Divya Parmar, Elaine M Baruwa, Patrick Zuber and Souleymane Kone

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Impact of wastage on single and multi-dose vaccine vials

Implications for introducing pneumococcal vaccines in developing countries

Divya Parmar,[1,2,*] Elaine M. Baruwa,[1,2] Patrick Zuber[3] and Souleymane Kone[3]

[1]GAVI's PneumoADIP; Johns Hopkins Bloomberg School of Public Health; Baltimore, MD USA; [2]Abt Associates; Bethesda, MD USA; [3]Immunization and Biologicals; World Health Organization; Geneva, Switzerland

Keywords: vaccine wastage, pneumococcal, PCV, developing countries, immunization

Abbreviations: WHO, world health organization; PCV, pneumococcal conjugate vaccine; BCG, baccile calmette guerin; DTP, diptheria-tetanus-pertussis; Hib, *Haemophilus influenzae type b*; HepB, hepatitis B; GAVI, The Global Alliance for Vaccines and Immunization; FSP, financial sustainability plans; OPV, oral polio vaccine; PQS, performance, quality and safety; FVC, fully vaccinated child; MDVP, multi-dose vial policy; PneumoADIP, the pneumococcal vaccines accelerated development and introduction plan

Introduction: Pneumococcal conjugate vaccines are expensive relative to those in the EPI systems of low-income countries. The current single-dose presentation costs more to store in the cold chain relative to multi-dose presentations but also has lower wastage rates. It is, therefore, important to determine the optimal balance of vial size and storage costs after adjusting for wastage.

Objectives: To project the cost implications of wastage when vaccine wastage rates vary across vial sizes using country specific wastage data.

Results: Only 19 (26%) of 72 GAVI eligible countries had analyzable wastage data at WHO/HQ. The median wastage rates for single, 2- and 10-dose vials were 5%, 7% and 10% respectively. However wastage varied between 1–10%, 1–27% and 4–44% for single, 2- and 10-dose vials respectively. The increased variance for multi-dose vial wastage implied wastage costs potentially greater than the savings realized from lower storage volumes.

Methods: For each potential vial size, we estimated cold chain costs and the cost of wasted vaccine doses using country level wastage data and projections of the price per dose of vaccine and cold chain storage.

Conclusions: The optimal vial-size for PCV is dependent upon country specific wastage rates but few countries have these data. There may be a role for both single and multi-dose vials that is best determined by local management and storage capacities making local wastage data critical. Without effective wastage monitoring and control there is a risk that wastage costs will possibly exceed the savings from multi-dose vials' lower storage costs.

Introduction

Infections caused by S*treptococcus Pneumoniae* are a major cause of morbidity and mortality all over the world. Pneumonia, febrile bacteraemia and meningitis are the most common manifestations of invasive pneumococcal disease. The World Health Organization (WHO) estimates that up to one million children under five die each year from pneumococcal diseases.[1] Most of these deaths occur in developing countries where pneumococcus is probably the most important pathogen of early infancy. Currently a 7-valent Pneumococcal Conjugate Vaccine (PCV), manufactured by Wyeth, is available. Availability of 10- and 13-valent vaccines are expected in the next 1–2 years.[2]

New vaccines such as PCV are expensive and are expected to cost 5–$7 per dose in developing countries[3] and 3 doses of PCV are required for each child. It has, therefore, become exceedingly important to determine its optimal vial size. Vial size refers to the size of the vial in which the vaccine is supplied. Multi-dose vials can have 2, 5, 6, 10, 20, etc. doses of vaccine in a vial while a single-dose vial has just one dose of the vaccine. The manufacturing costs in a multi-dose vial are spread over many doses and therefore they tend to cost less per dose as compared to a single-dose vial. Further multi-dose vials have lower cold chain costs however they are also thought to be associated with higher wastage.

