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Impact of measles vaccination strategies on vaccination rates in low-income and middle-income countries: a systematic review and meta-analysis

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ABSTRACT

Introduction While many interventions aim to raise measles vaccination coverage in low-income and middle-income countries (LMICs), their overall effectiveness and cost-effectiveness are unknown. We did a review to identify and synthesise scientific research that evaluated the impact and cost-effectiveness of measles vaccination strategies on measles vaccination coverage, timeliness, hospitalisation rates, and mortality.

Methods In this review, we searched for English-language articles published between 2012 and July 2023 in eight databases, including PubMed, ProQuest, MEDLINE (Ovid), Embase (Ovid), CINAHL, Scopus, Web of Science and the Cochrane Database of Systematic Reviews. We also included relevant grey literature sources. The review focused on studies evaluating the impact of vaccination strategies on vaccination-related outcomes in children under 5. Following Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines throughout the process, we used Covidence software to manage most review activities. Two independent reviewers screened articles, assessed their quality using the Joanna Briggs Institute guidelines and extracted data using a predefined electronic tool. We predetermined measles vaccination coverage and timeliness as the primary outcomes, with hospitalisation and mortality as secondary outcomes. A random-effects model was employed for the meta-analysis.

Results We identified 44 articles, of which 14 were included in the meta-analysis. The meta-analysis indicated that vaccination-targeting interventions such as vaccination reminders, cash incentives, community engagement and health education activities increase measles vaccination coverage (RR 1.19, 95% CI 1.10 to 1.27). Our analysis also indicated that interventions such as vaccine reminders, educational programmes and incentives improved timely vaccination. Furthermore, we identified cost-effective strategies such as geographically informed microplanning, unrestricted vial opening, supplementary immunisation activities, community engagement, outreach programmes and financial incentives.

Conclusion Most of the identified vaccination interventions significantly improve measles vaccination coverage and timeliness in LMICs while remaining cost-effective. Tailoring these interventions to local contexts is crucial for maximising their effectiveness in protecting children from measles and its adverse consequences.

PROSPERO registration number CRD42023433125.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Measles vaccination is an effective and cost-effective intervention to control the spread of measles virus.

⇒ There is low measles vaccination coverage in low-income countries although the WHO recommends 95% coverage with two doses of measles vaccination for children to control the spread of measles.

WHAT THIS STUDY ADDS

⇒ Vaccination reminder programmes, cash incentives, community engagement in planning and implementing vaccination campaigns and health promotion activities have the potential to raise timely vaccination and vaccination coverage.

⇒ On top of that, geographically informed microplanning, unrestricted vial opening, supplementary immunisation activities, community engagement, outreach programmes and financial incentives are cost-effective strategies.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The findings of our review brought a number of interventions that could potentially be effective and cost-effective in low-income settings. We suggest countries could adopt effective strategies in their local context.

⇒ Researchers could test and/or model the future effects of implementing one or more of strategies identified in this review.

INTRODUCTION

Measles is a highly contagious, vaccine-preventable disease that is caused by a virus in the paramyxovirus family.[1 2] The virus attacks the respiratory system first, then invades the

entire body, leading to illness, serious complications and sometimes death. It spreads easily through contact with infected individuals and through the air.[3] The basic reproductive number (R_0) is reported to be 12–18, making measles the most contagious disease.[4] In 2022, over 205 000 people worldwide contracted measles, with about 99% of cases concentrated in the WHO African, Eastern Mediterranean and South-East Asia regions.[5] This highlights the unequal burden of this disease on specific regions and disproportionately affects unvaccinated young children, claiming an estimated 361 lives daily.[6] Overall, measles is estimated to have caused in excess of 136 000 deaths mostly children aged under 5 years in 2022 that could have been averted with vaccines.[7]

Vaccination against measles is one of the most effective approaches to prevent the spread of measles. The WHO recommends at least 95% vaccination coverage with two doses to eliminate the virus.[8] However, globally, only 81% of 2-year-olds receive the first dose and 71% the second, leaving significant gaps in protection.[9] Countries tailor their vaccination strategies based on disease incidence and vaccine costs. Options include the measles-containing vaccine, the combined measles, mumps and rubella (MMR) vaccine (MMRV)[10] and the quadrivalent MMRV[11] that also protects against varicella. While individual and community factors influence vaccine uptake, weak health systems and broader national challenges often play a significant role in low coverage in low-income and middle-income countries (LMICs).[12 13] For instance, the COVID-19 pandemic caused a massive setback, with 61 million missed doses,[14] resulting in approximately 9 million measles cases, primarily in LMICs.[15]

Many community and national interventions have been implemented to improve measles vaccine uptake. Primary studies reported that supplementary immunisation activities (SIAs), vaccine reminder programmes and awareness creation activities could potentially raise measles vaccination coverage in LMICs.[16–18] Moreover, many of these interventions were cost-effective, demonstrating a solid return on investment.[19 20] However, despite the promising outcomes, gaps remain in synthesising evidence across diverse LMIC settings to understand the cumulative impact of these interventions on measles vaccination coverage and related health outcomes.

