HHS Public Access

Author manuscript

Vaccine. Author manuscript; available in PMC 2023 November 27.

Published in final edited form as:

Vaccine. 2021 July 30; 39(33): 4598–4610. doi:10.1016/j.vaccine.2021.05.019.

Systematic review of the costs for vaccinators to reach vaccination sites: Incremental costs of reaching hard-to-reach populations

Sachiko Ozawa[a,b,*], **Tatenda T. Yemeke**[a], **Elizabeth Mitgang**[c], **Patrick T. Wedlock**[c], **Colleen Higgins**[a], **Hui-Han Chen**[a], **Sarah W. Pallas**[d], **Taiwo Abimbola**[d], **Aaron Wallace**[d], **Sarah M. Bartsch**[c], **Bruce Y. Lee**[c]

[a]Division of Practice Advancement and Clinical Education, UNC Eshelman School of Pharmacy, University of North Carolina, Chapel Hill, NC, USA

[b]Department of Maternal and Child Health, UNC Gillings School of Global Public Health, University of North Carolina, Chapel Hill, NC, USA

[c]Public Health Informatics, Computational, and Operations Research (PHICOR), CUNY Graduate School of Public Health and Health Policy, New York City, NY, USA

[d]Global Immunization Division, U.S. Centers for Disease Control and Prevention (CDC), Atlanta, GA, USA

Abstract

Introduction: Economic evidence on how much it may cost for vaccinators to reach populations is important to plan vaccination programs. Moreover, knowing the incremental costs to reach populations that have traditionally been undervaccinated, especially those hard-to-reach who are facing supply-side barriers to vaccination, is essential to expanding immunization coverage to these populations.

Methods: We conducted a systematic review to identify estimates of costs associated with getting vaccinators to all vaccination sites. We searched PubMed and the Immunization Delivery Cost

[*]Corresponding author at: Practice Advancement and Clinical Education, UNC Eshelman, School of Pharmacy, University of North Carolina at Chapel Hill, CB#7574, Beard Hall 115G, Chapel Hill NC 27599, USA. ozawa@unc.edu (S. Ozawa).

CRediT Author statement

Sachiko Ozawa: Conceptualization, Methodology, Investigation, Supervision, Writing – Original Draft. **Tatenda T. Yemeke:** Methodology, Investigation, Data Analysis, Writing – Original Draft. **Elizabeth Mitgang:** Methodology, Investigation, Writing – Review & Editing. **Patrick T. Wedlock:** Investigation, Writing – Review & Editing. **Colleen Higgins:** Investigation, Writing – Review & Editing. **Hui-Han Chen:** Investigation, Writing – Review & Editing. **Sarah W. Pallas:** Conceptualization, Methodology, Writing – Review & Editing. **Taiwo Abimbola:** Conceptualization, Methodology, Writing – Review & Editing. **Aaron Wallace:** Conceptualization, Methodology, Writing – Review & Editing. **Sarah M. Bartsch:** Investigation, Writing – Review & Editing. **Bruce Y. Lee:** Conceptualization, Writing – Review & Editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Disclaimer

The findings in this manuscript are the views of the authors and do not represent the official position of the U.S. Centers for Disease Control and Prevention.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.vaccine.2021.05.019.

Catalogue (IDCC) in 2019 for the following costs to vaccinators: (1) training costs; (2) labor costs, per diems, and incentives; (3) identification of vaccine beneficiary location; and (4) travel costs. We assessed if any of these costs were specific to populations that are hard-to-reach for vaccination, based on a framework for examining supply-side barriers to vaccination.

Results: We found 19 studies describing average vaccinator training costs at $0.67/person vaccinated or targeted (SD $0.94) and $0.10/dose delivered (SD $0.07). The average cost for vaccinator labor and incentive costs across 29 studies was $2.15/dose (SD $2.08). We identified 13 studies describing intervention costs for a vaccinator to know the location of a beneficiary, with an average cost of $19.69/person (SD $26.65), and six studies describing vaccinator travel costs, with an average cost of $0.07/dose (SD $0.03). Only eight of these studies described hard-to-reach populations for vaccination; two studies examined incremental costs per dose to reach hard-to-reach populations, which were 1.3–2 times higher than the regular costs. The incremental cost to train vaccinators was $0.02/dose, and incremental labor costs for targeting hard-to-reach populations were $0.16–$1.17/dose.

Conclusion: Additional comparative costing studies are needed to understand the potential differential costs for vaccinators reaching the vaccination sites that serve hard-to-reach populations. This will help immunization program planners and decision-makers better allocate resources to extend vaccination programs.

Keywords

Costs; Vaccination; Immunization; Hard-to-reach; Vaccinator

1. Introduction

Global routine immunization coverage has stalled in recent years, where far too many people around the world continue to have insufficient access to vaccines, including nearly 20 million infants each year [1-4]. Recently, coronavirus disease 2019 (COVID-19) mitigation efforts that imposed limitations on population movement have interrupted mass vaccination campaigns and reduced caregivers' ability to take children for routine vaccination [3,4], further threating prior gains in immunization coverage. Improvements in immunization coverage from current levels require more concerted and targeted efforts, making immunization initiatives prioritize expansion into populations that have traditionally been undervaccinated [5,6]. The World Health Organization's (WHO) Immunization Agenda 2030 and Gavi's (the Vaccine Alliance) 2021–2025 strategy aim to extend the benefits of vaccines to everyone, everywhere [7,8]. As immunization programs consider such expansions, economic evidence on how much it may cost for vaccinators to reach different populations becomes especially important to plan vaccination programs. Studies have shown that incremental costs are greater when countries start from a high baseline immunization coverage, making it more costly to reach higher levels of coverage [9-12]. Efforts by vaccinators to reach hard-to-reach populations may be costlier than reaching the general population because of the additional efforts required, often through outreach and campaigns.

Hard-to-reach and hard-to-vaccinate populations include those that have been described in the literature as high-risk, marginalized, undervaccinated, or unvaccinated populations, and efforts to vaccinate them have been termed as “reaching the last mile” or strategies to “leave no one behind” [7,8]. Hard-to-reach populations can be described as those facing supply-side barriers to vaccination, compared to hard-to-vaccinate populations facing demand-side barriers; some populations face both supply- and demand-side barriers [13]. This study focuses on the supply-side barriers to vaccination, such as those due to geography by distance or terrain, transient or nomadic movement, healthcare provider discrimination, lack of healthcare provider recommendations, inadequate vaccination systems, war and conflict, home births or other home-bound mobility limitations, or legal restrictions [13]. Not vaccinating these hard-to-reach populations can result in high vaccine-preventable disease burden, which can thwart disease control and eradication efforts. Moreover, these populations can potentially become sources of new disease outbreaks [14,15]. Reaching such hard-to-reach populations to offer vaccination services is a necessary first step, which can directly increase coverage for populations that already have high vaccine demand and acceptance. Though beyond the scope of this review, other strategies with additional costs to address demand-side barriers would be needed to increase vaccination of hard-to-reach populations who are hard to vaccinate.

We identified four steps required for a vaccinator to reach vaccination sites. Specifically, vaccinators need to: (1) be trained to administer vaccines; (2) be willing and available to vaccinate; (3) know the location of beneficiaries; and (4) travel to vaccination sites for vaccinators to successfully vaccinate beneficiaries [16]. In order to vaccinate hard-to-reach populations, there may be additional challenges involved in each of these steps. For example, additional vaccinators may need to be hired or trained to administer vaccines in areas with weak immunization systems, or where vaccinators may not be willing or available for outreach activities [17,18]. Vaccinators may not know the specific locations of hard-to-reach populations due to poor record-keeping or population movement [19,20]. Moreover, it may be difficult for vaccinators to travel to the vaccination site due to geographic barriers, legal restrictions, or war/conflict [21-23].

While previous studies have estimated the costs of the immunization service delivery overall [9-12], prior reviews have not explored potential differential costs for vaccinators to reach hard-to-reach populations. Understanding the costs for vaccinators to reach vaccination sites and administer vaccines, especially the incremental costs for targeting hard-to-reach beneficiaries, can help with immunization program planning and ensure adequate resource allocation. This systematic review documents current evidence on the costs associated with each of the steps for vaccinators to reach vaccination sites, and how much more it may cost for vaccinators to reach hard-to-reach populations.

2. Methods

We developed search strings to identify costs associated with each step involved in vaccinators reaching vaccination sites. The costs associated with the four steps were: (1) costs for vaccinators to be trained to administer vaccines; (2) costs for vaccinators to be willing and available to vaccinate (i.e., receive salary, per diem, and/or incentives); (3)

costs for vaccinators to know the location of beneficiaries; and (4) costs for vaccinators to travel to vaccination sites. We ran separate searches for each of the four steps using terms for cost and immunization/vaccination and specific search terms related to each step. These additional search terms encompassed: (1) training; (2) salary, per diem, incentives, and labor; (3) record-keeping, registry, immunization information systems, geographic information systems (GIS), microplanning; and (4) transport, travel, outreach, campaign, and supplementary immunization activities (SIA) (see Appendix 1 for complete search terms). The search was conducted and reported according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) reporting guidelines [24].