There is very limited literature examining the preferred vial size for EPI vaccines. In Madagascar, a mixed solution was found

*Correspondence to: Divya Parmar; Email: dparmar@jhsph.edu
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Table 1. Summary of data on vaccine wastage rates available for 19 GAVI eligible countries

Vial size	Range (Min-Max)	Percentile	Value	Median	N	Formulation
1	1%–10%	P25	5%	5%	7	Liquid[1]
		P75	5%			
2	1%–27%	P25	5%	7%	26	Liquid-lyophilized[2]
		P75	11%			
10	4%–44%	P25	8%	10%	8	Liquid[3]
		P75	13%			

[1]Pentavalent (single-dose vial); [2]Pentavalent (2-dose vial); [3]DTP, DTP-HepB, HepB.

to be most appropriate thus multi-dose vials were recommended for routine mass immunization campaigns while single-dose vaccines were recommended for non-routine immunization days.[4] In Bangladesh, it was found that the existing cold-chain equipment had enough spare capacity to introduce and sustain the storage of single-dose vials of Hepatitis B vaccine.[5] This would have been of great potential benefit to Bangladesh, which has reported very high multi-dose wastage rates, 30–59% at ward level for DTP (Diphtheria-Tetanus-Pertussis) and as high as 84% for BCG (Bacillus Calmette Guérin).[6] A study assessing the cost effectiveness of using a single-dose pre-filled Uniject HepB presentation in Indonesia found that although the cost per injection was lower using vials and syringes, after adjusting for wastage there was no price advantage over the use of a Uniject device.[7]

The first objective of this study is to determine the cost implications of wastage when wastage rates vary over vial sizes. Using simple assumptions about the cost of PCV in different vial sizes, we estimate and compare the costs of vaccinating a hypothetical birth cohort over a range of wastage rates and vial sizes. This analysis helps to put the study in context by showing how much vaccine wastage might cost donors/countries if they were to introduce PCV at current wastage rates. The second objective is to repeat this exercise to estimate the potential cost of wastage for specific countries.

Since PCV is a new vaccine, data on wastage rates for PCV in any vial size is not available. According to WHO guidelines, if the new vaccine is of a similar formulation, follows a similar schedule and there is no change in vial size then the wastage rates for the existing vaccine can be used to estimate the requirements for the new vaccine.[8] Therefore the analysis used the wastage rates for other vaccines to estimate the likely cost of wastage of PCV in different vials. Since PCV is a liquid vaccine, analysis used data available from other liquid vaccines as far as possible. Due to lack of data if other vaccine formulations are used, the implications of using such formulations are stated.

Results

Wastage rates. The availability of country-specific, vial-size specific and vaccine-formulation specific wastage rate data is very limited. From 72 GAVI eligible countries, data was available for only 19 countries.

Table 1 shows the range, median, 25th and 75th percentiles for wastage rates by vial size and formulation.

According to the MDVP of WHO, multi-dose vials of vaccines like Hib, DTP and HepB from which one or more doses of vaccine have been removed during an immunization session can be used for up to 4 weeks if kept under appropriate conditions like cold chain. This is applicable for only liquid vaccines that contain preservatives. The 2-dose wastage rates are for DTPHepBHib pentavalent liquid + lyophilized (LLy) vaccine. Once opened and reconstituted, the vaccine must be used immediately and any unused doses have to be discarded. The 10-dose vial rates are all for liquid vaccines which can be used for longer periods. MDVP may therefore be responsible for the low 10-dose vial wastage, diminishing the vial size effect. Currently, we are not aware of any manufacturer intending to use a preservative in the liquid PCV vaccine and so we believe that wastage rates for a 10-dose PCV vial would be higher than those shown here; the 2-dose vial wastage would be similar.

Vaccine costs. To see the impact of wastage on PCV, two-way sensitivity analyses varying the wastage rates for single-dose vials with those of 2 and 10-dose vials were conducted, **Figure 1**. Wastage for single-dose vial was varied from 0–10% while 0–20% for a multi-dose vial of PCV. The graph shows the pair wise comparisons of PCV costs between a single and a multi-dose vial at different wastage rates. Since we do not anticipate that any country should have more than 10% wastage using a single-dose vial, it can be seen that a 2-dose vial is always undesirable compared to a single-dose vial, once the 2-dose wastage rates exceed 11% (1b). Similarly, a 10-dose vial is always undesirable once its wastage exceed 14% (1a).

In **Figure 2**, we introduce the notion of discounting the price per dose for a multi-dose vial as compared to a single-dose vial. Holding the price per dose in a single-dose vial at $5, if 10-dose vial is $0.25 cheaper per dose (Point A), 10-dose vial wastage needs to be 5 percentage points higher than the wastage for a single-dose vial in order for the single-dose vial to be cheaper. If the difference in wastage is less than 5 percentage points, then the 10-dose vial is cheaper. Since our limited data suggests that single-dose vial median wastage is 5%, this implies that if 10-dose vial wastage is higher than 10%, a single-dose vial is cheaper even with the $0.25 discount. With a $0.50 discount, the single-dose vial does not become more efficient until the 10-dose vial wastage exceeds 15%. Note that these results are not adjusted for cold chain costs.

