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Costs of Interventions to Increase Vaccination Coverage Among Children in the United States: A Systematic Review

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Abstract

Background: The Community Preventive Services Task Force (CPSTF) has recommended several interventions that have been demonstrated to be effective at increasing vaccination coverage.

Objective: Conduct a systematic review to examine the costs of interventions designed to increase vaccination coverage among children and adolescents in the United States.

Data Sources: PubMed, EconLit, Embase, and Cochrane.

Study Eligibility, Participants, and Interventions: Peer-reviewed articles from January 1, 2009 to August 31, 2019.

Appraisal and Synthesis Methods: Studies were identified with systematic searches of the literature, reviewed for inclusion criteria, abstracted for data on intervention, target population,

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costs, and risk of bias. Cost measures were reported as costs per child in the target population, costs per vaccinated child, incremental costs per vaccinated child, and costs per vaccine dose administered. Results were stratified by intervention type, vaccine, and age group.

Results: Thirty-seven studies were identified for full-text review. Across all interventions and age groups, the cost per child ranged from $0.10 to $537.38, and the incremental cost per vaccinated child ranged from $6.52 to $5,098.57. Provider assessment and feedback interventions had the lowest (median) cost per child ($0.17) and a healthcare system-based combined intervention with multiple components had the lowest (median) incremental cost per vaccinated child ($26.65). A community-based combined intervention with multiple components had the highest median cost per child ($537.38) and the highest median incremental cost per vaccinated child ($5,098.57).

Limitations: A small number of included intervention types and inconsistent cost definition.

Conclusions: There is substantial variability in the costs of CPSTF-recommended interventions.

Keywords

Child; preschool; child; adolescent; costs and cost analysis; infant; newborn; infant; systematic review; United States; vaccination coverage

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Childhood vaccinations prevent serious illness and death,[1] and can generate substantial cost savings for both payers and society as a whole.[2] Although vaccination coverage for many routinely-recommended childhood vaccines has increased since the introduction of the Vaccines for Children program in 1994, coverage levels for some vaccines, such as the human papillomavirus (HPV) and influenza vaccine, are still well below the *Healthy People 2020* targets.[1,3]

The Guide to Community Preventive Services (Community Guide) conducted a series of systematic literature reviews on the effectiveness of interventions in increasing vaccination coverage rates. Based on the findings, the Community Preventive Services Task Force (CPSTF) recommended 13 types of interventions found to be effective in increasing coverage at the population level.[4–6] In a later effort the Community Guide conducted additional systematic reviews focusing on the costs of these interventions.[4,5] The most recent cost review was published in 2016,[4] including studies from 1998 to 2012. This review focused on vaccinations for all age groups in high-income countries, as defined by the World Bank.[4] Other recent systematic reviews on the costs of vaccination coverage interventions, which were not conducted by the Community Guide, have focused on a different research objective or on a narrower group of vaccinations than our review. For example, one recent review investigated the costs of interventions that only targeted HPV vaccination.[7] Another review looked at countries around the world and estimated cost-effectiveness of interventions while controlling for different levels of initial vaccination coverage and different levels of national wealth.[8]

The objective of this systematic review was to evaluate the costs of interventions designed to increase vaccination coverage, implemented in communities around the United States. We identify studies described in peer-reviewed publications during the past decade. We attempt to develop a deeper understanding of the costs of the interventions by examining overall and incremental costs (when a control group without intervention was available) by subgroups of age and intervention type, for all types of vaccinations recommended for children and adolescents. The findings could help policymakers, program directors, and clinical managers to understand the financial and budgetary resources that may be needed to achieve vaccination coverage goals among targeted children and adolescents.

Methods

We searched for peer-reviewed studies that were published in English during the last 10 years from January 1, 2009 to August 31, 2019, using PubMed,[9] EconLit,[10] Embase,[11] and Cochrane[12] databases (last searched September 25, 2019). This time period was selected to reflect interventions implemented in the current technological and healthcare environment. We did not search any gray literature that was not peer-reviewed or published. Titles and abstracts from these databases were searched using the following terms: ("vaccination" OR "immunization") AND "cost*" AND ("child*" OR "adolescen*" OR "infant*"). These were then reviewed by one author (KH) for adherence to our inclusion criteria, which included studies conducted in the United States, focusing on children under 18 years, and reported any cost information. Additional studies that met the inclusion criteria were incorporated into this study following our review of citation lists in the remaining studies and consulting with subject matter experts (SMEs) who had conducted research on increasing vaccination coverage or issues related to a particular vaccine. SMEs were provided the list of studies we identified from the searches of titles, abstracts and citation lists, and submitted suggestions for additional studies.