Although a couple of systematic reviews have synthesised evidence on the impact of various vaccination strategies on overall childhood vaccination coverage and completion in LMICs, these reviews generally lack focus on measles-specific interventions.[21 22] The results identified in these reviews suggest that interventions, including health education, vaccine reminders, financial incentives, home-based records and community leader involvement, can significantly improve overall vaccination coverage. However, these reviews have primarily focused on general vaccination outcomes and often overlooked the timeliness of vaccination, an essential factor in achieving optimal benefits. Furthermore, they have yet to exhaustively examine critical outcomes such as measles infection rates, hospitalisation and mortality.

In addition, there is a need to provide evidence that demonstrates the effectiveness of measles vaccination strategies and their cost-effectiveness, which is critical to informing policy decisions in resource-limited settings. The Measles and Rubella Strategic Plan (2012)[23] highlights the importance of supporting interventions that improve the effectiveness and cost-effectiveness of vaccination programmes.

Our systematic review aims to fill these gaps by synthesising evidence on the effectiveness and cost-effectiveness of specific measles vaccination strategies. We have focused on interventions that improve measles vaccination coverage, timeliness and associated health outcomes, including measles infection, hospitalisation and mortality. This review provides a more targeted understanding of how these interventions work in different LMIC settings, offering actionable insights for policy-makers to enhance measles vaccination efforts.

METHODS

Search strategy and data sources

We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines.[24] Our process began with formulating our review questions using the Population, Intervention, Comparator and Outcome (PICO) framework. We identified the main concepts from the PICO elements and compiled a comprehensive list of relevant key terms. We then conducted an exhaustive search for synonyms and held several discussions to ensure that our included terms were appropriate and thorough. To organise the identified terms, we employed Boolean operators (OR and AND) according to their respective categories. Additionally, we used truncation to capture all variations of root words.

We selected eight relevant databases for our systematic search, including PubMed, ProQuest, MEDLINE (Ovid), Embase (Ovid), CINAHL, Scopus, Web of Science and the Cochrane Database of Clinical Trials. To gather grey literature, we also explored websites and databases such as ProQuest Dissertations & Theses Global, GreyNet International, the WHO Library Catalogue, Google Scholar and Google. We searched Google Scholar using the main key terms (measles, vaccine, child and coverage) and by considering synonym terms of the main key terms. We also searched the reference lists of the retrieved articles to find any overlooked articles that may have been missed during the database search.

Initially, we adjusted our search terms to suit the MEDLINE (Ovid) database, identifying appropriate subject headings to enhance our access to relevant literature. We filtered our searches by publication date, study type, language and other pertinent criteria. Throughout this process, we engaged in multiple discussions within our team and sought repeated consultations with a professional librarian.

We initially developed a search strategy in MEDLINE, which was then adapted for other databases. This involved modifying our search strategy to accommodate the different syntax and indexing systems used across each database. We also adjusted the subject headings according to each database's specific guidelines.

The database was searched between 20 June 2023 and 11 July 2023. A detailed list of the search terms used in the MEDLINE (Ovid) database is provided in online supplemental file I.

Inclusion and exclusion criteria

The PICO framework summarised the eligibility criteria. The intervention recipients included children under 5 years of age eligible for measles vaccination according to their respective countries' guidelines. We examined various interventions designed to increase vaccination coverage and timeliness. These interventions included vaccine reminder programmes, incentives, vaccination campaigns (SIA), educational programmes, vial opening thresholds, vial types and other relevant strategies.

We focused on two primary outcomes: measles vaccination coverage and timeliness of vaccination. Timeliness was assessed relative to each country's specific measles vaccination schedule and the window period suggested by the included studies. The secondary outcomes we included were measles infection, measles-related hospitalisations and deaths. Additionally, for economic evaluation studies, we considered averted measles cases, disability-adjusted life-years (DALYs) and deaths.

We included study designs that allow comparisons between two or more groups including randomised controlled trials (RCTs), cluster-RCTs (cRCTs), quasi-experimental studies, observational studies with comparison group and economic evaluations published in English in or after 2012 (aligned with WHO's Measles and Rubella Strategic Plan).[23] We excluded case reports, case series, animal studies, review articles, editorials and retracted papers. Our synthesis incorporated studies conducted in lower, lower-middle or upper-middle-income countries as defined by the previous and current World Bank classifications.[25]

Screening and data extraction

We used Covidence[26] a web-based systematic review software for deduplication of entries, as well as title and abstract screening, full-text evaluation and data extraction. After removing all duplicates, two independent reviewers, KY and FTB, screened titles and abstracts, followed by a full-text review. Disagreements were resolved through consensus and with the involvement of a third reviewer, AM. The reviewers recorded their reasons for excluding articles during full-text screening.[24]

We extracted data in Covidence using an adapted comprehensive data extraction checklist for both interventional RCT and non-RCT studies, sourced from the Cochrane Library (online supplemental file II).[27] This checklist was crucial in ensuring a systematic and thorough approach to data collection, enabling us to capture relevant information across all studies consistently. Two authors, KY and FTB, piloted the tool, extracted data from four preliminary studies and subsequently compared their findings to ensure consistency and accuracy. Based on this pilot, we made a few adjustments to the checklist to accommodate issues related to our systematic review.