The costs expected for different vial-sizes, adjusted for cold chain, for Country A are shown in **Figure 3**. We see that when wastage rates are as low as the 25th percentile, the 10-dose vial

vaccine is most efficient. However, the extra expense in terms of vaccine costs and storage costs when the vaccine wastage rate approximates the 75th percentile reverses this result with the single-dose vial becoming more efficient. This result holds comparing a single-dose to a 2-dose vial or from a 2-dose to a 10-dose vial, regardless of whether 25th or 75th percentile rates are used.

This analysis takes into account the costs of PCV and cold chain for only one year. In practice, cost of cold chain is spread across several years while the cost of vaccines is incurred yearly. Therefore, once cold chain investments are made, the benefits of reducing wastage by changing vial size carry over for a longer period than has been presented here while the cost of vaccines wasted will be incurred for each of those years.

Country specific costs of wastage. Table 2 shows country specific costs of vaccine wasted for currently used DTPHepBHib pentavalent and hypothetical PCV presentations. Cost of wastage for PCV is shown for all countries. Cost of wastage for pentavalent vaccine is only shown for countries where wastage rates for pentavalent is known. Pentavalent is chosen for comparison as data on wastage rates for this vaccine is known for most of the countries included in this analysis.

Using empirical wastage rates, almost $4.5 million worth pentavalent vaccines could have been wasted in Kenya in 2005, when the reported wastage rate was 27%. In Bolivia this figure is estimated to be $0.13 million in 2003, with 5% wastage. If Kenya, with wastage rate of 27%, were to introduce PCV in a single-dose vial, the cost of vaccine wastage would be about $6 million. In 2006, Kenya reduced its wastage to 5% and at this wastage rate Kenya would save almost $0.55million. The purpose of **Table 2** is to illustrate the fact that the absolute cost of wastage can be very large and if steps are not taken to control wastage this cost will increase when a more expensive vaccine is introduced. This table suggests that there can be substantial savings both at the country and donor levels if wastage can be rigorously monitored and controlled.

Country specific comparisons adjusting for cold chain costs. The difference in vaccine and cold chain costs, associated with different vial-sizes of PCV were estimated for countries. As wastage rates for PCV are not available, wastage rates available for other vaccines for that country are used to calculate the cost of vaccinating a child with 3 doses of PCV. We present the data for Mali, Kenya and Ghana, for which we have more than one available wastage rate, to illustrate the impact of wastage for different vial-sizes (**Fig. 4**).

For Kenya, at almost any wastage rate (5 to 27%), a single-dose vial of PCV would be optimal compared to a 2-dose vial, with the costs of procuring excess vaccine far outweighing the cost of expanding cold chain capacity, as the 27% rate is approached. It is unrealistic to assume that any country can reduce wastage to 0% and 5% is probably an acceptable and achievable target.

We note that the drop in wastage from 27% to 5% occurred within a single year. We have no information as to why this occurred. This level of wastage reduction does not appear to have been foreseen by even Kenya's planners as the Financial Sustainability Plan (FSP) for Kenya used wastage rates of