We conducted all searches in the MEDLINE/PubMed database on May 20, 2019 and restricted the search results to human studies published in English since 2000. We additionally supplemented our search by reviewing all references compiled in the Immunization Delivery Cost Catalogue (IDCC) by the Immunization Costing Action Network (ICAN) as of October 2019 and abstracted additional studies not captured in our initial search [25]. The IDCC provides a catalogue of immunization delivery unit costs across low- and middle-income countries (LMICs), for various delivery strategies, extracted from a systematic review of peer-reviewed literature, reports, and grey literature [25]. For each step, five study members independently screened titles and abstracts and assessed full texts for eligibility, with at least two reviewers screening each study. The five study reviewers were research associates with master's level training in global health or public health disciplines. During this screening process, we eliminated papers where the content was not specific to vaccination or vaccination programs or did not include costing data disaggregated by the mechanism of interest (See Appendix 2 for a full list of inclusion and exclusion criteria). For example, we excluded studies that reported overall transport costs including costs for transporting vaccines and cold-chain equipment, for which costs specific to vaccinator travel could not be disaggregated. We focused on studies that conducted primary data collection and excluded studies that reported modeled costs. We read through systematic reviews to identify any additional studies that would meet our inclusion/exclusion criteria. The entire study team reached consensus for the inclusion of discrepant studies through discussion, based on inclusion and exclusion criteria decided *a priori*. A single study reviewer conducted data abstraction of all studies that met final inclusion. A Microsoft Excel spreadsheet form was used to extract data fields across all studies.

For each included study, we extracted information across several fields: the type of vaccines targeted or delivered; the size of the target populations; mode of intervention delivery (routine immunization or SIA); and the number of doses delivered. We abstracted all study reported costs, including overall program or intervention costs, costs per dose administered, costs per person vaccinated, or costs per person targeted by the intervention. For studies that only reported overall costs, we used the reported number of doses delivered or the size of the target populations to calculate the cost per dose administered or cost per person vaccinated/targeted. We converted all costs to 2019 $US dollars, using the consumer price index [26]. To contextualize the scale of the reported costs, we estimated each cost per dose or cost per person vaccinated/targeted as a proportion (%) of the respective study country's gross domestic product (GDP) per capita [27]. Further, for each cost per dose estimate from a LMIC, we calculated a percentage as compared to the respective country's predicted

delivery cost per dose for routine delivery of childhood vaccines [28]. We also extracted descriptive information on the setting and context in which relevant costs were collected or intervention was costed, such as whether the costs came from a national immunization program or a small-scale pilot intervention. We classified each study setting by country income status according to the World Bank [29].

We reviewed full texts of each included study to assess whether the study described costs of vaccinators to reach hard-to-reach populations based on our proposed framework for defining hard-to-reach populations for vaccination [13]. Supply-side mechanisms that made populations 'hard-to-reach' were described based on mechanisms that acted as barriers to vaccinate populations (due to geography by distance or terrain, transient or nomadic movement, healthcare provider discrimination, lack of healthcare provider recommendations, inadequate vaccination systems, war and conflict, home births or other home-bound mobility limitations, or legal restrictions) [13]. In classifying whether a study reported costs specific to a hard-to-reach population, we included any study which implicitly described such barriers, even if the study itself may not have explicitly used the term 'hard-to-reach' to describe targeted beneficiaries. For each study subsequently classified as targeting hard-to-reach beneficiaries, we noted the relevant hard-to-reach mechanism(s).

3. Results

Our initial MEDLlNE/PubMed database search yielded 967 records across the four searches for the costs associated with vaccinators reaching vaccination sites. We identified an additional 33 relevant studies in the IDCC catalogue. Screening the combined 1000 titles and abstracts for relevancy resulted in 147 studies, of which full texts were reviewed for final inclusion. We excluded 54 studies that did not describe the mechanisms of interest in our study. We further excluded 22 studies that did not include costing data or reported combined immunization cost categories that were not specific to vaccinator costs. We excluded one study that was not about human vaccination, one modeling study without primary data collection, and another study whose full text was not accessible. Fig. 1 summarizes our literature search process that led to the final inclusion of 67 studies across the four search strings, which consisted of 54 unique publications (i.e. 13 studies appeared in multiple search strings) [30-83].

Of the 67 studies included across the four search strings, 29 studies were on the costs associated with vaccinators being willing and available to conduct vaccination, 19 studies were on the costs associated with vaccinators being trained to administer vaccinations, 13 studies were on the costs associated with vaccinators knowing the location of the vaccine beneficiaries, and six studies were on travel costs of vaccinators getting to the vaccination sites. Among the 54 unique studies conducted in 57 settings, 18 studies (32%) were in low-income countries, 15 (26%) in lower-middle income countries, eight (14%) in upper-middle income countries, and 16 (28%) in high-income countries. Overall, included studies took place in 26 unique countries. Two-thirds of studies were conducted in the context of routine immunization programs (n = 38, 67%), while the remaining one-third examined costs of mass vaccination campaigns and outreach/SIAs (n = 17, 30%); two studies took place in both settings (n = 2, 3%).

Fig. 1 also summarizes the distribution of eight unique studies that described costs for hard-to-reach populations, and studies that reported the incremental costs to reach hard-to-reach populations above regular costs. Across all four search strings, only two studies reported differences in the costs to reach hard-to-reach populations through outreach/SIA compared to reaching general populations through routine immunization services [35,67]. Across the eight studies that described hard-to-reach populations for vaccination, the distribution of reported mechanisms that make a population hard-to-reach is shown in Fig. 2. Some studies described more than one mechanism. The majority of studies (n = 5) described costs of reaching populations facing geographic barriers [35,42,51,67,76], while three studies examined populations with inadequate vaccination systems [40,54,79], and one study estimated the costs to reach a transient population [35]. We did not identify studies examining the costs to reach populations facing other supply-side barriers to vaccination, such as healthcare provider discrimination, lack of healthcare provider recommendations, war and conflict, home births or other home-bound mobility limitations, or legal restrictions. Below, we describe the findings for each cost category.

3.1. Costs for vaccinators to be trained to administer vaccines

Table 1 summarizes the data extracted from 19 identified studies, which included 21 cost estimates associated with training vaccinators to administer vaccines [30-48]. We identified or calculated vaccinator training costs per person vaccinated/targeted from eight studies, where the average cost was $0.67 per person vaccinated/targeted [standard deviation (SD) $0.94]. Across country income levels, this ranged from $0.53 per person vaccinated/targeted (SD $0.64) in low-income countries (n = 5) to $0.90 per person vaccinated/targeted (SD $1.26) in lower-middle income countries (n = 3). Across five low-income countries the average costs per person vaccinated/targeted as a proportion of countries' gross domestic product (GDP) per capita was 0.055% (SD 0.059%). Among three lower-middle income countries, the average costs per person vaccinated/targeted as a proportion of GDP per capita was 0.053% (SD 0.074%). In reported cost per dose terms as a proportion of GDP per capita, average costs per dose were 0.006% (SD 0.004%) and 0.006% (SD 0.006%) across four low-income countries and across three middle-income countries, respectively. Average vaccinator training costs were $0.10 per dose (SD $0.07) across seven studies. Average vaccinator training costs were $0.06 per dose (SD $0.04), $0.16 per dose (SD $0.07), and $0.14 per dose across four low-income country studies, two lower-middle income studies, and one upper-middle income country study, respectively. Across seven cost per dose estimates from LMICs, the average vaccinator training costs per dose amounted to 5.643% (range 1.360%-9.583%, SD 2.371%) of the respective countries' predicted delivery cost per dose for routine delivery of childhood vaccines.

Among the 19 studies, we identified only three studies that described vaccinator training costs specifically targetting hard-to-reach populations [35,40,42] (Table 1). Geographic barriers to vaccination by distance or terrain were reported in two studies [35,42], while transient or nomadic movement, and inadequate health systems were each reported in one study [40]. The average vaccinator training cost in a study from Benin (low-income country) in which beneficiaries faced geographical distance and terrain barriers to vaccination was $0.02 per dose [42]. In Bangladesh (lower-middle income country) where beneficiaries in

an urban slum faced a barrier of an inadequate health system, the vaccinator training cost for an intervention to improve vaccination services and access to vaccination was $2.68 per person vaccinated [40]. The costs for training vaccinators for an intervention in Cameroon (lower-middle income country) in which beneficiaries faced distance and transient/nomadic movement barriers to vaccination was $57.47 [35]. The intervention involved vaccination outreach to the beneficiaries living in villages over 20 km from the nearest health facility, as well as a fixed site delivery strategy for the beneficiaries who lived close to health facilities [35]. This study directly compared the vaccinator training costs based on the beneficiary population targeted. Average vaccinator training costs to reach hard-to-reach populations who were targeted through outreach were $0.04 per dose, compared to $0.02 per dose for populations that lived near health facilities (incremental cost of $0.02) [35].

3.2. Costs for vaccinators to be willing and available to vaccinate

We identified 29 studies that included 36 cost estimates associated with vaccinators being willing and available to administer vaccines (Table 2) [31,32,35,37,39,41,42,45-47,49-67]. These costs consisted of labor and personnel costs, such as salaries and per diems, as well as the costs of incentives. The average costs for vaccinators to be willing and available to vaccinate were $2.01 per dose (SD $2.06) across 25 cost estimates from 19 studies. These average vaccinator costs were $0.64 per dose (SD $0.68) across eight cost estimates from low-income countries, $2.59 per dose (SD $2.25) across seven lower-middle income country cost estimates, and $1.35 per dose (SD $0.72) across five cost estimates from upper-middle income countries. Average vaccinator salary, per diem, and incentive costs rose to $4.02 per dose (SD $2.08) across five cost estimates from high-income countries. These average costs were 0.066% (SD 0.064%), 0.130% (SD 0.126%), 0.018% (SD 0.010%), and 0.007% (SD 0.004%) of countries' GDP per capita across low-, lower-middle, upper-middle, and high-income countries, respectively. Across 20 cost per dose estimates from LMICs, the average salary, per diem, and incentive costs amounted to 64.840% (range 1.117%-349.677%, SD 77.807%) of the respective countries' predicted delivery cost per dose for routine delivery of childhood vaccines. None of the studies estimated the opportunity costs of vaccinators taking time away from treating other patients.

