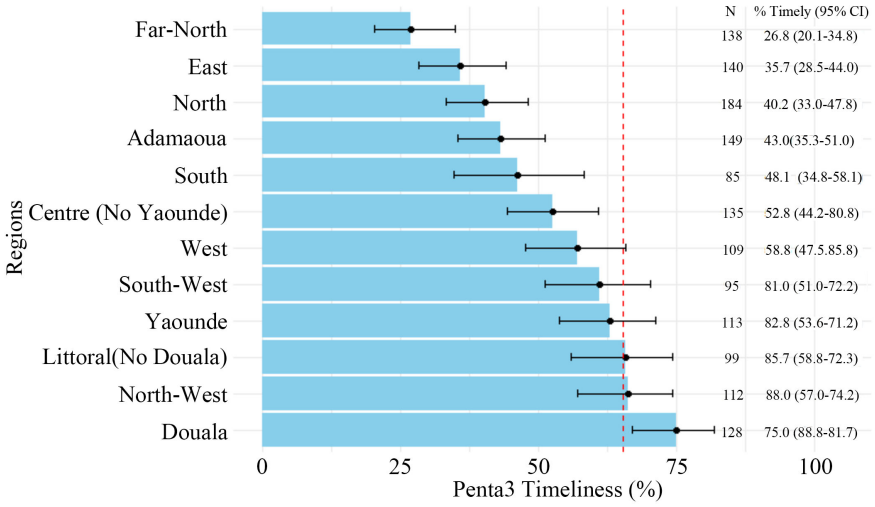


Figure S2. Cumulative coverage on cards seen with vaccination date among children aged 12 to 35 months.



Timeliness means percentage (proportion) of children who received vaccine within the window of opportunity (see **Table S1**). Dotted red line is the proportion of children with card possession that have vaccination dates (65.3%).

Figure S3. Penta3 vaccination timeliness among regions in children aged 12 to 35 months (N = 1447) Cameroon MICS, 2014.

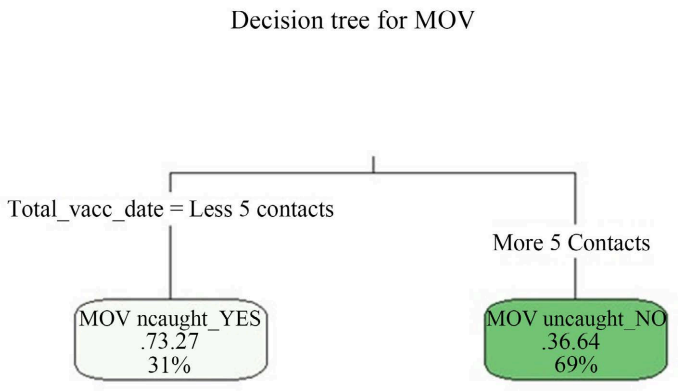


Figure S4. Final decision tree for MOV with previous uncaught vaccines, Cameroon MICS, 2014.

Table S1. Vaccination timeliness (early, on time, and delayed) and window of opportunity according the Cameroon National schedule and WHO recommendations.

Vaccines	Early (days)	On time: window of opportunity (days): min-max	Late (days)
BCG		0 - 7	>7
OPV0		0 - 7	>7
MCV1	<270	270 - (270 + 28)	>298
YF	<270	270 - (270 + 28)	>298
ROTA1	<42	42 - 72.5	>72.5
ROTA2	<70	70 - 100.5	>100.5
PENTA1	<42	42 - 72.5	>72.5
PENTA2	<70	70 - 100.5	>100.5
PENTA3	<98	98 - 128.5	>128.5
OPV1	<42	42 - 72.5	>72.5
OPV2	<70	70 - 100.5	>100.5
OPV3	<98	98 - 128.5	>128.5
PCV1	<42	42 - 72.5	>72.5
PCV2	<70	70 - 100.5	>100.5
PCV3	<98	98 - 128.5	>128.5

Table S2. Sources of vaccination for antigens from Cameroon MICS, 2014.