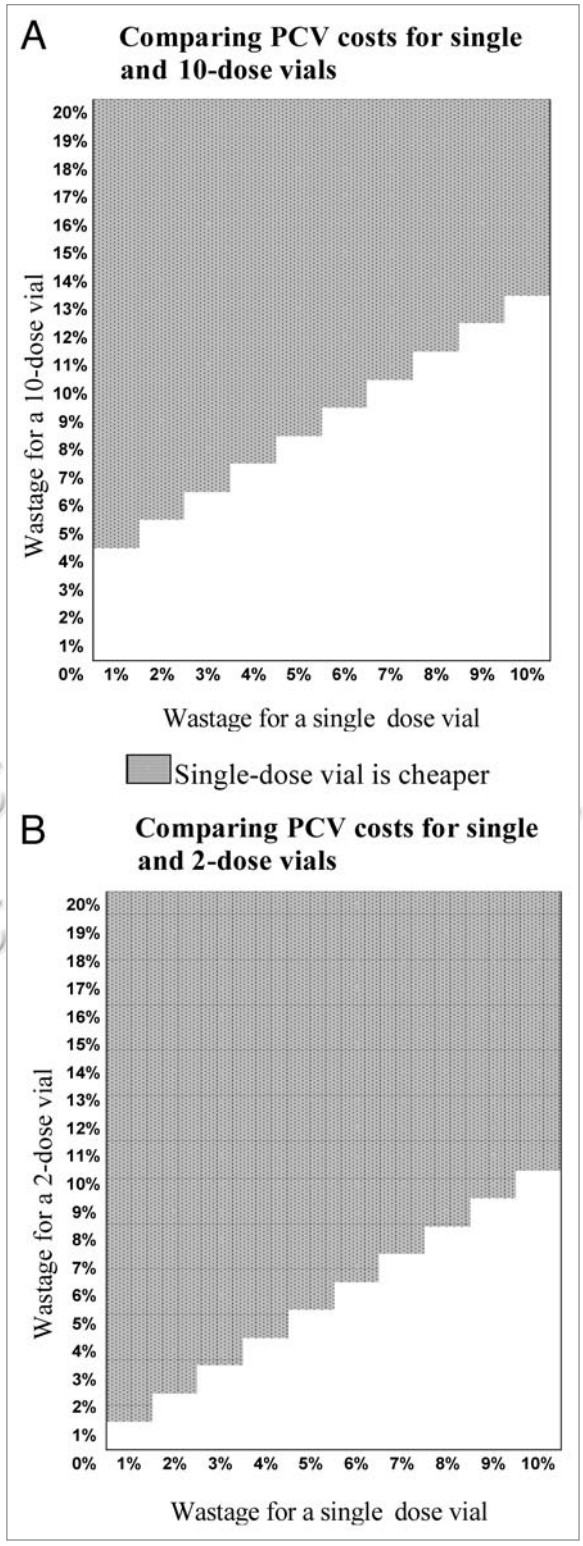


Figure 1. Sensitivity analysis: Comparing cost per dose of PCV in different vial-sizes. (Cost does not include the cold chain costs) Price of PCV: $5/dose (single-dose vial); $5/dose (2-dose vial); $4.80/dose (10-dose vial).