We identified four studies that described salary, per diem, and incentive costs for the vaccinators targeting vaccine beneficiaries and caregivers who were classified as hard-to-reach [35,51,54,67] (Table 2). Three studies described geographic barriers to vaccination by distance or terrain that made beneficiaries hard to reach for vaccination [35,51,67], and one study described an inadequate health system as a barrier [54]. The average costs for vaccinators to be willing and available to vaccinate in studies targeting hard-to-reach populations were $2.05 per dose (SD $2.39) across three studies [35,51,67], and $22.58 per person targeted in one study [54].

Two studies directly compared these costs for vaccinators based on the difficulty of reaching beneficiaries. A study in Cameroon reported average vaccinator salary costs for vaccinators targeting remote hard-to-reach populations at $5.28 per dose, compared to $4.11 per dose for vaccinators targeting the general population (incremental cost of $1.17) [35]. The second study in Haiti (low-income country) reported personnel costs for vaccinators conducting

outreach in a mass vaccination campaign, targeting beneficiaries who were hard-to-reach due to geographic barriers (i.e., terrain, in a mountainous region that is difficult to traverse) [67]. The average vaccinator labor cost to reach hard-to-reach populations was $0.53 per dose, compared to $0.37 per dose for the general population (incremental cost of $0.16) [67].

3.3. Costs for vaccinators to know the location of beneficiaries

The costs associated with vaccinators to know the location of vaccine beneficiaries were identified from 13 studies involving 20 interventions (Table 3) [68-80]. These interventions included tracking and recall-reminders (n = 11), immunization registries (n = 6), and interventions using mobile phones and geospatial technology (n = 3). Average costs for vaccinators to know the location of beneficiaries were $19.69 per person vaccinated/targeted (SD $26.65) across 18 interventions. The majority (n = 16) came from high-income countries with average tracking, reminders, and registry costs at $22.01 per person vaccinated/targeted (SD $27.39). Average cost per person vaccinated/targeted were 0.034% (SD 0.044%) of high-income countries' GDP per capita. Average costs in the two LMIC studies were $0.71 per person vaccinated/targeted (0.082% of GDP per capita) for a geospatial mapping intervention in Haiti (low-income country) and $1.41 per person vaccinated/targeted (0.004% of GDP per capita) for a cellphone-based tracking intervention in Kenya (lower-middle income country) [76,80]. The cost per dose for the geospatial mapping intervention to locate vaccine beneficiaries in Haiti represented 35.576% of the country's predicted delivery cost per dose for routine delivery of childhood vaccines.

We identified two studies reporting the costs of interventions to know the location of hard-to-reach populations for vaccination [76,79] (Table 3). One study tried to overcome geographic terrain barriers and reported the cost per person targeted as $0.71 and the cost per dose as $0.37 [76]. Another study described inadequate health system barriers to vaccination, only reporting overall costs [79]. Both studies focused on reaching rural populations, and neither directly compared to vaccinator costs of identifying hard-to-reach populations vis-à-vis general populations.

3.4. Costs for vaccinators to travel to vaccination sites

Table 4 summarizes the data extracted from six studies that described travel costs for vaccinators to get to vaccination sites [45,60,62,81-83]. Across the four studies that reported costs of vaccinators to travel to the vaccination sites in cost per dose terms, in Indonesia (upper-middle income country), Cameroon (lower-middle income country), Honduras (lower-middle income country), and Colombia (upper-middle income country), the average vaccinator travel cost was $0.07 (0.002% of GDP per capita) per dose (SD $0.03) [60,62,81,82]. Across four cost per dose estimates from middle-income countries, the average vaccinator travel costs per dose amounted to 3.439% (range 2.580%-4.615%, SD 0.779%) of the respective countries' predicted delivery cost per dose for routine delivery of childhood vaccines. We did not identify any studies that described vaccinator travel costs for vaccinators targeting hard-to-reach populations.

4. Discussion

Our review of the costs associated with vaccinators reaching vaccination sites found limited evidence on vaccinator costs to reach beneficiaries who have hard-to-reach barriers for vaccination, with only eight studies describing such costs. Evidence on the differential vaccinator costs targeting hard-to-reach populations was scarce, with only two studies reporting the costs comparing hard-to-reach populations with populations that were easier-to-reach [35,67]. Estimates based on these studies suggest that the vaccinator costs for training and labor were 1.3–2 times higher to reach hard-to-reach populations compared to reaching the general populations, comparing costs of outreach efforts vis-à-vis costs of routine immunization. Indeed costs for SIAs are likely to be higher than routine immunization given requirements to train more people or travel farther to support a vaccination campaign.

While the studies we found mostly examined cost differences by mode of delivery (i.e. SIA vs. routine immunization) and were targeting beneficiaries facing geographic barriers to vaccination, it is important to note that not all hard-to-reach populations have to be reached through SIAs. For example, interventions could improve healthcare provider recommendations or reduce healthcare provider discrimination, resulting in greater delivery of vaccinations of hard-to-reach populations through routine immunization. Additional interventions could include strategies such as periodic intensification of routine immunization (PIRI) [84], increased delivery points, or expanded service hours and other interventions. Studies of interventions to improve immunization coverage should consider including detailed cost information to facilitate analysis of the costs specific to hard-to-reach populations. Our review did not identify studies examining vaccinator costs to reach populations facing such supply-side barriers to vaccination.

Understanding the differential costs associated with vaccinators getting to vaccination sites to serve hard-to-reach populations is key to allocating adequate resources and developing strategies to improve immunization coverage. Only accounting for average vaccinator costs across all beneficiaries may lead to an underestimation of costs needed to reach hard-to-reach populations. This could result in lower immunization coverage, as vaccination programs with fixed resources would likely reach fewer target populations than initially planned. Furthermore, vaccinator costs to reach hard-to-reach populations are likely to differ based on context, specific populations, and the barriers to vaccinations they face. Thus, more studies are needed to understand the cost differences for vaccinating different hard-to-reach populations. For example, most of the hard-to-reach barriers to vaccination identified in our study were geographic in nature (distance or terrain) or were due to inadequate health systems or transient or nomadic movement. We found no data examining vaccinator costs to reach the beneficiaries who face other barriers, such as healthcare provider discrimination, lack of healthcare provider recommendations, war and conflict, home births or other home-bound mobility limitations, or legal restrictions [13]. Greater evidence is needed on the vaccinator costs to reach populations facing non-geographic barriers.

Prior studies and systematic reviews have synthesized the costs of immunization programs and interventions to improve immunization coverage [9-12,85,86]. While these costing

studies have examined differential costs by country, targeted vaccines, and types of interventions, none have focused on the potential cost differences for vaccinators to reach hard-to-reach populations, compared to vaccinators reaching populations that are not hard-to-reach. To understand such potential cost differences, we focused on four costs that vaccinators incur to get to vaccination sites, namely: (1) the cost of vaccinator training; (2) labor, per diem, and incentives; (3) tracking, reminders, and registries; and (4) travel. We did not identify any studies that estimated differences in vaccinator costs in identifying beneficiaries to vaccinate or to travel to the beneficiaries' locations comparing hard-to-reach populations with general populations. Furthermore, opportunity costs of time of vaccinators treating other patients were not typically included in costing of immunization programs. Hard-to-reach barriers to vaccination may magnify these opportunity costs, especially when vaccinators may have to take longer time away from treating other patients to train, identify, and travel to vaccinate hard-to-reach populations.

We note some limitations to our study. First, our systematic literature search did not include gray literature and focused on studies in English published since 2000. As in any systematic search, our search results are limited to articles captured through keyword searches and our search terms did not necessarily capture all possible vaccination mechanisms or interventions. While we supplemented our MEDLINE/PubMed search by reviewing studies compiled in the IDCC [25], we may have missed studies that were not indexed in these databases. Future studies should consider including other search engines and databases, as well as expanding the search strategy to include grey literature for a more comprehensive review of the available literature. For example, targeted searches of grey literature from the global polio eradication initiative (GPEI) [87], which has made concerted efforts to deliver polio vaccines to hard-to-reach populations, may yield further information on vaccinator costs in the polio context. Further, while out of scope for our current study, there may be shared costs within the health system for vaccine beneficiaries who are hard-to-reach for other health services beyond vaccination. Therefore, future studies should consider reviewing costs in the context of efforts to reach beneficiaries that are hard-to-reach across health services, such as those that integrate vaccination with maternal health services or other preventative health interventions [88-90].

Second, our analyses and cost comparisons are limited by differences in study methods and contexts in which the studies were conducted. Extracted costs came from different types of interventions, ranging from costs of small-scale pilot interventions to costs of national-level immunization programs across varying countries and target vaccines. Thus, caution should be applied in interpreting and comparing costs across studies. Third, hard-to-reach populations were not consistently defined across studies. We applied definitions focusing on supply-side barriers that make populations difficult to reach with vaccination [13]. However, the lack of common terminology for barriers faced by hard-to-reach populations made it difficult to classify studies targeting hard-to-reach populations. In addition, we did not consider costs of additional strategies to increase vaccination demand and acceptance among hard-to-reach populations who are also hard-to-vaccinate.

Finally, to ensure consistency and comparability in cost components, we excluded the costs that did not specify vaccinator cost components. We found limited evidence on the costs of

vaccinator travel, and this may be due to costing studies often reporting aggregated transport costs, including bundled costs for transporting vaccines, supplies, and personnel. Despite these limitations, to our knowledge, this study is the first to assess from the literature the differential costs of vaccinators getting to the vaccination sites, targeting the hard-to-reach populations compared to the general populations.