For critical appraisal, we used the Joanna Briggs Institute critical appraisal tools specific to each study design.[28] The studies were then classified into three categories based on the proportion of 'yes' responses to the appraisal questions: low, moderate or high risk of bias. A study was rated as 'low' risk of bias if it had 80% or more 'yes' responses to the relevant questions, indicating good methodological quality. A study was rated as 'moderate' risk of bias if it scored between 60% and 79% 'yes' responses, suggesting some methodological limitations. Finally, a study was classified as 'high' risk of bias if it scored less than 60% 'yes' responses, reflecting significant concerns regarding its quality.

Two reviewers (KY and FTB) independently conducted the data extraction and critical appraisal. Any discrepancies were resolved through discussion and the involvement of a third reviewer (AM). The critical appraisal results are presented in online supplemental file III tables 1–5.

Data synthesis and presentation

Considering the diversity in intervention types, we used Stata V.14 for descriptive statistics (StataCorp)[29] and R-studio V.4.1.1 (RStudio Public Benefit Corporation)[30] for meta-analysis. Additionally, we used QGIS V.3.23.3 (QGIS Development Team, Open Source Geospatial Foundation Project)[31] to visualise the geographical distribution of the included studies. We conducted a meta-analysis for RCT, cRCT and quasi-experimental studies due to their robust methodologies to measure the effect of strategies. At the same time, we narratively synthesised findings from observational studies because of the diversity in outcomes and interventions. Similarly, findings of economic evaluations are presented in a table alongside a narrative synthesis.

We conducted a meta-analysis for the primary outcome, measles vaccination coverage. However, due to variations in how timeliness was defined across studies, high heterogeneity and wide CIs, we opted to narrate findings related to timeliness. Similarly, for the secondary outcomes of mortality and hospitalisation, we chose a narrative synthesis approach due to potential limitations in statistical power and heterogeneity.

Intervention types associated with each outcome category were considered subgroups in the meta-analysis. The treatment effect of the interventions was estimated using risk ratios (RR) with their corresponding 95% CI. We applied random effect meta-analysis to account for heterogeneity and presented the findings using forest plots. The heterogeneity

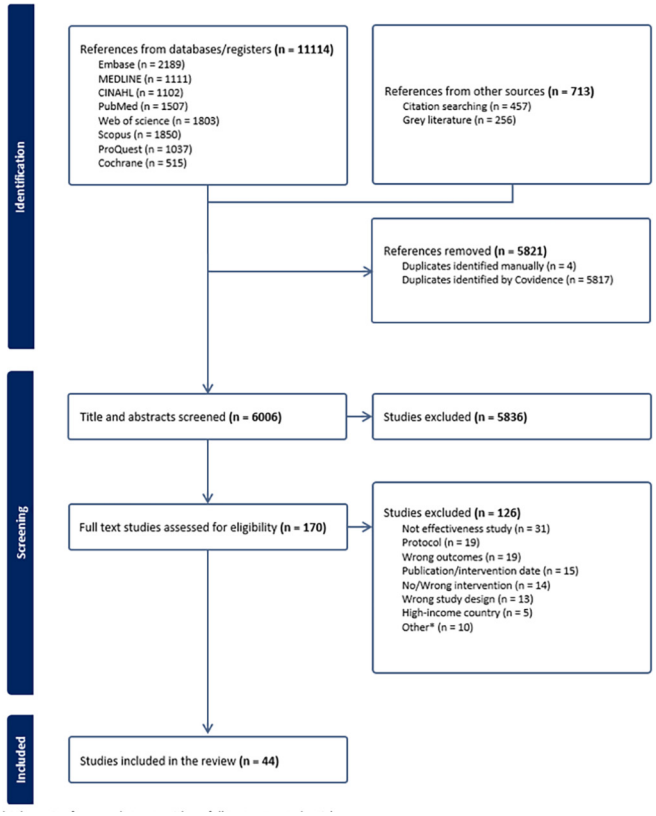


Figure 1 PRISMA flow diagram indicating the review process. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

between studies and subgroups was assessed by Higgins I^2 statistic. We assessed potential publication bias using Egger's regression test. The p value from Egger's regression test was slightly higher than 0.05, suggesting no significant publication bias (online supplemental file IV). Additionally, for studies classified as high risk of bias in the meta-analysis, we performed a sensitivity analysis by excluding these studies to assess their impact on the results. The analysis showed that the overall RR remained almost unchanged (1.18 (95% CI 1.08, 1.30)), indicating that the high-risk studies did not substantially affect the overall findings.

Patient and public involvement

Patients or the public were not directly involved in this systematic review.

RESULTS

Description of included studies

Our database and citation search identified 11 827 published articles and grey literature. After deduplication, we screened 6006 unique records. 44 research articles met all inclusion criteria and were included in the data synthesis (figure 1).