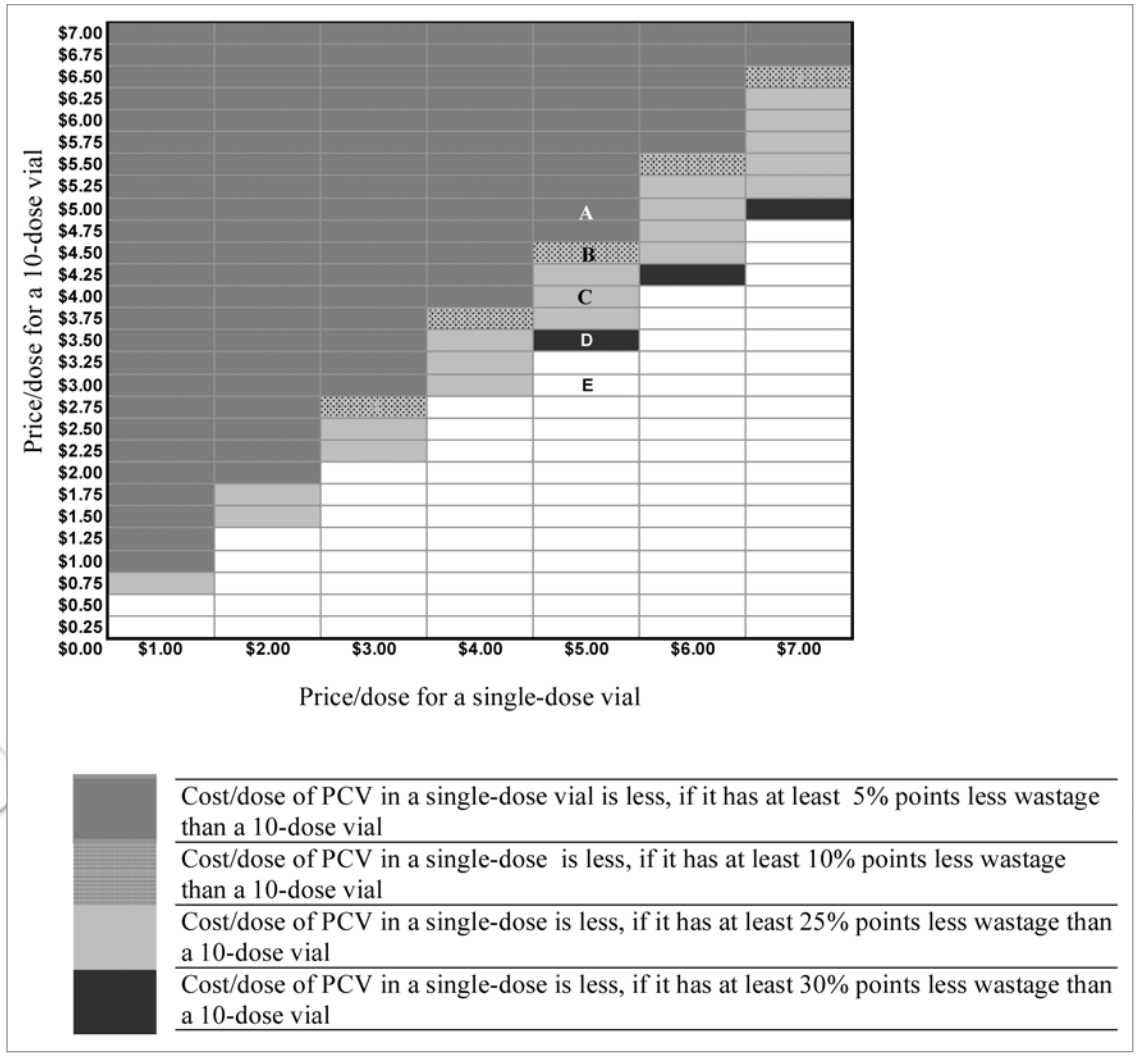


Figure 2. Two-way sensitivity analysis: Comparing cost per dose of PCV in single and 10-dose vials for different price per dose (Cost includes cold chain costs). From A to E, the price of PCV in single-dose vial is constant at 5$; the optimal vial size will depend on the price/dose of PCV in a 10-dose vial and the difference in wastage between the vial-sizes. e.g., Point A: single-dose vial costs $5/dose, same as a 10-dose vial; single-dose vial will be cheaper if its wastage is at least 5% points lower than that for a 10-dose vial. Point B: 10-dose vial costs $4.50/dose; single-dose vial will be cheaper if its wastage is at least 10% points lower than that for a 10-dose vial.

22 and 20% for 2005 and 2006 to estimate the requirement for DTP-HepB vaccine.[9]

Ghana on the other hand, had a relatively low wastage for 2-dose pentavalent vaccines. With wastage of 3% the 2-dose is likely to be the cheapest but if the wastage increases to 6%, a single-dose vial becomes more cost efficient.

Mali, which had wastage rates for both a 2-dose and a 10-dose vial over 2 years, reduced its 10-dose vial wastage rate from 17 to 8% between 2004 and 2005. This difference in wastage would potentially reduce costs by $756,000 or $1.70 per fully vaccinated child (FVC) if the vaccine in question was PCV.

Discussion

The main objectives of this study were to determine the cost implications of wastage in general, given that wastage is expected to vary according to vial size and at a country specific level. The main finding is that there is insufficient monitoring and control of vaccine wastage in GAVI eligible countries assuming that the data available from the WHO are indeed representative of the currently available data for GAVI countries. We were able to obtain wastage rate data for only 19 of the 72 GAVI eligible countries. Where the available data identified vaccine formulation, vial size was not always specified. This is important as the data presented here strongly suggests that wastage differs by vaccine formulation and vial size, with lyophilized vaccines having higher wastage than liquid and larger vials having higher wastage than smaller vials. In addition, we hypothesize that if few countries are reporting wastage to WHO, it is likely that few countries are monitoring wastage and therefore wastage is likely to be higher in the remaining 74% of GAVI countries not considered in this analysis due to the lack of wastage data. Though this is most likely the reason for many countries that don't have vaccine wastage data, it needs to be explored further.

It is possible that the lack of focus on wastage may be due to the fact that the primary objective to date has been to vaccinate as many children as possible. The efficiency with which this objective is achieved has been secondary, particularly when vaccines are relatively cheap (or donor financed). Since PCV is relatively expensive, the potential costs of wastage are likely to be high. Therefore, there is an urgent need to improve wastage monitoring.

This study shows that wastage rates can have a major impact on the cost of a FVC when vaccines are expensive. With high wastage rates, as seen for multi-dose presentations in many countries, countries incur avoidable costs from over-ordering vaccines and storing this 'surplus'. A single-dose vial can avoid these costs.

In general, there is limited donor funding for the maintenance and running of a cold chain system compared to what is available for vaccine procurement. If countries pay for most or all of their own cold chain management it is not unreasonable for them to limit cold chain costs to the best of their ability.