Vaccination status	bcg	opv0	opv1	opv2	opv3	penta1	penta2	penta3	pcv1	pcv2	pcv3	mcv1	yf
Vaccinated with date = 1	1396	1283	1403	1347	1256	1403	1350	1255	1357	1307	1224	1119	1115
Vaccinated from recall = 2	7	5	6	5	5	5	5	7	8	6	6	13	14
Don't know = 3	16	20	12	29	47	6	18	34	20	30	40	72	63
Total	1447	1447	1421	1447	1447	1447	1447	1447	1447	1447	1447	1447	1192
Total surveyed = 2214; 1447 with HBR *i.e.*, 65.3% of card possession													

Table S3. MOSV with delayed dose, mother's age, domestic violence, vaccination contacts; Cameroon MICS, 2014.

		Had MOSV (%)			Had MOSV uncorrected (%)			Had MOSV All corrected (%)		
Characteristic	**Overall**	**YES**	**NO**		**YES**	**NO**		**YES**	**NO**	
	N = 1447	N = 1307	N = 140	**p**	N = 759	N = 688	**p**	N = 161	N = 1286	**p**
Penta 3 delayed status				0.4			<0.001			0.7
0 = NO	900	840 (93)	60 (6.7)		554 (62)	346 (38)		84 (9.3)	816 (91)	
1 = YES	435	400 (92)	35 (8.0)		195 (45)	240 (55)		43 (9.9)	392 (90)	
Missing	112	67	45		10	102		34	78	
Domestic violence (in quartile)				0.034			0.7			>0.9
Q1	2	1 (50)	1 (50)		1 (50)	1 (50)		0 (0)	2	
Q2	410	364 (89)	46 (11)		214 (58.8)	196 (48)		45 (12.3)	365 (89)	
Q3	312	292 (94)	20 (6.4)		173 (59.2)	139 (45)		33 (11.3)	279 (89)	
Q4	723	650 (90)	73 (10)		371 (57.0)	352 (49)		83 (12.8)	640 (89)	
Grouped quartiles				0.068			0.5			0.8
Q1 + Q2	412	365 (89)	47 (11)		215 (59)	197 (48)		45 (12.3)	367 (89)	
Q3	312	292 (94)	20 (6.4)		173 (59.2)	139 (45)		33 (11.3)	279 (89)	
Q4	723	650 (90)	73 (10)		371 (57.0)	352 (49)		83 (12.8)	640 (89)	
Household head religion				0.017			0.07			0.13
Catholic	543	500 (92)	43 (7.9)		296 (59.2)	247 (45)		56 (11.2)	487 (90)	
Protestant	372	341 (92)	31 (8.3)		207 (60.7)	165 (44)		37 (10.8)	335 (90)	
Other Christian	315	269 (85)	46 (15)		139 (51.6)	176 (56)		44 (16.3)	271 (86)	
Muslim	101	90 (89)	11 (11)		48 (53.3)	53 (52)		8 (8.8)	93 (92)	
Animist	116	107 (92)	9 (7.8)		69 (64.4)	47 (41)		16 (15)	100 (86)	
Domestic violence				0.6			0.4			0.7
0	724	657 (91)	67 (9.3)		336 (51.1)	724		646 (98.3)	724	
1	723	650 (90)	73 (10)		352 (54.1)	723		640 (98.4)	723	
Women age (years)	26 (23 - 32)	26 (23 - 32)	25 (22 - 30)	0.2	26 (23 - 32)	26 (23 - 32)	0.7	26 (22 - 31)	26 (23 - 32)	0.069
Women age (years)				0.6			0.5			0.018
<25	575	514 (89)	61 (11)		311 (60.5)	264 (46)		55 (10.7)	520 (90)	
25 - 44	852	774 (91)	78 (9.2)		439 (56.7)	413 (48)		100 (13)	752 (88)	
≥44	20	19 (95)	1 (5.0)		9 (47.3)	11 (55)		6 (30)	14 (70)	
Vitamine A status (6 months)				0.015			<0.001			<0.001
No upatke	657	576 (88)	81 (12)		288 (50)	369 (56)		100 (17.3)	557 (85)	
Recent dose	710	657 (93)	53 (7.5)		430 (65.4)	280 (39)		53 (7.8)	657 (93)	