Of the 44 studies, 28 (64%) were in the WHO African region, with 8 studies in Nigeria and 6 in Guinea-Bissau (figure 2). 11 (25%) were cRCT, 9 (20.5%) RCTs, 11 (25%) were quasi-experimental, 10 (22.7%) were economic evaluation and the rest were observational studies. Regarding interventions, 38 (86.4%) implemented a single intervention, 5 (11.4%) tested 2 interventions and 1 study (2.7%) employed 3 interventions, resulting in a total of 51 interventions analysed. The most frequent intervention types were vaccine reminders (31.4%), followed by vaccination

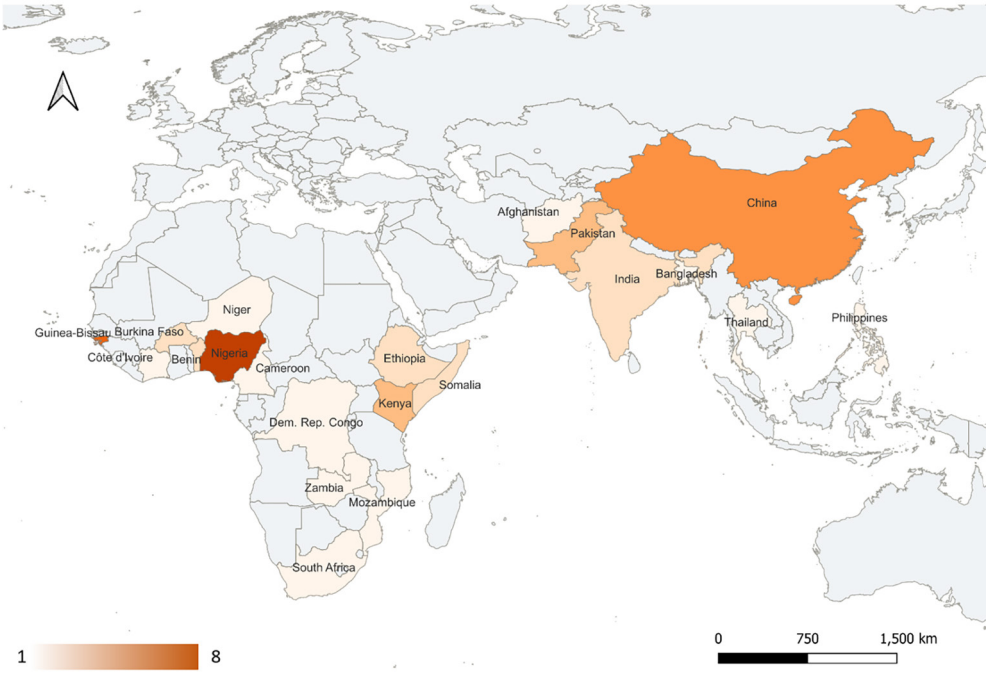


Figure 2 Geographical distribution of included studies.

campaigns (15.7%) and financial incentives (13.7%) (table 1).

Effect of strategies on measles vaccination coverage

We found that measles vaccination interventions raised vaccination coverage by 19% (RR 1.19; 95% CI 1.09 to 1.29), but there was a high study and subgroup heterogeneity (overall studies I^2: 95%).

The pooled result of 11 interventions[16 32–39] indicated that vaccine reminder programmes using mobile phone call and text message increased measles vaccine coverage (RR 1.19, 95% CI 1.05 to 1.36). Six studies examined financial incentives in the form of conditional and unconditional cash transfer programs[32 33 37 40 41] and found a 13% increase (RR 1.13, 95% CI 1.00 to 1.28). Similarly, three subgroups, each consisting of a single study, found that engaging traditional and religious leaders (community-engagement), tracking of demographic changes and immunisation status (information management) and improving the knowledge of caregivers with health education (knowledge) positively raised measles vaccination coverage (figure 3).

In addition to the studies included in the meta-analysis, we reviewed six quasi-experimental studies that assessed the vaccination coverage preintervention and postintervention,[42–47] two analytical cross-sectional studies[48 49] and one cohort study.[50] Two studies using telephone-assisted vaccination reminder programmes[50 51] reported significant increases in measles vaccination completion rates. Similarly, two health education programmes[43 48] and two studies on school entry vaccination checks[42 45] reported significant increases in measles vaccination coverage. Additionally, researchers found positive impacts on measles vaccination coverage from outreach programmes,[49] mass vaccination campaigns[46] and price reductions[44] (table 2).

Effect of strategies on measles vaccination timeliness

Most of the included studies define timeliness as a period of 1–4 weeks from 9 months of age, except for one study that set its reference from 8 months of age. Vaccine reminders delivered via mobile phones and professional healthcare worker-led education programmes for caregivers effectively improved timely childhood vaccination. Specifically, from three studies,[35 39 41] investigating the impact of telephone-based and reminder bracelets on timely measles vaccination, two[35 39] reported significant improvements in timeliness. Knowledge improvement programmes, including in-person training for mothers and elders[52] and targeted mobile app educational content,[53] improved adherence to the measles vaccination schedule. A 150 Kenyan Shilling (US$1.50) incentive and a text message reminder improved timely vaccination (table 3).[41]

Effect of strategies on hospitalisation and mortality

Most studies found no significant impact of measles vaccination strategies on hospitalisation and all-cause mortality. While Byberg *et al*[54] found a significantly lower death because of measles vaccination campaign, two studies by Varma *et al*[17 55] did not find an effect on death and hospitalisation. Additionally, three RCTs investigating the effect of early childhood measles vaccination on all-cause mortality and hospitalisation did not find any significant effect.[56–58] A cluster-randomised trial by Byberg *et al*[59] tested the effect of restricting measles vial opening to the condition where at least six children should present to open 10-dose containing vaccine with unrestricted vial opening. The study found no significant difference in mortality rates (online supplemental file V).