5. Conclusion

Our study found limited evidence for costs of vaccinators to reach hard-to-reach populations and how they may differ from costs to reach easier-to-reach populations across countries, vaccines, and intervention contexts. In order to extend vaccination to hard-to-reach populations, future studies should better estimate these potential differential costs to improve immunization program planning and financing. Stakeholders in immunization economics and costing, such as ICAN, should consider including the hard-to-reach framework and definitions in the development of costing tools and best practice methods to enable greater understanding of immunization delivery costs among hard-to-reach populations.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Funding

Research reported in this publication was supported by the Centers for Disease Control and Prevention (CDC) via contract 5 NU2GGH002000-02-00, the Eunice Kennedy Shriver National Institute of Child Health and Human Development (NICHD) Office of Behavioral and Social Sciences Research (OBSSR) via grant U01HD086861, and by National Institute of General Medical Sciences (NIGMS) as part of the Models of Infectious Disease Agent Study (MIDAS) network under grant R01 GM127512.

References

[1]. Peck M, Gacic-Dobo M, Diallo MS, Nedelec Y, Sodha SS, Wallace AS. Global Routine Vaccination Coverage, 2018. MMWR Morb Mortal Wkly Rep 2019;68:937–42. [PubMed: 31647786]

[2]. World Health Organization. Immunization coverage; 2020. Retrieved from https://www.who.int/news-room/fact-sheets/detail/immunization-coverage.

[3]. World Health Organization. Progress and Challenges with Achieving Universal Immunization Coverage; 2020. Retrieved from https://www.who.int/immunization/monitoring_surveillance/who-immuniz.pdf.

[4]. Hamid H, Mallhi TH, Naseer MS, Younas I, Rashid MA, Pervaiz A, et al. The COVID-19 pandemic threatens the Expanded Program on Immunization: recommendations for sustaining vaccination goals. Drugs Ther Perspect 2020;36:523–5. [PubMed: 32921974]

[5]. Sodha SV, Dietz V. Strengthening routine immunization systems to improve global vaccination coverage. Br Med Bull 2015;113:5–14. [PubMed: 25649959]

[6]. Oyo-Ita A, Wiysonge CS, Oringanje C, Nwachukwu CE, Oduwole O, Meremikwu MM. Interventions for improving coverage of childhood immunisation in low- and middle-income countries. Cochr Database Syst Rev 2016;7:Cd008145.

[7]. World Health Organization. Immunization Agenda 2030: A Global Strategy to Leave No One Behind; 2020. Retrieved from https://www.who.int/teams/immunization-vaccines-and-biologicals/strategies/ia2030.

[8]. Gavi (the Vaccine Alliance). Phase V (2021-2025); 2021. Retrieved from https://www.gavi.org/our-alliance/strategy/phase-5-2021-2025.

[9]. Ozawa S, Yemeke TT, Thompson KM. Systematic review of the incremental costs of interventions that increase immunization coverage. Vaccine. 2018;36:3641–9. [PubMed: 29754699]

[10]. Pegurri E, Fox-Rushby JA, Damian W. The effects and costs of expanding the coverage of immunisation services in developing countries: a systematic literature review. Vaccine. 2005;23:1624–35. [PubMed: 15694515]

[11]. Munk C, Portnoy A, Suharlim C, Clarke-Deelder E, Brenzel L, Resch SC, et al. Systematic review of the costs and effectiveness of interventions to increase infant vaccination coverage in low- and middle-income countries. BMC Health Serv Res 2019;19:741. [PubMed: 31640687]

[12]. Portnoy A, Ozawa S, Grewal S, Norman BA, Rajgopal J, Gorham KM, et al. Costs of vaccine programs across 94 low- and middle-income countries. Vaccine. 2015;33(Suppl 1):A99–A108. [PubMed: 25919184]

[13]. Ozawa S, Yemeke TT, Evans DR, Pallas SE, Wallace AS, Lee BY. Defining hard-to-reach populations for vaccination. Vaccine. 2019;37:5525–34. [PubMed: 31400910]

[14]. Akil L, Ahmad HA. The recent outbreaks and reemergence of poliovirus in war and conflict-affected areas. Int J Infect Dis. 2016;49:40–6. [PubMed: 27237735]

[15]. Gracey M, King M. Indigenous health part 1: determinants and disease patterns. Lancet 2009;374:65–75. [PubMed: 19577695]

[16]. Cox SN, Wedlock PT, Pallas SW, Mitgang EA, Yemeke TT, Bartsch SM, et al. A systems map of the economic considerations for vaccination: Application to hard-to-reach populations. Vaccine. 2021 May 24:S0264-410X (21)00605-8.

[17]. Bawa S, Shuaib F, Saidu M, Ningi A, Abdullahi S, Abba B, et al. Conduct of vaccination in hard-to-reach areas to address potential polio reservoir areas, 2014–2015. BMC Public Health. 2018;18:1312. [PubMed: 30541501]

[18]. Haq Z, Shaikh BT, Tran N, Hafeez A, Ghaffar A. System within systems: challenges and opportunities for the Expanded Programme on Immunisation in Pakistan. Health Research Policy and Systems. 2019;17:51. [PubMed: 31101060]

[19]. Kaji A, Parker DM, Chu CS, Thayatkawin W, Suelaor J, Charatrueangrongkun R, et al. Immunization Coverage in Migrant School Children Along the Thailand-Myanmar Border. J Immigr Minor Health 2016;18:1038–45. [PubMed: 26483180]

[20]. Anderson EL. Recommended solutions to the barriers to immunization in children and adults. Mo Med. 2014;111:344–8. [PubMed: 25211867]

[21]. Silwal RC, Jimba M, Poudyal AK, Poudel KC, Wakai S. Improving immunization services under the armed conflict in rural Nepal. Public Health. 2006;120:805–8. [PubMed: 16879846]

[22]. Hussain SF, Boyle P, Patel P, Sullivan R. Eradicating polio in Pakistan: an analysis of the challenges and solutions to this security and health issue. Globaliz. Health 2016;12:63.

[23]. Woodward A, Howard N, Wolffers I. Health and access to care for undocumented migrants living in the European Union: a scoping review. Health Policy Plan. 2014;29:818–30. [PubMed: 23955607]

[24]. Moher D, Liberati A, Tetzlaff J, Altman DG, The PG. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 2009;6:e1000097. [PubMed: 19621072]

[25]. Immunization Costing Action Network (ICAN). Immunization Delivery Cost Catalogue (IDCC); 2019. Retrieved from http://immunizationeconomics.org/ican-idcc/.

[26]. U.S. Bureau of Labor Statistics. Consumer Price Index; 2017. Retrieved from https://www.bls.gov/cpi/tables/home.htm.

[27]. World Bank. World Development Indicators; 2020. Retrieved from http://datatopics.worldbank.org/world-development-indicators/.

[28]. Portnoy A, Vaughan K, Clarke-Deelder E, Suharlim C, Resch SC, Brenzel L, et al. Producing Standardized Country-Level Immunization Delivery Unit Cost Estimates. PharmacoEconomics. 2020;38:995–1005. [PubMed: 32596785]

[29]. World Bank. World Bank Country and Lending Groups; 2017. Retrieved from https://datahelpdesk.worldbank.org/knowledgebase/articles/906519.

[30]. Robinson JS, Burkhalter BR, Rasmussen B, Sugiono R. Low-cost on-the-job peer training of nurses improved immunization coverage in Indonesia. Bull World Health Organ 2001;79:150–8. [PubMed: 11242822]

[31]. Griffiths UK, Hutton G, Das Dores Pascoal E. The cost-effectiveness of introducing hepatitis B vaccine into infant immunization services in Mozambique. Health Policy Plan 2005;20:50–9. [PubMed: 15689430]

[32]. Mascarenas A, Salinas J, Tasset-Tisseau A, Mascarenas C, Khan MM. Polio immunization policy in Mexico: economic assessment of current practice and future alternatives. Public Health. 2005;119:542–9. [PubMed: 15826896]

[33]. Griffiths UK, Korczak VS, Ayalew D, Yigzaw A. Incremental system costs of introducing combined DTwP-hepatitis B-Hib vaccine into national immunization services in Ethiopia. Vaccine. 2009;27:1426–32. [PubMed: 19146901]

[34]. Colombini A, Badolo O, Gessner BD, Jaillard P, Seini E, Da Silva A. Costs and impact of meningitis epidemics for the public health system in Burkina Faso. Vaccine. 2011;29:5474–80. [PubMed: 21641952]

[35]. Ebong CE, Levy P. Impact of the introduction of new vaccines and vaccine wastage rate on the cost-effectiveness of routine EPI: lessons from a descriptive study in a Cameroonian health district. Cost effectiveness and resource allocation. C/E 2011;9:9. [PubMed: 21619674]

[36]. Hutubessy R, Levin A, Wang S, Morgan W, Ally M, John T, et al. A case study using the United Republic of Tanzania: costing nationwide HPV vaccine delivery using the WHO Cervical Cancer Prevention and Control Costing Tool. BMC medicine. 2012;10:136. [PubMed: 23146319]

[37]. Schaetti C, Weiss MG, Ali SM, Chaignat CL, Khatib AM, Reyburn R, et al. Costs of illness due to cholera, costs of immunization and cost-effectiveness of an oral cholera mass vaccination campaign in Zanzibar. PLoS NeglTrop Dis 2012;6:e1844.