Continued

Dose before the most recent	14	14	0 (0)	10 (71.4)	4 (29)	3 (21.4)	11 (79)	
DontKnow	66	60 (91)	6 (9.1)	31 (51.6)	35 (53)	5 (8.3)	61 (92)	
Age group (MICS 14 coding)				0.2		0.03		0.5
<20	128	115 (90)	13 (10)	57 (49.6)	71 (55)	14 (12.7)	114 (89)	
20 - 34	1091	979 (90)	112 (10)	588 (60.0)	503 (46)	116 (11.8)	975 (89)	
34 - 49	228	213 (93)	15 (6.6)	114 (53.5)	114 (50)	31 (14.6)	197 (86)	
Total eligible vaccination date for any dose				<0.001		<0.001		<0.001
0; >=5 contacts	999	944 (94)	55 (5.5)	639 (67.7)	360 (36)	58 (6.1)	941 (94)	
1; <5 contacts	448	363 (81)	85 (19)	120 (33.0)	328 (73)	103 (28.3)	345 (77)	

p p-value for the chi-squared test or Fisher Exact test for qualitative variables, and Wilcoxon-Mann-Whitney for group mean comparison; MOSV: MOV for simultaneous vaccines; the sum of MOSV uncorrected and MOSV all corrected, taken away from the Had MOSV is the estimate of the "Some BUT not all corrected".

Table S4. Percentage of visits with Missed Opportunities for Vaccination (MOV) for each dose, and for any dose (1+ doses), Cameroon MICS 2014.

Vaccine doses	Total eligible vaccination dates*	Vaccination dates with MOV	% vaccination dates with MOV	Overall vaccination dates for any dose	#vaccination dates with MOV for any dose	% vaccination dates with MOV for any dose	Sum total MOV for all doses	MOV rate
BCG	1572	72	4.58					
OPV0	3813	804	21.09					
OPV1	1685	104	6.17					
OPV2	1530	111	7.25					
OPV3	1455	188	12.92					
PENTA1	2957	586	19.82	6537	2892	44.3	4183	0.64
PENTA2	1774	287	16.18					
PENTA3	1517	316	20.83					
PCV1	3508	847	24.14					
PCV2	1882	386	20.51					
PCV3	1609	425	26.41					
YF	1090	517	47.43					
MCV1	933	57	6.11					

*Total number of vaccination date for which children were eligible for a dose.

Table S5. Comparison between unweighted and weighted estimates from the regression analyses of MICS 2014, Cameroon.