Cost-effectiveness of measles vaccination strategies

Five of the 10 economic evaluations[19 60–63] employed health outcome and cost modelling techniques, while the remaining 5[54 64–67] conducted evaluations alongside interventions. From the evaluations alongside interventions, Kaucley and Levy[66] suggested routine immunisation (RI) was a cost-effective strategy. At the same time, SIA was more cost-effective in situations with a higher proportion of previously unvaccinated children. Similarly, Doshi *et al*[67] found that a two-dose SIA strategy and a two-dose RI strategy were cost-effective compared with a one-dose approach, with the RI strategy being the most cost-effective. Besides, Ali *et al*[65] uncovered that GIS-assisted microplanning (map populations and measure distances using satellite imagery) instead of relying on census figures and community distance estimates was a cost-effective strategy. Additionally, engaging traditional and religious leaders to raise acceptance and uptake of measles vaccination raised the cost-effectiveness with a minimal additional cost.[64]

Economic evaluations based on projected outcomes indicated favourable results. In Benin and Mozambique, a 30% child presentation (three children for a 10-dose vial) threshold was optimal, whereas Niger required a 60% threshold.[60] A health promotion programme using Accredited Social Health Activists was cost-effective in India.[61] Zimmermann *et al*[62] suggested that decreasing the SIA interval to every 3 years was cost-effective in specific regions of Nigeria while increasing the frequency would benefit others annually. Outreach vaccination strategy in Kenya proved cost-effective in reaching hard-to-reach communities and averting DALYs at different coverage levels.[63] An extended cost-effectiveness analysis by Driessen *et al*[19] found that while SIAs achieved higher coverage overall, routine vaccination combined with financial incentives was most effective in encouraging vaccine use among economically vulnerable populations (online supplemental file VI).

DISCUSSION

We identified interventions that increased vaccination coverage and related outcomes. These include vaccination reminders, incentive mechanisms, education programmes, mass vaccination campaigns, community

Table 1 Characteristics of included studies

Study ID	Country	WHO region	Study design	Intervention type	Intervention recipients	Outcomes
Balogun *et al* 2022[52]	Nigeria	AFR	cRCT	Knowledge	Elder women	Timeliness
Varma *et al* 2023[55]	Guinea-Bissau	AFR	cRCT	Campaign	Children under 5	All-cause mortality/ hospitalisation
Byberg *et al* 2021[59]	Guinea-Bissau	AFR	cRCT	Vial opening*	Children under 5	All-cause Mortality
Grijalva-Eternod *et al* 2023[32]	Somalia	EMR	cRCT	Incentive	Caregivers	Coverage
				Reminder	Caregivers	Coverage
Chen *et al* 2016[16]	China	WPR	cRCT	Reminder	Caregivers	Coverage
Gibson *et al* 2017[33]	Kenya	AFR	cRCT	Reminder	Caregivers	Coverage
				Incentive and Reminder	Caregivers	Coverage
Krudwig *et al* 2020[80]	Zambia	AFR	cRCT	Vial type†	Children under 5	Coverage
Varma *et al* 2020[17]	Guinea-Bissau	AFR	cRCT	Campaign	Children under 5	Outpatient consultation
Oyo-Ita *et al* 2021[64]	Nigeria	AFR	cRCT	Community engagement	Traditional and religious leaders	Coverage
Ateudjieu *et al* 2022[81]	Cameroon	AFR	cRCT	Information management	Children under 5	Coverage
Seal *et al* 2023[18]	Somalia	EMR	cRCT	Knowledge	Caregivers	Coverage
Coleman *et al* 2020[50]	South Africa	AFR	Cohort study	Reminder	Caregivers	Coverage
Ogundele and Ogundele 2018[48]	Nigeria	AFR	Cross-sectional	Knowledge	Caregivers	Coverage
Edmond *et al* 2020[49]	Afghanistan	EMR	Cross-sectional	Outreach programme	Children under 5	Coverage
Ali *et al* 2020[65]	Nigeria	AFR	EE	Information management	Health system	Cases, deaths and DALYs averted
Wedlock 2019[60]	Benin, Niger, Mozambique	AFR	EE	Vial opening	Children under 5	DALYs averted
Kaucley and Levy 2015[66]	Benin	AFR	EE	Campaign	Children under 5	Measles cases averted
Bettampadi *et al* 2019[61]	India	SEAR	EE	Community engagement	Children under 5	Cases, deaths and MCV doses
Zimmermann *et al* 2019[62]	Nigeria	AFR	EE	Campaign	Children under 5	Cases averted, costs saved
Lee *et al* 2019[63]	Kenya	AFR	EE	Outreach programme	Children under 5	Cases, deaths and DALYs averted
Driessen *et al* 2015[19]	Ethiopia	AFR	EE	Campaign, incentive	Children under 5	Measles deaths averted
Byberg *et al* 2017[20]	Guinea-Bissau	AFR	EE	Vial opening	Health system	Life years gained
Doshi *et al* 2017[67]	DRC	AFR	EE	Campaign, routine	Children under 5	Deaths averted
Oyo-Ita *et al* 2021[64]	Nigeria	AFR	EE	Community engagement	Traditional and religious leaders	Coverage
Xu *et al* 2022[53]	China	WPR	Quasi	Reminder	Caregivers	Timeliness
Duan *et al* 2018[42]	China	WPR	Quasi	School entry check	Children under 5	Coverage