The remaining set of included studies were given a full-text review, where intervention cost measures and other relevant characteristics were extracted by at least 2 independent reviewers (KH, ZT or BC) using a standardized data abstraction form. Any inconsistencies between reviewers were rechecked by a third reviewer (AL) and resolved by discussion. The extracted characteristics included intervention type, target population, target vaccines, reach or intervention group size, and measures of cost. During the full-text review, any studies that did not meet the inclusion criteria were excluded. When there were multiple publications on the same intervention, the one published first or reporting more cost information was included as a single study. Risk of bias was assessed by 2 independent reviewers (KH and ZT) for the studies that were included after the full text review, using the Newcastle-Ottawa Scale for nonrandomized studies and the Cochrane Collaboration Tool for randomized controlled studies.[13,14]

Based on systematic reviews on effectiveness, the CPSTF categorizes interventions as being recommended, recommended against, or having insufficient evidence. A recommended intervention means the systematic review of existing studies shows strong or sufficient evidence for the CPSTF to determine that the intervention is effective, whereas an intervention having insufficient evidence means the evidence provided by the existing studies is insufficient for the CPSTF to determine whether the intervention is effective or not.[15] There were 13 interventions/intervention combinations recommended by CPSTF, but most studies in our review focused on 6 of them: 1) Vaccination programs in schools and organized child care centers; 2) client reminder and recall systems; 3) community-based interventions implemented in combination; 4) standing orders; 5) provider assessment and feedback; and 6) healthcare system-based interventions implemented in combination. One study focused on clinic-based education, an intervention categorized by the CPSTF as having insufficient evidence. The target populations included young children 0 to 10 years old (or those in elementary schools), adolescents 11 to 17 years old (or those in secondary schools), and children of all ages (or those in both elementary and secondary schools). Our outcome measures, which were tabulated in the abstraction forms for each study, are defined below.

Total cost:

The cost of resources to implement interventions, including but not limited to labor, equipment, materials, and facilities. Following previous reviews of intervention costs,[4] total cost excluded the cost of purchasing a vaccine when applicable. This ensures that the differences in intervention costs are not driven by vaccine prices. However, it should also be noted that components included in the intervention costs, that is, in-kind costs, may still vary widely across studies.[16–18] Selected cost components were compared when itemized costs were available.

Intervention group size:

The number of children in the treatment group of the intervention. In many studies, the intervention group is the same as the treatment group.[16–37] Some exceptions are the studies that included separate treatment and control groups,[38–52] where we considered the treatment group as the intervention group.

Cost per child:

The average cost of interventions per person in the intervention group, or cost per child = total cost/intervention group size.

Number of vaccinated children:

The number of children that appeared to be vaccinated due to the intervention, compared with the preintervention baseline, or number of vaccinated children = number of vaccinated children after the intervention − number of vaccinated children before the intervention. In some studies,[45,52] the number of vaccinated children before intervention was zero by design.

Cost per vaccinated child:

The average cost of interventions per person vaccinated due to the intervention, or cost per vaccinated child = total cost/number of vaccinated children.

Number of incremental vaccinated children:

The number of children who were vaccinated due to the intervention, compared with the pre-intervention baseline, and the control group without intervention. As an equation:

$$
\begin{aligned}
&(\text{number of vaccinated children in the treatment group after the intervention} \\
&- \text{number of vaccinated children in the treatment group before the intervention}) \\
&- (\text{number of vaccinated children in the control group after the intervention} \\
&- \text{number of vaccinated children in the control group before the intervention}) .
\end{aligned}
$$

If there was no control group, an estimate of children who were incrementally vaccinated could not be calculated. Negative numbers of incremental vaccinated children were considered to be missing in one study.[38] In 3 studies[43,48,51] on school-based influenza vaccination programs, spillover effects were possible to calculate. Spillover effects were measured as the number of additional vaccinated children in the treatment group, as compared to the control group, who received vaccinations somewhere other than the school clinic. Presumably, the increased awareness from the school-based clinic prompted the parents to vaccinate their children outside of the school location.

Incremental cost per vaccinated child:

The average cost of interventions per incrementally vaccinated child, or incremental cost per vaccinated child = total cost/number of incremental vaccinated children.

Number of doses administered:

The number of doses administered due to the intervention (spillover effects not included).

Cost per dose:

The average cost of interventions per dose administered, or cost per dose = total cost/number of doses administered.

All cost measures were adjusted to 2019 US dollars using the Consumer Pricing Index for Medical Care.[53] After an initial assessment of our analytical sample, we decided to present our primary results as medians instead of means, due to the small sample size among stratified results. Medians would be less influenced by outlier values. The median and interquartile ranges were presented when there were more than 3 measures. Where only 2 or 3 measures were available, we reported min-max ranges instead of interquartile ranges. Means weighted by sample size were also reported as secondary results. A formal meta-analysis was not performed due to the variability in intervention types and cost measures. All analyses were conducted in Excel 2016 (Microsoft Corporation, Redmond, Washington).

In our primary results presentation, estimated costs are stratified by intervention type (vaccination programs in schools and organized child care centers; client reminder and recall systems; clinic-based education when used alone; community-based interventions implemented in combination; standing orders; provider assessment and feedback; and healthcare system-based interventions implemented in combination), by children's age (young children: 0–10 years old or in elementary schools, and adolescents: 11–17 years old or in secondary schools), and by vaccine type (childhood series; adolescent series; and influenza vaccines). Community- and healthcare system-based interventions implemented in combination involved a variety of components and outcomes (sometimes more than just vaccinations, eg, well-child care visits[41]), which differed across studies. Therefore, when presented results stratified by intervention type, for those 2 types we decided to show cost measures by individual study rather than by intervention type. Given the heterogeneity in characteristics within intervention type, our estimated costs are further stratified by vaccine type, to provide cost information that might be more meaningful in certain settings which are more homogenous than aggregate intervention type. Among influenza vaccines, we decided to present costs separately for seasonal influenza vaccines and influenza A (H1N1)pdm09 vaccines, which we refer to as 2009 H1N1 pandemic vaccines. We conducted a sensitivity analysis that revisited the primary results by intervention type after excluding the interventions targeting 2009 H1N1 pandemic vaccines, as the costs of those interventions implemented during the pandemic might be very different. For reminder and recall interventions, we assessed costs for different modes, such as mail, postcard, phone call, message, and email, because reminder and recall systems studies included the largest number of studies (n = 15) across all intervention types. For the results stratified by vaccine type and reminder/recall mode, we presented the outcomes focused on cost per capita (ie, cost per child and cost per vaccinated child). In all subgroup analyses described above, we excluded studies that did not report cost breakdowns by children's age, vaccine type, or mode of client reminder and recall systems from the corresponding stratified cost analyses.