[38]. Quentin W, Terris-Prestholt F, Changalucha J, Soteli S, Edmunds WJ, Hutubessy R, et al. Costs of delivering human papillomavirus vaccination to schoolgirls in Mwanza Region, Tanzania. BMC Med. 2012;10:137. [PubMed: 23148516]

[39]. Khan IA, Saha A, Chowdhury F, Khan AI, Uddin MJ, Begum YA, et al. Coverage and cost of a large oral cholera vaccination program in a high-risk cholera endemic urban population in Dhaka, Bangladesh. Vaccine. 2013;31:6058–64. [PubMed: 24161413]

[40]. Hayford K, Uddin MJ, Koehlmoos TP, Bishai DM. Cost and sustainability of a successful package of interventions to improve vaccination coverage for children in urban slums of Bangladesh. Vaccine. 2014;32:2294–9. [PubMed: 24631083]

[41]. Usuf E, Mackenzie G, Lowe-Jallow Y, Boye B, Atherly D, Suraratdecha C, et al. Costs of vaccine delivery in the Gambia before and after, pentavalent and pneumococcal conjugate vaccine introductions. Vaccine. 2014;32:1975–81. [PubMed: 24503271]

[42]. Kaucley L, Levy P. Cost-effectiveness analysis of routine immunization and supplementary immunization activity for measles in a health district of Benin. Cost Effect Resour Alloc 2015;13:14.

[43]. Sarker AR, Islam Z, Khan IA, Saha A, Chowdhury F, Khan AI, et al. Estimating the cost of cholera-vaccine delivery from the societal point of view: A case of introduction of cholera vaccine in Bangladesh. Vaccine. 2015;33:4916–21. [PubMed: 26232545]

[44]. Ngabo F, Levin A, Wang SA, Gatera M, Rugambwa C, Kayonga C, et al. A cost comparison of introducing and delivering pneumococcal, rotavirus and human papillomavirus vaccines in Rwanda. Vaccine. 2015;33:7357–63. [PubMed: 26519548]

[45]. Chatterjee S, Pant M, Haldar P, Aggarwal MK, Laxminarayan R. Current costs & projected financial needs of India's Universal Immunization Programme. Indian J Med Res. 2016;143:801–8. [PubMed: 27748306]

[46]. Griffiths UK, Bozzani FM, Chansa C, Kinghorn A, Kalesha-Masumbu P, Rudd C, et al. Costs of introducing pneumococcal, rotavirus and a second dose of measles vaccine into the Zambian immunisation programme: Are expansions sustainable?. Vaccine. 2016;34:4213–20. [PubMed: 27371102]

[47]. Yu W, Lu M, Wang H, Rodewald L, Ji S, Ma C, et al. Routine immunization services costs and financing in China, 2015. Vaccine. 2018;36:3041–7. [PubMed: 29685593]

[48]. Teshome S, Desai S, Kim JH, Belay D, Mogasale V. Feasibility and costs of a targeted cholera vaccination campaign in Ethiopia. Human Vacc Immunother. 2018;14:2427–33.

[49]. Glazner JE, Steiner JF, Haas KJ, Renfrew B, Deutchman M, Berman S. Is reimbursement for childhood immunizations adequate? evidence from two rural areas in Colorado. Public Health Rep (Washington DC) 1974;2001(116):219–25.

[50]. Glazner JE, Beaty BL, Pearson KA, Elaine Lowery N, Berman S. Using an immunization registry: effect on practice costs and time. Ambul Pediatr Off J Ambul Pediatric Assoc. 2004;4:34–40.

[51]. Hoang MV, Nguyen TBY, Kim BG, Dao LH, Nguyen TH, Wright P. Cost of providing the expanded programme on immunization: findings from a facility-based study in Viet Nam, 2005. Bull World Health Organ 2008;86:429–34. [PubMed: 18568271]

[52]. Cavailler P, Lucas M, Perroud V, McChesney M, Ampuero S, Guerin PJ, et al. Feasibility of a mass vaccination campaign using a two-dose oral cholera vaccine in an urban cholera-endemic setting in Mozambique. Vaccine. 2006;24:4890–5. [PubMed: 16298025]

[53]. Yoo BK, Szilagyi PG, Schaffer SJ, Humiston SG, Rand CM, Albertin CS, et al. Cost of universal influenza vaccination of children in pediatric practices. Pediatrics 2009;124(Suppl 5):S499–506. [PubMed: 19948581]

[54]. Banerjee AV, Duflo E, Glennerster R, Kothari D. Improving immunisation coverage in rural India: clustered randomised controlled evaluation of immunisation campaigns with and without incentives. BMJ (Clinical research ed). 2010;340:c2220.

[55]. Cho BH, Asay GR, Lorick SA, Tipton ML, Dube NL, Messonnier ML. Costs of school-located influenza vaccination clinics in Maine during the 2009–2010 H1N1 pandemic. J School Nurs Off Publ Natl Assoc School Nurses. 2012;28:336–43.

[56]. Lin CJ, Nowalk MP, Zimmerman RK. Estimated costs associated with improving influenza vaccination for health care personnel in a multihospital health system. Joint Comm J Qual Patient Saf. 2012;38:67–72.

[57]. Al-lela OQ, Bahari MB, Al-abbassi MG, Salih MR, Basher AY. Estimation of immunization providers' activities cost, medication cost, and immunization dose errors cost in Iraq. Vaccine. 2012;30:3862–6. [PubMed: 22521848]

[58]. Yin Z, Beeler Asay GR, Zhang L, Li Y, Zuo S, Hutin YJ, et al. An economic evaluation of the use of Japanese encephalitis vaccine in the expanded program of immunization of Guizhou province, China. Vaccine. 2012;30:5569–77. [PubMed: 22698453]

[59]. Adachi K, Coleman MS, de la Motte Hurst C, Vargas ML, Oladele A, Weinberg MS. Costs of, and reimbursement for, vaccines: a case study at the Board of Health Refugee Services in DeKalb county, Georgia. Vaccine. 2013;31:2317–22. [PubMed: 22910285]

[60]. Castaneda-Orjuela C, Romero M, Arce P, Resch S, Janusz CB, Toscano CM, et al. Using standardized tools to improve immunization costing data for program planning: the cost of the Colombian Expanded Program on Immunization. Vaccine. 2013;31(Suppl 3):C72–9. [PubMed: 23777695]

[61]. Levin CE, Van Minh H, Odaga J, Rout SS, Ngoc DN, Menezes L, et al. Delivery cost of human papillomavirus vaccination of young adolescent girls in Peru, Uganda and Viet Nam. Bull World Health Organ 2013;91:585–92. [PubMed: 23940406]

[62]. Janusz CB, Castaneda-Orjuela C, Molina Aguilera IB, Felix Garcia AG, Mendoza L, Diaz IY, et al. Examining the cost of delivering routine immunization in Honduras. Vaccine. 2015;33(Suppl 1):A53–9. [PubMed: 25919175]

[63]. Ruhago GM, Ngalesoni FN, Robberstad B, Norheim OF. Cost-effectiveness of live oral attenuated human rotavirus vaccine in Tanzania. Cost Effect Resour Alloc 2015;13:7.

[64]. Le Gargasson JB, Nyonator FK, Adibo M, Gessner BD, Colombini A. Costs of routine immunization and the introduction of new and underutilized vaccines in Ghana. Vaccine. 2015;33(Suppl 1):A40–6. [PubMed: 25919173]

[65]. Mvundura M, Lorenson K, Chweya A, Kigadye R, Bartholomew K, Makame M, et al. Estimating the costs of the vaccine supply chain and service delivery for selected districts in Kenya and Tanzania. Vaccine. 2015;33:2697–703. [PubMed: 25865467]

[66]. Moodley I, Tathiah N, Sartorius B. The costs of delivering human papillomavirus vaccination to Grade 4 learners in KwaZulu-Natal, South Africa. S Afr Med J 2016;106.

[67]. Routh JA, Sreenivasan N, Adhikari BB, Andrecy LL, Bernateau M, Abimbola T, et al. Cost Evaluation of a Government-Conducted Oral Cholera Vaccination Campaign-Haiti, 2013. Am J Trop Med Hygiene. 2017;97:37–42.

[68]. Horne PR, Saarlas KN, Hinman AR. Costs of immunization registries: experiences from the All Kids Count II Projects. Am J Prev Med 2000;19:94–8. [PubMed: 10913898]

[69]. Rask KJ, Wells KJ, Kohler SA, Rust CT, Cangialose CB. Measuring immunization registry costs: promises and pitfalls. Am J Prev Med 2000;18:262–7. [PubMed: 10722994]

[70]. Rask KJ, Wells KJ, Kohler SA, Rust CT, Cangialose CB. The cost to providers of participating in an immunization registry. Am J Prev Med 2000;19:99–103.

[71]. Rask KJ, LeBaron CW, Starnes DM. The costs of registry-based immunization interventions. Am J Prev Med 2001;21:267–71. [PubMed: 11701296]

[72]. Fontanesi JM, Flesher DS Jr, De Guire M, Lieberthal A, Holcomb K. The cost of doing business: cost structure of electronic immunization registries. Health Serv Res 2002;37:1291–307. [PubMed: 12479497]

[73]. McKenna VB, Sager A, Gunn JE, Tormey P, Barry MA. Immunization registries: costs and savings. Public Health Rep (Washington DC) 1974;2002(117):386–92.

[74]. Szilagyi PG, Humiston SG, Gallivan S, Albertin C, Sandler M, Blumkin A. Effectiveness of a citywide patient immunization navigator program on improving adolescent immunizations and preventive care visit rates. Arch Pediatr Adolesc Med 2011;165:547–53. [PubMed: 21646588]

[75]. Kempe A, Saville A, Dickinson LM, Eisert S, Reynolds J, Herrero D, et al. Population-based versus practice-based recall for childhood immunizations: a randomized controlled comparative effectiveness trial. Am J Public Health 2013;103:1116–23. [PubMed: 23237154]

[76]. Teng JE, Thomson DR, Lascher JS, Raymond M, Ivers LC. Using Mobile Health (mHealth) and geospatial mapping technology in a mass campaign for reactive oral cholera vaccination in rural Haiti. PLoS NeglTrop Dis 2014;8:e3050.