Continued

Table 1 Continued

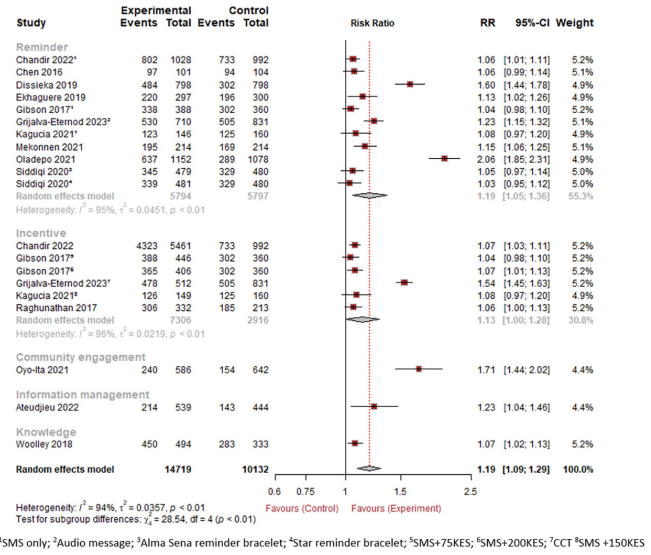
Study ID	Country	WHO region	Study design	Intervention type	Intervention recipients	Outcomes
Kaewkungwal *et al* 2015[51]	Thailand	SEAR	Quasi	Reminder	Caregivers	Coverage
Lu *et al* 2017[43]	China	WPR	Quasi	Knowledge	Caregivers	Coverage
Raghunathan *et al* 2017[40]	India	SEAR	Quasi	Incentive	Caregivers	Coverage
Woolley *et al* 2018[82]	Philippines	WPR	Quasi	Knowledge	Caregivers	Coverage
Ali *et al* 2020[44]	Pakistan	EMR	Quasi	Price reduction	Caregivers	Coverage
Zuo *et al* 2020[45]	China	WPR	Quasi	School entry check	Children under 5	Coverage
Uddin *et al* 2016[46]	Bangladesh	SEAR	Quasi	Campaign	Children under 5	Coverage
Byberg *et al* 2017[54]	Guinea-Bissau	AFR	Quasi	Campaign	Children under 5	All-cause Mortality
Oladepo *et al* 2021[34]	Nigeria	AFR	Quasi	Reminder	Caregivers	Coverage
Ekhaguere *et al* 2019[35]	Nigeria	AFR	RCT	Reminder	Caregivers	Coverage/ timeliness
Schoeps *et al* 2018[56]	Burkina Faso	AFR	RCT	Early vaccination‡	Infants	Hospitalisation/ mortality
Dissieka *et al* 2019[36]	Cote d'Ivoire	AFR	RCT	Reminder	Caregivers	Coverage
Chandir *et al* 2022[37]	Pakistan	EMR	RCT	Incentive	Caregivers	Coverage
				Reminder	Caregivers	Coverage
Nielsen *et al* 2022[57]	Guinea-Bissau	AFR	RCT	Early vaccination‡	Infants	All-cause mortality
Fisker *et al* 2018[58]	Burkina Faso and Guinea-Bissau	AFR	RCT	Early vaccination‡	Infants	All-cause mortality
Siddiqi *et al* 2020[38]	Pakistan	EMR	RCT	Reminder	Caregivers	Coverage
				Reminder	Caregivers	Coverage
Kagucia *et al* 2021[41]	Kenya	AFR	RCT	Reminder	Caregivers	Coverage/ timeliness
				Incentive	Caregivers	Coverage/ timeliness
Mekonnen *et al* 2021[39]	Ethiopia	AFR	RCT	Reminder	Caregivers	Coverage/ timeliness

*Vial opening refers to the number of children to present to open a 10-dose vial.
†Vial type refers to 5 dose vs 10 dose vial comparison.
‡Strategy to vaccinate children months before the age at vaccination as indicated in the country's vaccination schedule.
AFR, African Region; cRCT, cluster-RCT; DALYs, disability-adjusted life-years; EE, economic evaluation; EMR, Eastern Mediterranean Region; MCV, measles-containing vaccine; RCT, randomised controlled trial; SEAR, South East Asian Region; WPR, Western Pacific Region.

engagement strategies and vial opening thresholds. Among these, reminders, incentives, community engagement and knowledge improvement interventions significantly boosted coverage, with an overall 19% increase reported in this review. Notably, vaccine reminder programmes proved most effective as supported by the established knowledge that forgetting vaccination schedules is a common reason for missed or delayed vaccinations.[68] Consequently, reminder programmes, as supported by other reviews,[69 70] hold significant potential to increase vaccination uptake.