Results

The results of the search are shown in Figure 1. After de-duplication, the initial search identified 2,800 studies. After reviewing the titles and abstracts, we excluded 2,761 studies that did not focus on interventions to increase vaccination coverage or that focused on adults or that focused on countries other than the United States. After reviewing the citation lists in the remaining studies and consulting with SMEs, we identified an additional 9 studies that met the inclusion criteria and incorporated them into the review. A total of 48 studies were given a full-text review. During the full-text review, 9 studies that did not report any of the 4 cost measures (defined in the Methods section) were excluded. Two publications[30,54] reported the same costs of school-based clinics in Maine; the one published first[30] was included in the final analyses as a single study. Two other publications[22,55] focused on the same intervention, which was the Centers for Disease Control and Prevention's Assessment, Feedback, Incentives, and eXchange Program in North Carolina. Of these 2 publications, the one that reported more cost information[22] was included as a single study. Following exclusions made during the full text review, there were 37 studies included in the final analytical sample. The risk-of-bias assessment concluded that several studies were at risk of certain types of bias, mainly due to uncontrolled important confounders for nonrandomized studies and unblind participants for randomized controlled studies. The risk of other types of bias, such as selective reporting, seemed low in most of the included studies.

Overall personal/labor costs constituted the majority of the total intervention costs with few exceptions.[20,21,39] Start-up/preclinic and running/clinic costs were roughly comparable.[36,52]

We categorized the 37 studies into 4 groups based on their focus on vaccine type and target population: Childhood series (n = 8), HPV vaccinations and other adolescent series (n = 15), influenza vaccinations (n = 13), and both childhood and adolescent series (n = 1). Among the 13 studies on influenza, 4 focused on younger children, 1 focused on both younger children and adolescents and reported cost breakdowns for each group, and the remaining 8 studies did not report cost breakdowns by age of the target population. Three studies focused on 2009 H1N1 pandemic vaccinations and 10 studies focused on seasonal influenza vaccinations. Most of the included studies can be categorized as 1 of 2 types of interventions: Vaccination programs in schools and organized child care centers (n = 14) and client reminder and recall systems (n = 15). Eight studies focused on 5 other types of interventions. Of the 15 studies on client reminder and recall systems, 14 studies reported cost breakdowns by age of the target population and one study including both young children and adolescents did not break down cost by age. Of the 14 studies on vaccination programs in schools and organized child care centers, 8 studies reported cost breakdowns by age and 6 studies targeted both young children and adolescents but did not report costs separately for them.

Table 1 presents the median and ranges of 4 types of cost measures, stratified by intervention type and children's age. Across all intervention types and age groups, the cost per child ranged from $0.10 to $537.38, and the incremental cost per vaccinated child ranged from $6.52 to $5,098.57. To summarize across all intervention types, the median cost per child ranged from $0.17 (provider assessment and feedback interventions) to $537.38 (a community-based combined intervention involving reminder/recall, case management and home visit). The median cost per vaccinated child ranged from $1.52 (a healthcare system-based combined intervention involving health plan, immunization information system, and physician incentive programs) to $1,221.32 (a community-based intervention involving reminder/recall, case management, and home visit implemented in combination).With respect to intervention type, median incremental cost per vaccinated child, and median cost per dose administered followed the same pattern as median cost per vaccinated child, with the most expensive being one of the community-based combined interventions and the least expensive being one of the healthcare system-based combined interventions. In most cases, median incremental cost per vaccinated child was greater than median cost per vaccinated child, and median cost per vaccinated child was greater than median cost per child (Fig. 2). Means weighted by sample size roughly showed similar rankings of intervention types by cost, although they differed from the medians substantially in magnitudes in many cases.

Table 2 shows cost per child and cost per vaccinated child, stratified into 3 groups corresponding to vaccines in the childhood series, adolescent series, and influenza vaccines. Interventions related to influenza vaccine are further divided by age (0–10 and 11–17 years), and type (seasonal and 2009 H1N1 pandemic vaccines). Overall, interventions targeting the adolescent series had the lowest cost per vaccinated child (median: $8.31), followed by interventions targeting influenza vaccine (median: $29.30) and interventions targeting the childhood series (median: $54.84). Among interventions focusing on influenza vaccinations, the costs varied substantially by age, where the cost per vaccinated child was higher for adolescents, but cost per child was higher for young children. Because the age groups used in the age-stratified analysis in Table 1 corresponded closely with the age groups of children that were targeted by the childhood and adolescent immunization schedule, the results presented in Table 2 were largely consistent with the age-stratified results for each intervention that was presented in Table 1. Among the 3 intervention types where costs could be measured among different age groups (ie, vaccination programs in schools and organized child care centers, client reminder and recall systems, and community-based interventions implemented in combination), interventions targeting children 11 to 17 years were generally less expensive compared to the same intervention targeting children 0 to 10 years. The costs of interventions targeting influenza vaccinations also varied by vaccine type: Interventions targeting 2009 H1N1 pandemic vaccines had higher cost per child (median: $23.65) compared to interventions targeting seasonal influenza vaccine (median cost per child: $6.65). The 3 studies that focused on 2009 H1N1 pandemic vaccines evaluated vaccination programs in schools and organized child care centers. Removing the studies focusing on the 2009 H1N1 pandemic vaccines, we obtained slightly different cost measures for vaccination programs in schools and organized child care centers. In this sensitivity analysis, the median cost per child for all age groups was $7.29, which was quite similar to the full sample measures reported in Table 1.