[77]. Kempe A, Saville AW, Dickinson LM, Beaty B, Eisert S, Gurfinkel D, et al. Collaborative centralized reminder/recall notification to increase immunization rates among young children: a comparative effectiveness trial. JAMA pediatrics. 2015;169:365–73. [PubMed: 25706340]

[78]. Kempe A, Saville AW, Beaty B, Dickinson LM, Gurfinkel D, Eisert S, et al. Centralized Reminder/Recall to Increase Immunization Rates in Young Children: How Much Bang for the Buck?. Academic pediatrics. 2017;17:330–8. [PubMed: 27913163]

[79]. Chandir S, Dharma VK, Siddiqi DA, Khan AJ. Feasibility of using global system for mobile communication (GSM)-based tracking for vaccinators to improve oral poliomyelitis vaccine campaign coverage in rural Pakistan. Vaccine. 2017;35:5037–42. [PubMed: 28802756]

[80]. Mokaya E, Mugoya I, Raburu J, Shimp L. Use of cellular phone contacts to increase return rates for immunization services in Kenya. Pan African Med J. 2017;28:24.

[81]. Levin CE, Nelson CM, Widjaya A, Moniaga V, Anwar C. The costs of home delivery of a birth dose of hepatitis B vaccine in a prefilled syringe in Indonesia. Bull World Health Organ 2005;83:456–61. [PubMed: 15976897]

[82]. Sume GE, Fouda AA, Kobela M, Nguele S, Emah I, Atem P. A locally initiated and executed measles outbreak response immunization campaign in the nylon health district, Douala Cameroon 2011. BMC Res Notes. 2013;6:100. [PubMed: 23497712]

[83]. Schutte C, Chansa C, Marinda E, Guthrie TA, Banda S, Nombewu Z, et al. Cost analysis of routine immunisation in Zambia. Vaccine. 2015;33(Suppl 1):A47–52. [PubMed: 25919174]

[84]. Mantel C, Cherian T. New immunization strategies: adapting to global challenges. Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz. 2020;63:25–31. [PubMed: 31802153]

[85]. Gandhi G, Lydon P. Updating the evidence base on the operational costs of supplementary immunization activities for current and future accelerated disease control, elimination and eradication efforts. BMC Public Health. 2014;14:67. [PubMed: 24450832]

[86]. Hui C, Dunn J, Morton R, Staub LP, Tran A, Hargreaves S, et al. Interventions to Improve Vaccination Uptake and Cost Effectiveness of Vaccination Strategies in Newly Arrived Migrants

in the EU/EEA: A Systematic Review. Int J Environ Res Public Health 2018:15. [PubMed: 30577626]

[87]. Aylward B, Tangermann R. The global polio eradication initiative: Lessons learned and prospects for success. Vaccine. 2011;29:D80–5. [PubMed: 22486981]

[88]. Jacobs B, Lindelow M, Xayyavong P, Sackett P. Building on community outreach for childhood vaccination to deliver maternal and child health services in Laos: a feasibility assessment. Reprod Health Matt. 2012;20:112–21.

[89]. Ryman TK, Briere EC, Cartwright E, Schlanger K, Wannemuehler KA, Russo ET, et al. Integration of routine vaccination and hygiene interventions: a comparison of 2 strategies in Kenya. J Infect Dis 2012;205(Suppl 1):S65–76. [PubMed: 22315389]

[90]. Dicko A, Toure SO, Traore M, Sagara I, Toure OB, Sissoko MS, et al. Increase in EPI vaccines coverage after implementation of intermittent preventive treatment of malaria in infant with Sulfadoxine -pyrimethamine in the district of Kolokani, Mali: results from a cluster randomized control trial. BMC Public Health. 2011;11:573. [PubMed: 21767403]

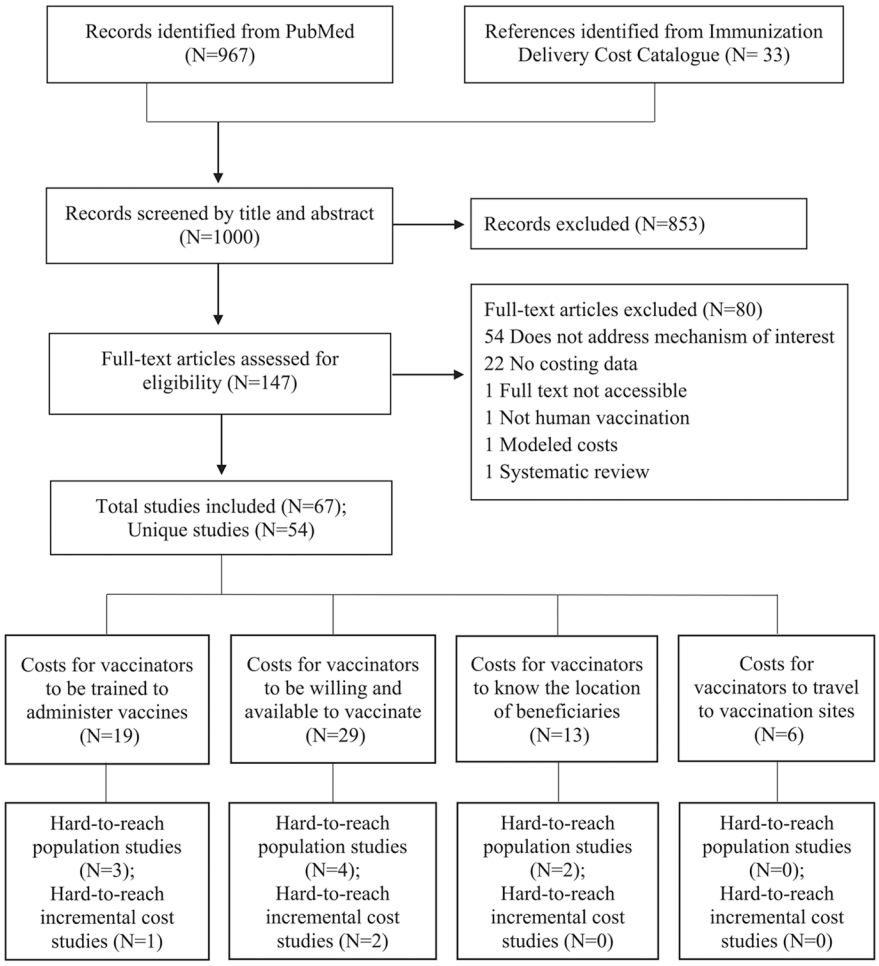

Fig. 1.

Literature search process for systematic review of costs for vaccinators to reach vaccination sites, 2000–2019.

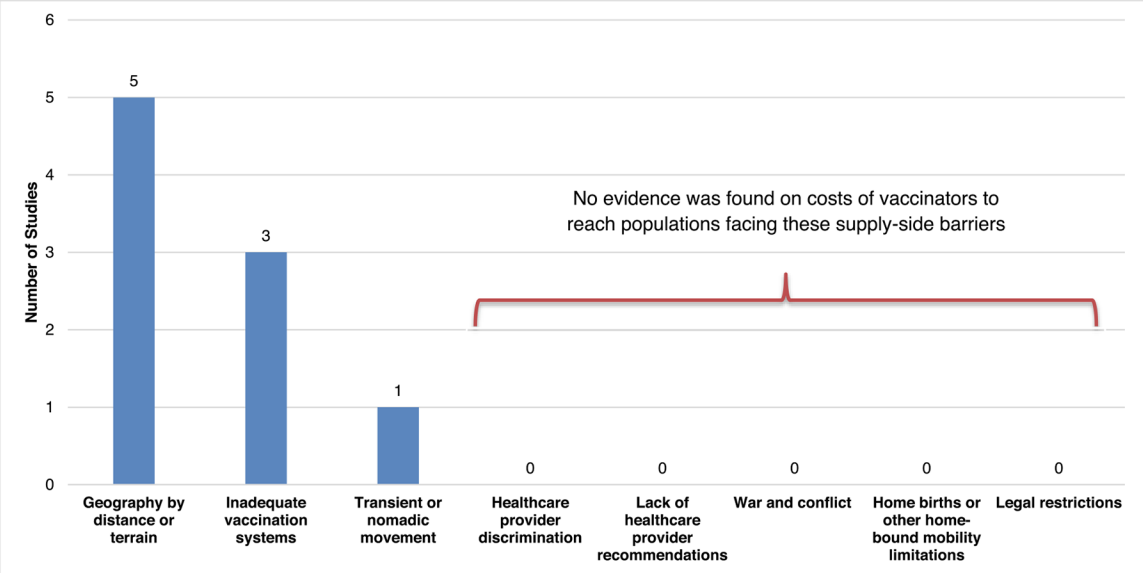

Fig. 2.

Distribution of mechanisms that make a population hard-to-reach, across studies describing costs of vaccinators to reach hard-to-reach populations, systematic review, 2000–2019.

Table 1

Costs for vaccinators be trained to administer vaccines, systematic review, 2000–2019.