Countries set their own measles vaccination schedules based on local contexts. LMICs with high measles rates typically vaccinate children earlier compared with developed countries.[9] In this review, all studies except one used 9 months of age as the reference point for timely measles vaccination (one study in China used 8 months). Children with parents who received reminder text messages or phone calls were more likely to be vaccinated within the recommended time frame. Interventions based on mobile phones show promise as a tool to increase timely vaccination coverage. This approach has also been successful in improving vaccination timeliness for other childhood and adult vaccines.[71]

Knowledge improvement programmes and incentives positively impacted timely receipt of the first measles



¹SMS only; ²Audio message; ³Alma Sena reminder bracelet; ⁴Star reminder bracelet; ⁵SMS+75KES; ⁶SMS+200KES; ⁷CCT ⁸SMS +150KES

Figure 3 Pooled effect measles vaccination strategies on measles vaccination coverage in LMIC (2012–2023). CCT, Conditional Cash Transfer; LMIC, low-income and middle-income country.

vaccine dose, according to each country's specific schedule. Parental awareness is a crucial factor influencing childhood vaccination decisions. Therefore, behaviour change communication and related knowledge improvement programmes are essential for parents and anyone involved in vaccination decisions, particularly those with limited awareness about the importance of timely vaccination. Another study reported that financial and non-financial incentives can also motivate parents to attend vaccination clinics on time although the long-term sustainability of incentives requires further investigation.[72] Implementing a combination of these strategies can significantly increase the likelihood of timely vaccination among infants.

Our review found that most measles vaccination strategies may not lead to significant changes in child survival rates. While limited in number, studies across various regions reported no substantial impact of early vaccination, campaigns or alternative vial strategies on outpatient visits, hospitalisations or all-cause mortality; however, many contextual factors are important such as years included in the analysis, endemic measles activity and baseline measles immunisation rate. It is important to note that measuring all-cause mortality directly from a specific vaccination strategy is challenging due to other factors influencing child survival, as well as the studies not being powered for outcomes such as all-cause mortality. However, it is well established that measles vaccination itself reduces overall mortality rates, as shown in systematic reviews comparing vaccinated and unvaccinated children.[73]

Table 2 The effect of measles vaccination-related intervention on measles vaccination coverage in LMICs (2012–2023)

Author year	Intervention	Outcomes	Main finding
Coleman *et al* 2020[50]	Vaccine reminder	Measles vaccination coverage	All 87 (100%) children in the intervention group got vaccinated with measles vaccine at 9 months of age while 85 (94%) from the control group got vaccinated.
Kaewkungwal *et al* 2015[51]	Vaccine reminder	Measles vaccination coverage	Measles vaccination coverage raised from 89.2% to 89.6% after the mobile phone based reminder was implemented
Ogundele and Ogundele 2018[48]	Knowledge: health education	Measles vaccination coverage	From the included studies in the intervention area, 91.8% received measles vaccine compared with 64% in the non-intervention area. The difference was significant.
Lu *et al* 2017[43]	Knowledge: dialogue with the community, and decision-makers	Measles vaccination coverage	Coverage of one-dose measles-containing vaccine (MCV) increased from 83.8% at baseline to 90.1% after Communication for Development. Two-dose MCV coverage increased from 68.5% to 77.6%.
Duan *et al* 2018[42]	School entry check	Measles vaccination coverage	After the introduction of school entry check the coverage of MCV 2 has raised from 95.7% to 95.9% but the change was not statistically significant.
Zuo *et al* 2020[45]	School entry check	Measles vaccination coverage	MCV2 coverage at kindergarten entry increased from 53% before the policy to 98% after implementation of school entry check. The annual incidence of measles among the total population declined from 280 in 2003 per million to 0.3 per million in 2018.
Edmond *et al* 2020[49]	Outreach programme	Measles vaccination coverage	Measles vaccination coverage was significantly higher in the intervention (73.8%) than the control (57.3%) districts.
Uddin *et al* 2016[46]	Campaign	Measles vaccination coverage	Measles and rubella vaccine coverage was less than 13% before the campaign and significantly raised to 90% after the campaign.
Ali *et al* 2020[44]	Price reduction	Measles vaccination coverage	Measles vaccination coverage raised from 42% to 79% between baseline and end line.

LMICs, low-income and middle-income countries.

Table 3 Effect of measles vaccination strategies on measles vaccination timeliness in LMIC (2012–2023)