Client reminder and recall systems were among the least expensive of all the interventions included in this review, having the lowest cost per vaccinated child for young children and the second lowest cost per vaccinated child for adolescents. Table 2 also summarizes the costs of client reminder and recall systems by implementation mode (eg, letter, post card, text message, phone call). In terms of cost per child, the least expensive mode was phone call reminders (median: $0.59) and the most expensive was postcards (median: $10.32). For cost per vaccinated child, phone call reminders were also the least expensive mode (median: $2.39) and letter and phone call combined reminders were among the most expensive modes (median: $132.45).

An online appendix contains additional information. This includes: 1) Details about the methods; 2) Figure 1, the search protocol for PubMed; 3) Table 1, definitions of outcome measures, 4) Table 2, characteristics of individual studies; 5) Table 3 describing bias assessment of nonrandomized studies; 6) Table 4, bias assessment of randomized studies; 7) Table 5, additional cost information by vaccine type; and 8) Table 6, additional cost information by mode of client recall and reminder systems.

Discussion

This study provides a summary of the costs of interventions designed to improve vaccination coverage among children and adolescents in the United States. We reported 4 types of cost measures for 7 intervention strategies, 6 of which have been recommended by the CPSTF based on sufficient evidence of effectiveness. Among these intervention strategies, the median cost per vaccinated child ranged from $1.52 to $1,221.32 and the median incremental cost per vaccinated child ranged from $26.65 to $5,098.57. The most expensive interventions, across all 4 types of cost measures, were 2 community-based combined interventions, while the least expensive intervention varied depending on the type of cost measure. Provider assessment and feedback had the lowest median cost per child and a healthcare system-based combined intervention had the lowest median for the other 3 types of cost measures. Our findings showed that there were variations in costs across different interventions as well as variations in costs for the same intervention across different studies.

The variability in costs across interventions and within the same intervention are likely to be a function of a multitude of characteristics that are unique to any given intervention or intervention setting. These characteristics might include the scope of the intervention, specific program objectives, intervention design, heterogeneity across locations, cost components included, effectiveness, and many other factors. Community-based interventions implemented in combination tend to be more intensive in terms of scope and follow up and may also target special populations with lower vaccination coverage, such as infants born in safety-net hospitals[46] and neonates or adolescents covered by Medicaid.[34,41] By design, such interventions may be more expensive to implement when compared to an intervention implemented alone, at a single moment in time, and targeting a general population. It is also noteworthy that 3 of our cost measures (cost per vaccinated child, incremental cost per vaccinated child, and cost per dose administered) are influenced not only by implementation cost but also by effectiveness. For example, given the same implementation cost it would be more expensive for a less effective intervention to vaccinate one additional child. Examining those measures together with cost per child would help depict intervention costs more thoroughly. We also observed variability among the interventions using client recall and reminder systems, because different modes of recall and reminder systems exhibited different costs. For example, recall and reminders sent by phone and email appeared to have a lower median cost per vaccinated child than those sent by traditional postal service (letter and postcard). Advances in information technology will likely continue to play a role in changing, and hopefully reducing, the cost structure associated with interventions to improve vaccination coverage.

Because the diversity of these characteristics could lead to substantial variations in intervention costs, it is difficult to accurately compare costs across different strategies. For this reason, we do not make recommendations on the priority of these intervention strategies. Local and regional decision-makers should consider all relevant attributes of an intervention, including costs, which ideally are itemized by components (eg, personnel, supplies, et al), benefits, practical feasibility, and the needs of their community, when selecting the most appropriate intervention to implement in their community.

Our review focused on recent assessments of interventions to increase vaccination coverage among children and adolescents in the United States. Therefore, the measures reported in this study may not be directly comparable to those in previous reviews targeting the general population of the United States or to those that looked at other countries,[4,5,8] or to those that focused on effectiveness.[56] One exception is that compared to a review specifically on influenza vaccination among the general population of the United States,[57] our results indicated that the interventions to increase influenza vaccination among children have higher (median) cost per person and higher (median) incremental cost per vaccinated person. Moreover, our cost ranking of intervention strategies was roughly consistent with the ranking reported by the Community Guide[4] even though the Community Guide study included interventions targeting both children and adults in several high-income countries.