Unweighted regression with sex interaction							Survey design accounted for within sex intrecation model						
term	estimate	stderror	statistic	pvalue	conflow	confhigh	term	estimate	stderror	statistic	pvalue	conflow	confhigh
(Intercept)	1.418	0.294	1.189	0.235	0.798	2.544	(Intercept)	1.40	0.30	1.12	0.26	0.77	2.56
region_cod1:HL41	1.362	0.421	0.734	0.463	0.596	3.119	region_cod1:HL41	1.50	0.40	1.01	0.31	0.68	3.32
region_cod2:HL41	2.107	0.406	1.837	0.066	0.952	4.689	region_cod2:HL41	2.23	0.45	1.80	0.07	0.93	5.36
region_cod3:HL41	**2.349**	**0.437**	**1.956**	**0.050**	**1.007**	**5.615**	**region_cod3:HL41**	**2.50**	**0.46**	**2.01**	**0.04**	**1.02**	**6.11**
region_cod4:HL41	2.006	0.423	1.645	0.100	0.877	4.632	region_cod4:HL41	2.08	0.54	1.36	0.18	0.72	6.02
region_cod5:HL41	0.988	0.450	−0.026	0.979	0.406	2.386	region_cod5:HL41	0.91	0.47	−0.21	0.84	0.36	2.28
region_cod6:HL41	1.569	0.411	1.097	0.273	0.703	3.532	region_cod6:HL41	1.52	0.43	0.99	0.32	0.66	3.51
region_cod7:HL41	1.402	0.383	0.882	0.378	0.660	2.975	region_cod7:HL41	1.46	0.41	0.92	0.36	0.65	3.25
region_cod8:HL41	1.232	0.408	0.511	0.609	0.553	2.750	region_cod8:HL41	1.05	0.43	0.11	0.91	0.45	2.42
region_cod9:HL41	2.263	0.440	1.857	0.063	0.962	5.427	**region_cod9:HL41**	**2.56**	**0.46**	**2.03**	**0.04**	**1.03**	**6.35**
region_cod10:HL41	1.064	0.509	0.121	0.904	0.388	2.882	region_cod10:HL41	1.09	0.53	0.16	0.88	0.39	3.05
region_cod11:HL41	1.733	0.448	1.227	0.220	0.724	4.221	region_cod11:HL41	2.33	0.48	1.75	0.08	0.90	6.01
region_cod12:HL41	1.315	0.407	0.672	0.502	0.592	2.939	region_cod12:HL41	1.37	0.42	0.76	0.45	0.61	3.11
region_cod1:HL42	0.852	0.410	−0.391	0.696	0.379	1.902	region_cod1:HL42	1.00	0.43	−0.01	0.99	0.43	2.33
region_cod2:HL42	1.246	0.405	0.542	0.588	0.563	2.766	region_cod2:HL42	1.29	0.43	0.59	0.55	0.55	3.02
region_cod3:HL42	1.302	0.379	0.697	0.486	0.619	2.746	region_cod3:HL42	1.24	0.41	0.53	0.60	0.56	2.78
region_cod4:HL42	1.946	0.420	1.583	0.113	0.857	4.477	region_cod4:HL42	2.48	0.43	2.10	0.04	1.06	5.78
region_cod5:HL42	1.150	0.443	0.315	0.752	0.481	2.742	region_cod5:HL42	1.22	0.47	0.43	0.67	0.49	3.07
region_cod6:HL42	**3.134**	**0.497**	**2.299**	**0.022**	**1.219**	**8.694**	**region_cod6:HL42**	**2.88**	**0.55**	**1.93**	0.05	**0.98**	**8.48**
region_cod7:HL42	0.917	0.419	−0.208	0.835	0.401	2.085	region_cod7:HL42	0.82	0.50	−0.39	0.70	0.31	2.19
region_cod8:HL42	1.501	0.419	0.969	0.333	0.662	3.444	region_cod8:HL42	1.36	0.42	0.72	0.47	0.59	3.10
region_cod9:HL42	1.134	0.402	0.312	0.755	0.515	2.502	region_cod9:HL42	1.58	0.44	1.05	0.30	0.67	3.74
region_cod10:HL42	1.369	0.487	0.646	0.518	0.529	3.597	region_cod10:HL42	1.76	0.50	1.13	0.26	0.66	4.72
region_cod11:HL42	**2.737**	**0.482**	**2.089**	**0.037**	**1.090**	**7.311**	**region_cod11:HL42**	**2.25**	**0.54**	**1.50**	**0.13**	**0.78**	**6.51**
region_cod12:HL42	NA	NA	NA	NA	NA	NA							
HL41:total_elig [T.1]	0.299	0.205	−5.875	0.000	0.199	0.446	HL41:total_elig1	0.27	0.24	−5.57	0.00	0.17	0.43
HL42:total_elig [T.1]	**0.279**	**0.222**	**−5.738**	**0.000**	**0.179**	**0.429**	**HL42:total_elig1**	**0.25**	**0.26**	**−5.31**	**0.00**	**0.15**	**0.42**
HL41:delayedpenta3 [T.1]	**0.536**	**0.187**	**−3.346**	**0.001**	**0.371**	**0.772**	**HL41:delayedpenta31**	**0.55**	**0.21**	**−2.89**	**0.00**	**0.36**	**0.82**
HL42:delayedpenta3 [T.1]	0.864	0.207	−0.705	0.481	0.576	1.300	HL42:delayedpenta31	0.73	0.25	−1.27	0.20	0.45	1.19

HL41 = male child; HL42 = female child; conflow-confhigh = lower and upper bounds of the estimate (logOR) 95% confidence interval.