Country, year [Ref]	Country income	Delivery mode	Study description	Vaccines, (Target population**)	Vaccinator training costs (US$ 2019)	Vaccinator training cost per person vaccinated/ targeted (US$ 2019) (%GDP per capita)	Vaccinator training cost per dose (US$ 2019)(% GDP per catita,% predicted country delivery cost per dose)	Hard-to-reach mechanism(s)
Indonesia, 2001 [30]	LMI	RI	Costing of nurse training intervention across 15 health centers	All EPI (Children)	$93.79 *	–	$0.09 (0.002%, 6.923%)	–
Mozambique, 2005 [31]	LI	RI	Costing of training costs for national introduction of hepatitis B vaccine	Hepatitis B (Children)	$71,621	$0.12 (0.025%)	–	–
Mexico, 2005 [32]	UMI	SIA	Costing of training costs for a national immunization week in one district	OPV (Children)	$7,274	–	$0.14 (0.001%, 5.555%)	–
Ethiopia, 2009 [33]	LI	RI	Costing of national vaccine introduction	Pentavalent (DTP–hepatitis B–Hib) (Children)	–	$0.26 (0.034%)	$0.05 (0.006%, 6.410%)	–
Burkina Faso, 2011 [34]	LI	SIA	Costing of training costs for a national reactive meningitis vaccination campaign	Meningitis (All)	$7,516	$0.01 (0.002%)	–	–
Cameroon, 2011 [35]	LMI	RI	Costing of training costs for EPI vaccine introduction in a health district	All EPI (Children)	$57	–	–	Geography by distance, Transient or nomadic movement
Tanzania, 2012 [36]	LI	RI	Costing of national vaccine introduction over 5 years	HPV (Adolescents)	–	–	$0.13 (0.013%, 5.828%)	–
Zanzibar (Tanzania), 2012 [37]	LI	SIA	Costing of training costs for mass cholera vaccination campaign	Cholera (All)	$11,325	$0.45 (0.043%)	–	–
Tanzania, 2012 [38]	LI	SIA	Costing of training costs for school-based HPV vaccination	HPV (Adolescents)	$7,503	$1.78 (0.170%)	–	–
Bangladesh, 2013 [39]	LMI	SIA	Costing of training costs for a mass cholera vaccination program in a city	Cholera (All)	$1,705	$0.01 (0.001%)	–	–
Bangladesh, 2014 [40]	LMI	RI	Costing of an intervention in slum areas of a city	All EPI (Children)	–	$2.68 (0.158%)	–	Inadequate health systems
Gambia, 2014 [41]	LI	RI	Costing of training costs for national vaccine introduction	Pentavalent (DTP–hepatitis B–Hib), pneumococcal (Children)	$11,427	–	–	–

Country, year [Ref]	Country income	Delivery mode	Study description	Vaccines, (Target population**)	Vaccinator training costs (US$ 2019)	Vaccinator training cost per person vaccinated/ targeted (US$ 2019) (%GDP per capita)	Vaccinator training cost per dose (US$ 2019)(% GDP per catita,% predicted country delivery cost per dose)	Hard-to-reach mechanism(s)
Benin, 2015 [42]	LI	SIA	Costing of training costs for measles supplementary immunization activity in one health district	Measles (Children)	$874	–	$0.02 (0.003%, 1.360%)	Geography by terrain, Geography by distance
Bangladesh, 2015 [43]	LMI	SIA	Costing of training costs for a mass cholera vaccination program in a city	Cholera (All)	$1,456	$0.01 (0.001%)	–	–
Rwanda, 2015 [44]	LI	RI	Costing of training costs for national introduction of pneumococcal vaccine	Pneumococcal (Children)	$26,683	–	–	–
Rwanda, 2015 [44]	LI	RI	Costing of training costs for national introduction of rotavirus vaccine	Rotavirus (Children)	$13,621	–	–	–
Rwanda, 2015 [44]	LI	RI	Costing of training costs for national introduction of HPV vaccine	HPV (Adolescents)	$49,317	–	–	–
India, 2016 [45]	LMI	RI	Costing of entire national immunization program	All EPI (Children)	$6,615,235	–	–	–
Zambia, 2016 [46]	LMI	RI	Costing of one-time national costs of vaccine introduction	Pneumococcal, Rotavirus, Measles second dose (Children)	$636,077	–	$0.23 (0.015%, 9.583%)	–
China, 2018 [47]	UMI	RI	Costing of national routine immunization program	All EPI (Children)	$46,608,608	–	–	–
Ethiopia, 2018 [48]	LI	SIA	Costing of training costs for mass vaccination campaign	Cholera (All)	$2,508	–	$0.03 (0.004%, 3.846%)	–

DTP = diphtheria, tetanus, and pertussis vaccine; EPI = Expanded Programme on Immunization; GDP = gross domestic product; Hib = *Haemophilus influenzae* type b vaccine; HPV = human papillomavirus vaccine; LI = low-income; LMI = lower-middle income; OPV = oral polio vaccine; RI = routine immunization; SIA = supplementary immunization activities; UMI = upper-middle income.

– Denotes not reported in study.

* Cost per vaccinator trained.

** All include children, adolescent, and adult target populations.

Note: 21 estimates of costs reflecting 19 studies.

Table 2

Costs for vaccinators to be willing and available to vaccinate (i.e. receive salary, per diem, and/or incentives), systematic review, 2000–2019.

Country, year [Ref]	Country income	Delivery mode	Study description	Vaccines (Target population**)	Vaccinator labor & incentive costs (US$ 2019)	Vaccinator labor & incentive cost per person vaccinated/targeted (US$ 2019) (% GDP per capita)	Vaccinator labor & incentive cost per dose (US$ 2019) (% GDP per capita, % predicted country delivery cost per dose)	Hard-to-reach mechanism(s)
USA, 2001 [49]	HI	RI	Costing of labor costs at private and public facilities	All EPI (Children)	–	–	$1.69-$2.41 (0.003%-0.004%)	–
USA, 2004 [50]	HI	RI	Costing of vaccine administration labor costs in medical practices after registry intervention	All EPI (Children)	–	–	$2.33 (0.004%)	–
Vietnam, 2008 [51]	LI	RI	Costing of personnel costs in a district for national EPI program	All EPI (Children)	$23,143	–	$0.28 (0.011%, 22.950%)	Geography by terrain
Mozambique, 2005 [31]	LI	RI	Costing of personnel costs for national EPI program	All EPI (Children)	$1,574,251	$2.71 (0.544%)	–	–
Mexico, 2005 [32]	UMI	SIA	Costing of personnel costs for national immunization week in a health district	OPV (Children)	$122,698	–	$2.40 (0.025%, 95.238%)	–
Mozambique, 2006 [52]	LI	SIA	Costing of salaries for a mass vaccination campaign in a city	Cholera (All)	$43,042	–	$0.44 (0.088%, 37.606%)	–
USA, 2009 [53]	HI	RI	Costing of labor costs in a sample of medical practices	Influenza (Children)	–	–	$2.55 (0.004%)	–
India, 2010 [54]	LMI	RI	Costing of labor costs for an intervention	All EPI (Children)	$17,182	$22.58 (1.123%)	–	Inadequate health systems
Cameroon, 2011 [35]	LMI	RI	Costing of salaries for a district EPI program	All EPI (Children)	$8,726	–	$5.42 (0.353%, 349.677%)	Geography by distance
USA, 2012 [55]	HI	SIA	Costing of labor costs for school-based intervention	Influenza (Children)	–	–	$7.09 (0.011%)	–
USA, 2012 [56]	HI	RI	Costing of labor costs for an intervention in a multihospital system	Influenza (Adults)	$26,441–$40,824	$1.93–$2.98 (0.003%-0.005%)	–	–
Iraq, 2012 [57]	UMI	RI	Costing of labor costs at five public clinics	All EPI (Children)	–	–	$1.98 (0.034%, 81.481%)	–
Tanzania, 2012 [37]	LI	SIA	Costing of staff allowances for mass vaccination campaign in selected districts	Cholera (All)	$39,338	$1.55 (0.147%)	–	–
China, 2012 [58]	UMI	RI	Costing of salaries for EPI immunization program in a province	All EPI (Children)	$18,745,042	–	$0.94 (0.010%, 43.925%)	–

Country, year [Ref]	Country income	Delivery mode	Study description	Vaccines (Target population**)	Vaccinator labor & incentive costs (US$ 2019)	Vaccinator labor & incentive cost per person vaccinated/targeted (US$ 2019) (% GDP per capita)	Vaccinator labor & incentive cost per dose (US$ 2019) (% GDP per capita, % predicted country delivery cost per dose)	Hard-to-reach mechanism(s)
USA, 2013 [59]	HI	RI	Costing of labor costs at a county clinic	All EPI (All)	–	–	$6.97 (0.011%)	–
Colombia, 2013 [60]	UMI	RI	Costing of personnel costs for national EPI program	All EPI (Children)	$25,439,956	–	$0.92 (0.014%, 30.463%)	–
Bangladesh, 2013 [39]	LMI	SIA	Costing of salaries for a mass vaccination campaign in a city	Cholera (All)	$130,998	$1.06 (0.062%)	–	–
Peru, 2013 [61]	UMI	SIA	Costing of personnel costs for school-based vaccine delivery	HPV (Adolescents)	–	–	$0.50 (0.007%, 18.726%)	–
Uganda, 2013 [61]	LI	SIA	Costing of personnel costs for school-based vaccine delivery	HPV (Adolescents)	–	–	$0.57 (0.089%, 31.843%)	–
Uganda, 2013 [61]	LI	SIA	Costing of personnel costs for outreach vaccine delivery	HPV (Adolescents)	–	–	$0.02 (0.004%, 1.117%)	–
Vietnam, 2013 [61]	LMI	SIA	Costing of personnel costs for school-based vaccine delivery	HPV (Adolescents)	–	–	$0.21 (0.008%, 17.213%)	–
Vietnam, 2013 [61]	LMI	RI	Costing of personnel costs for health facility-based vaccine delivery	HPV (Adolescents)	–	–	$0.21 (0.008%, 17.213%)	–
Gambia, 2014 [41]	LI	RI	Costing of personnel costs for national vaccine introduction	Pentavalent, Pneumococcal (Children)	$47,518	–	$0.10 (0.013%, 2.849%)	–
Honduras, 2015 [62]	LMI	RI	Costing of labor costs for entire national immunization program	All EPI (All)	$20,070,574	–	$5.02 (0.201%, 162.987%)	–
Tanzania, 2015 [63]	LI	RI	Costing of personnel costs for vaccine introduction in national EPI program urban facilities	Rotavirus (Children)	$4,576	–	–	–
Tanzania, 2015 [63]	LI	RI	Costing of personnel costs for vaccine introduction in national EPI program in rural facilities	Rotavirus (Children)	$2,030	–	–	–
Benin, 2015 [42]	LI	RI, SIA	Costing of personnel costs for routine and SIA activities in a health district	Measles (Children)	$19,777	–	$0.43 (0.048%, 29.251%)	–
Ghana, 2015 [64]	LMI	RI	Costing of salary costs for national routine immunization program	All EPI (Children)	$36,950,867	$36.55 (1.660%)	$3.90 (0.177%, 128.289%)	–
Ghana, 2015 [64]	LMI	RI	Costing of salary costs for national routine immunization program vaccine introductions	Pneumococcal, Rotavirus, Measles (Children)	$2,407,322	–	$0.74 (0.034%, 24.342%)	–