This study has some limitations. First, it included only 6 of the 13 CPSTF recommended types of interventions to increase vaccination coverage, with 2 intervention types accounting for more than 80% of the cost measures. A variety of factors could contribute to the small number of studies for some intervention types, including that these interventions may not be commonly implemented, may be difficult to evaluate, or lack cost information. A recent review focusing on effectiveness of interventions to improve access and coverage of adolescent immunizations included more types of interventions.[56] Second, 17 of the included studies were from New York or Colorado and the remaining 20 were from 13 states. Lacking geographic diversity makes it difficult to generalize our results to the regions of the United States that were not covered or to study spatial disparity in intervention costs. Third, many included studies did not report costs in detail or the costs were not consistently defined. For example, about 20% of the included studies did not explicitly report age-stratified cost measures and less than half of the included studies provided data needed to calculate incremental cost per vaccinated child by conducting randomized controlled trials with control groups. Fourth, several studies evaluated interventions that targeted children with specific risk factors for under-vaccination, such as children in rural areas or on Medicaid, and the costs to vaccinate these children may be higher. Future research could focus on identifying any additional disparities in the costs of interventions that specifically target populations with known risk factors. Fifth, there might be bias within and across the included studies. For example, many nonrandomized studies failed to control for important confounders. Due to the heterogeneity in the interventions and relatively small sample size, we were not able to formally assess publication or reporting bias through, for example, funnel plots. However, in most of the included studies cost information was reported as a secondary outcome to effectiveness. Our cumulative evidence on cost would tend to be less influenced by those potential biases. Finally, our literature search has some limitations. One author performed the initial screening by title and abstract. A recent study showed that single-reviewer abstract screening missed 13% of relevant studies.[58] We might omit search terms that helped identify more studies that met our inclusion criteria. We searched peer-reviewed published studies but did not pursue gray literature such as theses/dissertations and working papers.

Despite these limitations, our study offers an up-to-date synthesis of the literature and provides important insights on the costs of interventions designed to increase vaccination coverage among children and adolescents in the United States. Understanding the costs of interventions within different contexts, such as intervention type, age of the target population, and the vaccines of interest could help decision makers in allocating public health funds more efficiently when evaluating potential intervention strategies and in estimating the resources needed for carrying out an intervention. More high-quality evidence on cost of interventions within different specific contexts, which can be combined with existing evidence on effectiveness of interventions,[56] can be a priority for future study.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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What This Systematic Review Adds

This systematic review examined the costs of interventions designed to increase vaccination coverage among children and adolescents in the United States.

The costs of interventions varied substantially by intervention type, vaccine, and age group targeted.

How To Use This Systematic Review

Providers and communities looking to increase vaccination coverage among children and adolescents in the United States could use these results to inform their allocation of available resources across types of interventions, vaccines, and target populations.

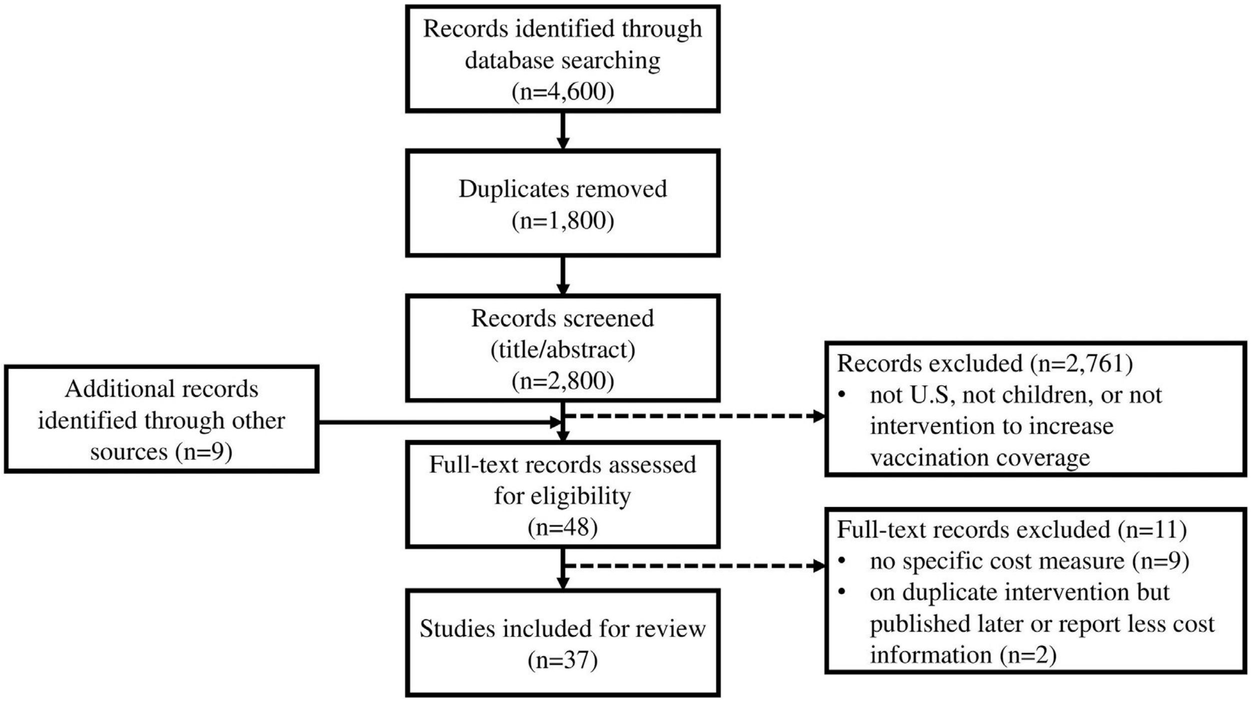

Figure 1.
Flow chart of literature search.