Author year	Intervention type	Timeliness defined	Main finding
Ekhaguere *et al* 2019[35]	Vaccine reminder	MCV 1 within 1 week of 9 months of age	Automated phone call and text reminders raised timely vaccination of children with measles vaccine in Nigeria (RR: 1.13, 95% CI: 1.02 to 1.26)
Kagucia *et al* 2021[41]	Vaccine reminder	MCV 1 within 2 weeks of 9 months of age	Mobile phone delivered text reminders did not have a significant effect of timeliness of measles vaccines in Kenya (RR: 1.13, 95% CI: 0.99 to 1.30)
Mekonnen *et al* 2021[39]	Vaccine reminder	MCV 1, between 4 days before and 4 weeks after 9 months of age	In the Ethiopian setting, mobile phone delivered text message raised on time measles vaccination by an absolute difference of 18.5% (one-tailed p<0.001)
Balogun *et al* 2022[52]	Knowledge	MCV 1 within 2 weeks of 9 months of age	Training given to elder women and mothers in Nigeria helped raising timely vaccination (χ^2=18.43; p<0.001)
Xu *et al* 2022[53]	Knowledge	MR within 1 month of 8 months of age	A study in China reported a mobile application-based education resulted in a better timely vaccine coverage (RR: 3.4, 95% CI: 2.0 to 5.7)
Kagucia *et al* 2021[41]	Incentive	MCV 1 within 2 weeks of 9 months of age	Additional financial incentive of 150 KES (US$1.50) raised the probability of getting timely vaccinated with measles vaccine (RR: 1.16; 95% CI: 1.01 to 1.32)

LMIC, low-income and middle-income country; MCV, measles-containing vaccine.

For wider implementation of a vaccination strategy, it is crucial to compare the relative costs and outcomes of different interventions or modelled scenarios. Cost-effectiveness analysis tells us the cost per unit of effect achieved (or achievable) when choosing a specific course of action. Decision-makers are more likely to accept a strategy if its cost per unit of benefit falls below a threshold defined by the authority's budgetary capacity.[74] Vaccinations are well established as cost-effective interventions for reducing preventable deaths and disabilities.[8] The majority of studies we included in this review identified cost-effective strategies, demonstrating their economic viability.

SIAs are crucial for catching up on missed vaccinations.[75] Compared with the significant risk of a measles outbreak, SIA campaigns offer a high return on investment, preventing a large number of cases and deaths despite the associated cost. Notably, our review found that combining SIAs with routine first-dose vaccinations is a highly efficient strategy. Furthermore, interventions like engaging community health workers and outreach measles vaccination programmes can further enhance the cost-effectiveness of measles vaccination efforts. This strategy was mentioned as one of the focus areas in the Measles and Rubella Strategic Framework 2021–2030.[76]

Poor planning is a major barrier to effective vaccination programmes in resource-limited settings.[77] Investing time and resources in the planning process can yield significant benefits during implementation. This review highlights that investing in microplanning using Geographic Information System (GIS) technology and satellite imagery significantly improves cost-effectiveness, aligning with findings of similar technology use in other LMICs.[78 79] Moreover, abandoning the strategy to require six children to present for vial opening could significantly improve immunisation rates with a relatively small additional investment that the country can afford. Recently, many countries are moving to a five-dose vial which can potentially reduce open vial wastage and increase measles vaccination coverage.[80]

The review has several strengths. First, to the best of our knowledge, this is the first review that addresses a range of experiences from different geographical settings within a varying economic category. Second, we conducted an exhaustive literature search across eight academic databases and various relevant websites to maximise the inclusion of pertinent information. Finally, we incorporated and presented comprehensive information on both the effectiveness and cost-effectiveness of measles vaccination strategies. However, the review has limitations. One limitation concerns the outcome of 'timeliness'. The definition of timeliness varied slightly across the studies as we used the authors' original definitions. The other limitation would be high heterogeneity between studies. Additionally, the Egger's test, which formally assesses funnel plot asymmetry, yields a p value just above 0.05. We would like to acknowledge the possibility of missing studies or unpublished results with minimal or negative effects. Although this suggests there is no strong evidence of publication bias (since a p value greater than 0.05 indicates no significant asymmetry), it is still important to interpret these results carefully. Lastly, we would like the readers to consider that some studies rated as high risk of bias could have slightly influenced the conclusions of this review.

Based on our findings we proposed the following policy and research implications: LMICs can adapt and pilot these programmes to assess their local suitability, effectiveness and cost-effectiveness. International aid organisations and non-governmental organisations, beyond

funding vaccine provision, could prioritise research on best practices to improve vaccination coverage and timeliness by allocating a greater proportion of funds to these programmes. This can lead to the development of better and more efficient methods for improving vaccination outcomes.

Well-planned SIAs with authentic community engagement during the planning and implementation stages would potentially avert a large number of cases, disability and deaths. Countries and stakeholders involved in childhood vaccination programmes can significantly improve planning and control of measles outbreaks by using evidence-informed decision-making. One highly effective approach is to model the future outcomes and costs of potential vaccination strategies. Furthermore, generation and synthesis of information on how underlying factors, such as malnutrition, vitamin A deficiency, and social and behavioural factors interact with measles vaccination coverage and adverse consequences. It is also crucial to investigate and address the social determinants of vaccine uptake for marginalised groups and communities, such as ethnic minorities, low-income families and those residing in hard-to-reach areas.

CONCLUSION

This review suggests that vaccination interventions in LMICs have the potential to significantly increase measles vaccination coverage and timeliness. Notably, strategies that involve vaccination reminder programmes and incentives were highly effective in raising coverage rates and ensuring timely vaccination. However, the studies did not find a direct impact of these interventions on hospitalisation and mortality rates. Building on the identified strengths of measles vaccination programmes, various strategies were found to improve their return on investment. By considering a country's willingness-to-pay threshold, cost-effective options included incorporating technology in microplanning, using incentives, engaging communities and implementing SIA campaigns.

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