Country, year [Ref]	Country income	Delivery mode	Study description	Vaccines (Target population**)	Vaccinator labor & incentive costs (US$ 2019)	Vaccinator labor & incentive cost per person vaccinated/targeted (US$ 2019) (% GDP per capita)	Vaccinator labor & incentive cost per dose (US$ 2019) (% GDP per capita, % predicted country delivery cost per dose)	Hard-to-reach mechanism(s)
Kenya, 2015 [65]	LI	RI	Costing of average salary and per diem costs across health facilities	All EPI (Children)	$7,062	–	$1.11 (0.065%, 52.606%)	–
Tanzania, 2015 [65]	LI	RI	Costing of average salary and per diem costs across health facilities	All EPI (Children)	$12,938	–	$2.38 (0.227%, 106.726%)	–
Zambia, 2016 [46]	LMI	RI	Costing of human resources costs for national vaccine introductions	Pneumococcal, Rotavirus, Measles (Children)	$2,846,024	$5.50 (0.357%)	–	–
South Africa, 2016 [66]	UMI	SIA	Costing of labor for a school- based vaccine delivery demonstration project	HPV (Adolescent)	–	$11.61 (0.182%)	–	–
India, 2016 [45]	LMI	RI	Costing of personnel costs for national EPI program	All EPI (Children)	$12,695,906	–	–	–
Haiti, 2017 [67]	LI	SIA	Costing of personnel costs for a mass vaccination campaign	Cholera (All)	$95,323	–	$0.44 (0.051%, 42.307%)	Geography by terrain
China, 2018 [47]	UMI	RI	Costing of personnel costs for national EPI program	All EPI (Children)	$882,434,726	$0.05 (0.001%)	–	–

EPI = Expanded Programme on Immunization; GDP = gross domestic product; HI = high income; HPV = human papillomavirus vaccine; LI = low-income; LMI = lower-middle income; OPV = oral polio vaccine; RI = routine immunization; SIA = supplementary immunization activities; UMI = upper-middle income; USA = United States of America.

– Denotes not reported in study.

** All include children, adolescent, and adult target populations.

Note: 36 estimates of costs reflecting 29 studies.

Table 3

Costs for vaccinators to know the location of beneficiaries, systematic review, 2000–2019.

Country, year [Ref]	Country income	Delivery mode	Study description	Vaccines (Target population**)	Beneficiary identification costs (US$ 2019)	Beneficiary identification cost per person vaccinated/targeted (US$ 2019) (% GDP per capita)	Beneficiary identification cost per dose (US$ 2019) (% GDP per capita, % predicted country delivery cost per dose)	Hard-to-reach mechanism(s)
USA, 2000 [68]	HI	RI	Costing of immunization registries	All EPI (Children)	–	$6.23(0.010%)	–	–
USA, 2000 [69]	HI	RI	Costing of immunization registries	All EPI (Children)	$699,761	$8.38 (0.013%)	–	–
USA, 2000 [70]	HI	RI	Costing of immunization registries across provider sites	All EPI (Children, Adolescents)	$9,542–$38,034	$1.01–$12.14 (0.002%-0.019%)	–	–
USA, 2001 [71]	HI	RI	Costing of immunization registry interventions	All EPI (Children)	–	$2.13–$4.39 (0.003%-0.007%)	–	–
USA, 2002 [72]	HI	RI	Costing of development and maintenance costs of immunization registries	All EPI (Children)	$392177; $8000	–	–	–
USA, 2002 [73]	HI	RI	Costing of development and maintenance costs of immunization registry	All EPI (Children)	$542,078	$8.55 (0.014%)	–	–
USA, 2011 [74]	HI	RI	Costing of immunization tracking and reminder/recall intervention	All EPI (Adolescent)	–	$71.75 (0.114%)	–	–
USA, 2013 [75]	HI	RI	Costing of population-based recall intervention in state counties	All EPI (Children)	$47,326	$3.52 (0.006%)	–	–
USA, 2013 [75]	HI	RI	Costing of practice-based recall intervention	All EPI	$15,421	$17.59 (0.028%)	–	–
Haiti, 2014 [76]	LI	SIA	Costing of mHealth and geospatial mapping intervention	Cholera (All)	$32,440	$0.71 (0.082%)	$0.37 (0.043%, 35.576%)	Geography by terrain
USA, 2015 [77]	HI	RI	Costing of a centralized reminder-recall intervention using an immunization information system	All EPI (Children)	$31,873	$3.52 (0.006%)	–	–
USA, 2015 [77]	HI	RI	Costing of a practice-based reminder-recall intervention using an immunization information system	All EPI (Children)	$3,049	$40.65 (0.065%)	–	–
USA, 2017 [78]	HI	RI	Costing of a centralized reminder-recall intervention using an immunization information system	All EPI (Children)	$16,806	$5.39 (0.009%)	–	–

Country, year [Ref]	Country income	Delivery mode	Study description	Vaccines (Target population**)	Beneficiary identification costs (US$ 2019)	Beneficiary identification cost per person vaccinated/targeted (US$ 2019) (% GDP per capita)	Beneficiary identification cost per dose (US$ 2019) (% GDP per capita, % predicted country delivery cost per dose)	Hard-to-reach mechanism(s)
USA, 2017 [78]	HI	RI	Costing of a practice-based reminder-recall intervention using an immunization information system	All EPI (Children)	$1,305	$86.99 (0.139%)	–	–
USA, 2017 [78]	HI	RI	Costing of a centralized reminder-recall intervention using an immunization information system	All EPI (Children)	$13,893	$5.00 (0.008%)	–	–
USA, 2017 [78]	HI	RI	Costing of a practice-based reminder-recall intervention using an immunization information system	All EPI (Children)	$1,283	$67.48 (0.107%)	–	–
USA, 2017 [78]	HI	RI	Costing of a centralized reminder-recall intervention using an immunization information system	All EPI (Children)	$10,726	$3.32 (0.005%)	–	–
USA, 2017 [78]	HI	RI	Costing of a practice-based reminder-recall intervention using an immunization information system	All EPI (Children)	$1,092	$14.00 (0.022%)	–	–
Pakistan, 2017 [79]	LMI	SIA	Costing of a global system for mobile communication (GSM)-based tracking intervention	OPV (Children)	$1,927	–	–	Inadequate health system
Kenya, 2017 [80]	LMI	RI	Costing of a cellphone-based tracking intervention	All EPI (Children)	–	$0.07–$2.74 (0.004%-0.160%)	–	–

EPI = Expanded Programme on Immunization; GDP = gross domestic product; HI = high-income; LI = low-income; LMI = lower-middle income; OPV = oral polio vaccine; RI = routine immunization; SIA = supplementary immunization activities; UMI = upper-middle income; USA = United States of America.

– Denotes not reported in study.

** All include children, adolescent, and adult target populations.

Note: 20 estimates of costs reflecting 13 studies.

Table 4

Costs for vaccinators to travel to vaccination sites, systematic review, 2000–2019.

Country, year [Ref]	Country income	Delivery mode	Study description	Vaccines	Vaccinator travel costs (US$2019)	Vaccinator travel cost per dose (US$2019) (% GDP per capita, % predicted country delivery cost per dose)	Hard-to-reach Mechanism(s)
Indonesia, 2005 [81]	UMI	SIA	Costing of transport costs for home visits in a home-based vaccine delivery intervention	Hepatitis B (Children)	–	$0.06 (0.001%, 4.615%)	–
Colombia, 2013 [60]	UMI	RI	Costing of entire national immunization program	All EPI (Children)	$2,893,030	$0.11 (0.002%, 3.642%)	–
Cameroon, 2013 [82]	LMI	SIA	Costing of transport and fuel costs for vaccinators for immunization campaign in a health district	Measles (Children)	–	$0.04 (0.003%, 2.580%)	–
Honduras, 2015 [62]	LMI	RI	Costing of entire national immunization program	All EPI (All)	$357,002	$0.09 (0.004%, 2.922%)	–
Zambia, 2015 [83]	LMI	RI	Costing of entire national immunization program	All EPI (Children)	$2,670,540	–	–
India, 2016 [45]	LMI	RI	Costing of entire national immunization program	All EPI (Children)	$30,169,482	–	–

EPI = Expanded Programme on Immunization; GDP = gross domestic product; LMI = lower-middle income; RI = routine immunization; SIA = supplementary immunization activities; UMI = upper-middle income.

– Denotes not reported in study.

* All includes children, adolescent, and adult target populations.

Note: No vaccinator travel cost per person was identified from the literature. Includes 6 estimates of costs reflecting 6 studies.