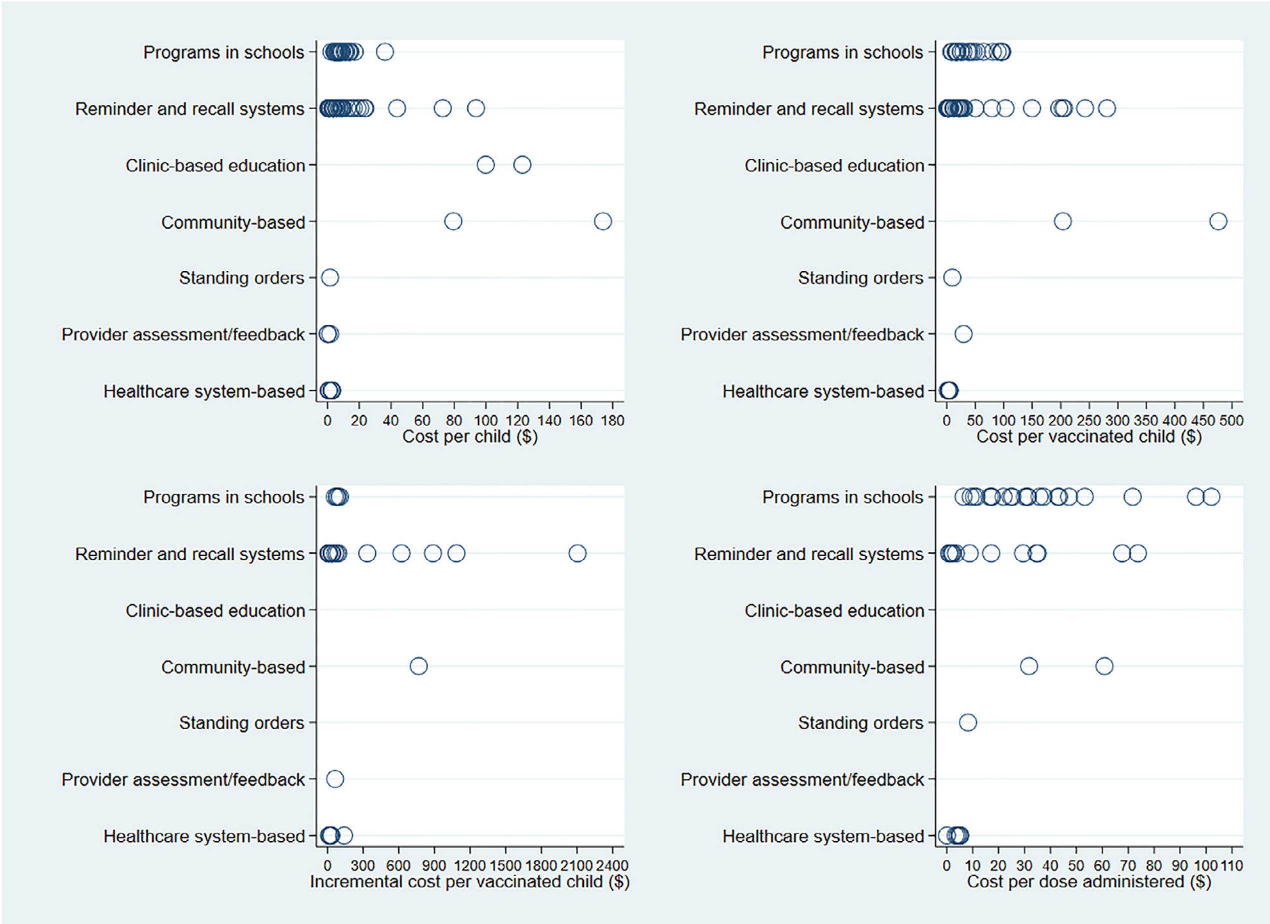

Figure 2.

Costs by intervention type, all measures in 2019 US$. One measure of cost per child ($537.38, from community-based interventions), 2 measures of cost per vaccinated child ($792.40 and $1,221.32, from programs in schools and community-based interventions), 2 measures of incremental cost per vaccinated child ($4,305.54 and $5,098.57, from reminder and recall systems and community-based interventions) and one measure of cost per dose administered ($290.15, from programs in schools) are not shown as these measures are significant outliers that did not fit in the plot area.

Table 1.

Cost by intervention strategy and children's age group, in 2019 US$

Intervention Strategy	Outcome	Cost Per Child*	Cost Per Vaccinated Child*	Incremental Cost Per Vaccinated Child*,†	Cost Per Dose Administered*
Enhancing access to vaccination services					
Vaccination programs in schools and organized child care centers (all age groups)	Median (IQR)	7.71 (5.26, 11.30)	39.62 (18.76, 80.82)	76.52‡ (76.33, 89.47)	31.08 (17.36, 45.27)
	Sample-weighted mean	20.59	54.06	82.72	56.86
	Number of measures	24	21	5	23
	References	16–18,21,23,26,29,36,43,48,51,52	16,18,23,26,29,36,43,48,51,52	43,48,51	16,17,23,24,26,29,30,36,43,48,52
0–10 y old (or in elementary schools)	Median (IQR)	11.11 (8.87, 12.78)	80.82 (64.47, 89.51)	83.00‡ (76.47, 93.04)	51.51 (31.26, 79.30)
	Sample-weighted mean	22.92	78.42	87.26	66.45
	Number of measures	7	5	4	4
	References	17,36,43,48,51	36,43,48,51	43,48,51	17,36,43
11–17 y old (or in secondary schools)	Median (IQR)	9.61 (4.19, 15.12)	97.51 (96.12, 792.40)§	59.33‡	96.12 (30.19, 290.15)§
	Sample-weighted mean	9.27	364.57	59.33	160.78
	Number of measures	4	3	1	3
	References	21,23,48,52	23,48,52	48	23,48,52
Increasing community demand for vaccinations					
Client reminder and recall systems (all age groups)	Median (IQR)	5.50 (3.16, 12.54)	22.13 (5.74, 64.82)	51.92 (33.83, 550.01)	8.85 (2.02, 34.64)
	Sample-weighted mean	2.50	16.47	173.74	6.58
	Number of measures	37	31	18	13
	References	19,25,27,28,31,32,37–40,42,44,45,47,49	19,25,27,28,32,38–40,42,44,45,47,49	38–40,42,44,45,47,49	25,37,38,40,42,45,47
0–10 y old (or in elementary schools)	Median (IQR)	9.62 (3.94, 21.42)	29.70 (21.98, 161.45)	//	32.04¶ (29.43, 34.64)§

Intervention Strategy	Outcome	Cost Per Child*	Cost Per Vaccinated Child*	Incremental Cost Per Vaccinated Child*,†	Cost Per Dose Administered*
	Sample-weighted mean	3.69	28.04		32.05
	Number of measures	15	12		2
	References	19,27,28,31,32,37	19,27,28,32		37
11 –17 y old (or in secondary schools)	Median (IQR)	3.85 (1.68, 8.36)	12.54 (3.01, 25.44)	41.24 (33.07, 621.92)	3.55 (1.81, 26.14)‡
	Sample-weighted mean	1.78	13.16	177.49	6.09
	Number of measures	21	18	17	11
	References	25,38–40,42,44,45,47	25,38–40,42,44,45,47	38–40,42,44,45,47	25,38,42,45,47
Clinic-based education when used alone (9–17 y old)	Median (IQR)	111.36¶ (99.78, 122.94)§	‖	‖	‖
	Sample-weighted mean	108.15			
	Number of measures	2			
	References	20			
Provider- or healthcare system-based interventions					
Standing orders (all age groups)	Median (IQR)	1.57	9.73	‖	8.22
	Sample-weighted mean	1.57	9.73		8.22
	Number of measures	1	1		1
	References	35	35		35
Provider assessment and feedback (11–17 y old)	Median (IQR)	0.17 (0.10, 1.62)§	29.54	63.29	29.54
	Sample-weighted mean	0.36	29.54	63.29	29.54
	Number of measures	3	1	1	1
	References	22,50	50	50	50
Interventions implemented in combination (individual studies)					
Community-based (0–10 y old): education, reminder/recall, and home visit	Median (IQR)	173.84	476.29	‖	31.75

Intervention Strategy	Outcome	Cost Per Child*	Cost Per Vaccinated Child*	Incremental Cost Per Vaccinated Child*,†	Cost Per Dose Administered*
	Sample-weighted mean	173.84	476.29		31.75
	Number of measures	1	1		1
	References	[34]	[34]		[34]
Community-based (0–10 y old): reminder/recall, case management and home visit#	Median (IQR)	537.38	1,221.32	5,098.57	//
	Sample-weighted mean	537.38	1,221.32	5,098.57	
	Number of measures	1	1	1	
	References	[46]	[46]	[46]	
Community-based (11–17 y old): patient tracking, reminder/recall, and home visit	Median (IQR)	79.36	203.66	767.02	60.86
	Sample-weighted mean	79.36	203.66	767.02	60.86
	Number of measures	1	1	1	1
	References	[41]	[41]	[41]	[41]
Healthcare system-based (11 –17 y old): education, electronic alerts, audit and feedback, and reminder/recall	Median (IQR)	2.50 (1.41, 2.74)	4.57 (4.14, 5.00)	26.65 (15.82, 32.57)	4.57 (4.14, 5.00)
	Sample-weighted mean	1.57	4.35	25.67	4.35
	Number of measures	6	6	5	6
	References	[38]	[38]	[38]	[38]
Healthcare system-based (0–17 y old): health plan, immunization information system, physician incentive programs	Median (IQR)	0.81	1.52	//	0.10
	Sample-weighted mean	0.81	1.52		0.10
	Number of measures	1	1		1
	References	[33]	[33]		[33]

IQR indicates interquartile range.

The numbers of measures can exceed the numbers of studies because a single study can report on multiple measures. The numbers of measures by age may not add up to the total number of measures because the measures[16,18,24,26,29,30,49] that did not report cost breakdowns by children’s age group (young children vs adolescents) are not included in either subgroup by age.

[*] If the number of measures is even, the median is the average of the 2 middle measures.

[†] Incremental cost per vaccinated child is the average cost over vaccinated children in addition to those who were vaccinated in the absence of intervention in control group.

[‡] In general, the incremental costs are greater than the cost per vaccinated child; however for school-based programs (all about influenza),[43,48,51] they consider the spillover effects of children who got vaccinated elsewhere, which yielded a lower incremental cost measure than might be expected.

[§] Min-max range is presented when there are 2 or 3 measures.

[//] Values are missing because none of the reviewed studies report them.

[¶] Mean with 2 measures.

[#] An intervention that targeted a low-income population with about 90% eligible for Medicaid.

Table 2.

Cost by vaccine type and mode of client recall and reminder systems, in 2019 US$

Vaccine	Outcome	Cost Per Child*	Cost Per Vaccinated Child*
Childhood series (ACIP Recommendation)	Median (IQR)	15.14 (4.02, 43.86)	54.84 (22.62, 231.29)
	Sample-weighted Mean	8.27	48.02
	Number of measures	17	14
	References	19,27,28,31,32,34,37,46	19,27,28,32,34,46
Adolescent series (HPV, MenACWY, Tdap)†	Median (IQR)	3.65 (1.49, 8.95);	8.31 (3.81, 34.74);
	Sample-weighted mean	3.67	63.47
	Number of measures	36	28
	References	20–23,25,38–42,44,45,47,50,52	23,25,38–42,44,45,47,50,52
Influenza (all age and subtype groups)	Median (IQR)	6.99 (4.74, 9.92)	29.30 (16.53, 53.23)
	Sample-weighted mean	20.57	34.49
	Number of measures	23	21
	References	16–18,26,29,35,36,43,48,49,51	16,18,26,29,35,36,43,48,49,51
Influenza, by children's age			
0–10 y old	Median (IQR)	11.11 (8.87, 12.78)	80.82 (64.47, 89.51)
	Sample-weighted mean	22.92	78.42
	Number of measures	7	5
	References	17,36,43,48,51	36,43,48,51
11–17 y old	Median (IQR)	2.42;	96.12;
	Sample-weighted mean	2.42	96.12
	Number of measures	1	1
	References	48	48
Influenza, by subtype			
Seasonal	Median (IQR)	6.65 (4.53, 8.58)	29.30 (16.53, 53.23)
	Sample-weighted mean	9.64	34.49
	Number of measures	21	21
	References	16,18,26,29,35,36,43,48,49,51	16,18,26,29,35,36,43,48,49,51
2009 H1N1 pandemic	Median (IQR)	23.65‡ (11.11, 36.19)§	‖

Vaccine	Outcome	Cost Per Child*	Cost Per Vaccinated Child*
	Sample-weighted mean	23.65	
	Number of measures	2	
	References	[17]	
Mode of client recall and reminder systems			
Mail			
Letter	Median (IQR)	9.62 (0.79, 23.29)§	104.11‡ (4.99, 203.23)§
	Sample-weighted mean	1.26	8.33
	Number of measures	3	2
	References	[37,40,45]	[40,45]
Postcard	Median (IQR)	10.32‡ (5.50, 15.14)§	24.00‡ (23.90, 24.10)§
	Sample-weighted mean	7.59	23.94
	Number of measures	2	2
	References	[28,44]	[28,44]
Letter + Postcard	Median (IQR)	4.02 (3.87, 18.95)§	30.41 (21.55, 79.28)§
	Sample-weighted mean	4.71	26.55
	Number of measures	3	3
	References	[27,32]	[27,32]
Phone			
Phone call	Median (IQR)	0.59 (0.56, 20.69)	2.39 (1.00, 205.86)
	Sample-weighted mean	4.09	37.35
	Number of measures	5	5
	References	[28,38,40]	[28,38,40]
Text message	Median (IQR)	3.65 (3.16, 6.13)	25.96 (11.38, 50.35)
	Sample-weighted mean	5.23	34.94
	Number of measures	5	5
	References	[42,44,49]	[42,44,49]
Letter + Phone call	Median (IQR)	8.73 (7.72, 14.69)	132.45‡ (22.28, 242.63)§
	Sample-weighted mean	15.00	102.45
	Number of measures	6	2
	References	[19,37,39]	[19,39]

Vaccine	Outcome	Cost Per Child*	Cost Per Vaccinated Child*
Email	Median (IQR)	3.65	17.56
	Sample-weighted mean	3.65	17.56
	Number of measures	1	1
	References	44	44

IQR indicates interquartile range; ACIP, Advisory Committee on Immunization Practices; HPV, human papillomavirus; MenACWY, Meningococcal group A, C, W-135 and Y; Tdap, tetanus, diphtheria, and pertussis.

The numbers of measures can exceed the numbers of studies because a single study can report on multiple measures. The numbers of measures do not add up to the total number of measures because the measures[33] that did not report cost breakdowns by vaccine are not included in any subgroup by vaccine, the measures[16,18,24,26,29,30,35,49] that did not report cost breakdowns by age for influenza vaccine are not included in either subgroup by age, and the measures[25,27,28,31,32,47] that did not report cost breakdowns by mode of recall and reminder are not included in any subgroup by mode.

*If the number of measures is even, the median is the average of the 2 middle measures.

†Varicella vaccination is part of the childhood recommendation schedule rather than the adolescent schedule. In 3 studies[22,33,44] varicella vaccinations were included as part of a catch-up program aimed at adolescents who missed their childhood varicella vaccinations.

‡Mean with 2 measures.

§Min-max range is presented when there are 2 or 3 measures.

//Values are missing because none of the reviewed studies report them.