Single or multi-dose vials can minimize costs but the optimal vial-size choice is very sensitive to country specific wastage rates. Since wastage differs across countries, one particular vial-size may not be applicable for all countries. The optimal vial-size also depends on the immunization coverage, session size and number of delivery points. For larger sessions and higher coverage rates a multi-dose vial may be more apt. But for smaller sessions if the 10-dose vial of PCV doesn't contain a preservative, once opened it will have to be used in the same session and any unused doses will have to be discarded. In this case the cost of wastage is likely to be high. Therefore, the optimal solution may be a mix of different vial sizes. In this analysis, a single-dose vial is compared to a 10-dose vial. Further research needs to be done to consider other in-between sizes.

Many countries would find it cheaper to introduce 10-dose vials upfront when they consider cold chain investment costs. But without first analyzing the wastage rates in that country this can be an extremely costly solution. For a global or a bilateral donor, who is funding PCV in many countries, lack of country-specific wastage rates makes a 10-dose vial potentially costly as the cost of wastage in countries with higher wastage rates is likely to vastly outweigh the savings in cold chain storage costs in countries with low rates. Currently, PCV is available only in single-dose prefilled glass syringes that are not automatically disabled, which leads to increased waste disposal and safety concerns associated with the potential reuse of syringes and needles especially for developing countries. Moreover, it is provided in packages of 10 syringes requiring approximately 61.2 cubic centimeters per dose, which will require substantial increases in cold chain and delivery systems and is therefore not a viable solution for most of the developing countries.

Further, research is required to study the cost implications of increasing shipment frequencies which can reduce volume requirements both into and within countries and may provide a feasible solution to the cold chain capacity issues.

Study limitations. Data available on wastage rates was extremely limited and we were unable to validate the estimates in this analysis. Wastage rates were available for only 19 countries, amounting to 41 data points. Ghana and Malawi accounted for 7 of these points. Malawi was the only country which had regional and central surveillance data on opened and closed vial wastage to support the estimates of wastage rate. Bangladesh was the only country from South East Asia and it is questionable as to whether it truly represents the region as it has relatively high wastage rates. In addition, Mali, Rwanda, Niger and Kenya each reported sharp decreases in their wastage rates within 2–3 years and we are only able to hypothesize the reasons for these decreases. It is possible that the application of the MDVP lowered wastage in Niger and Mali or maybe these countries went through a 'learning curve' and lowered their wastage as their health workers grew familiar with the vaccines. However, DTP was not new to Niger, and Rwanda had introduced pentavalent 3 years prior to the wastage decrease, suggesting that the learning curve took up to 5 years.

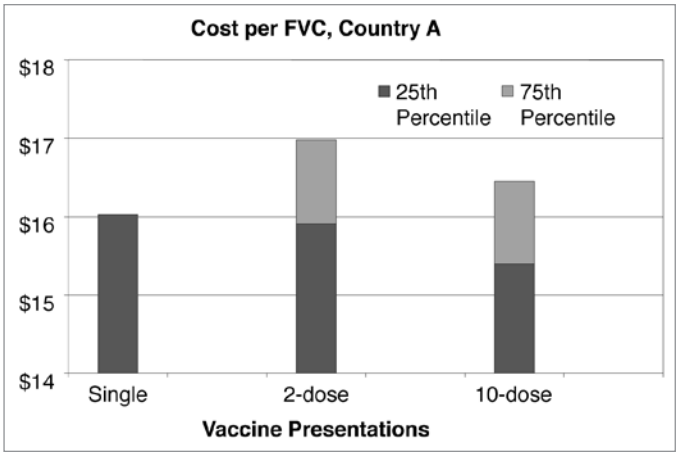


Figure 3. Cost for a fully vaccinated child (FVC) with 3 doses of PCV, adjusted for cold chain costs, Country A.

Due to lack of data we were unable to identify the cause of wastage. If most of the wastage is occurring due to cold chain failures like inadequate infrastructure, power shortages and poor maintenance, changing the vial size will not reduce this wastage. In fact by using single-dose vials, which are more expensive, the cost of wastage from these causes can be further increased.

Due to lack of data only cost of cold-rooms at central level and cost of ice-lined refrigerators at the provincial and district levels are considered in cold-chain costs. Other cold chain costs like transportation and maintenance are not included. These costs are underestimated for both multi and single dose-vials but since the cold chain requirements of single-dose vials are more, this favours single-dose vials more. It should also be noted that the cost of expanding cold chain systems is spread across years, but the cost of wasted vaccines will be incurred every year.

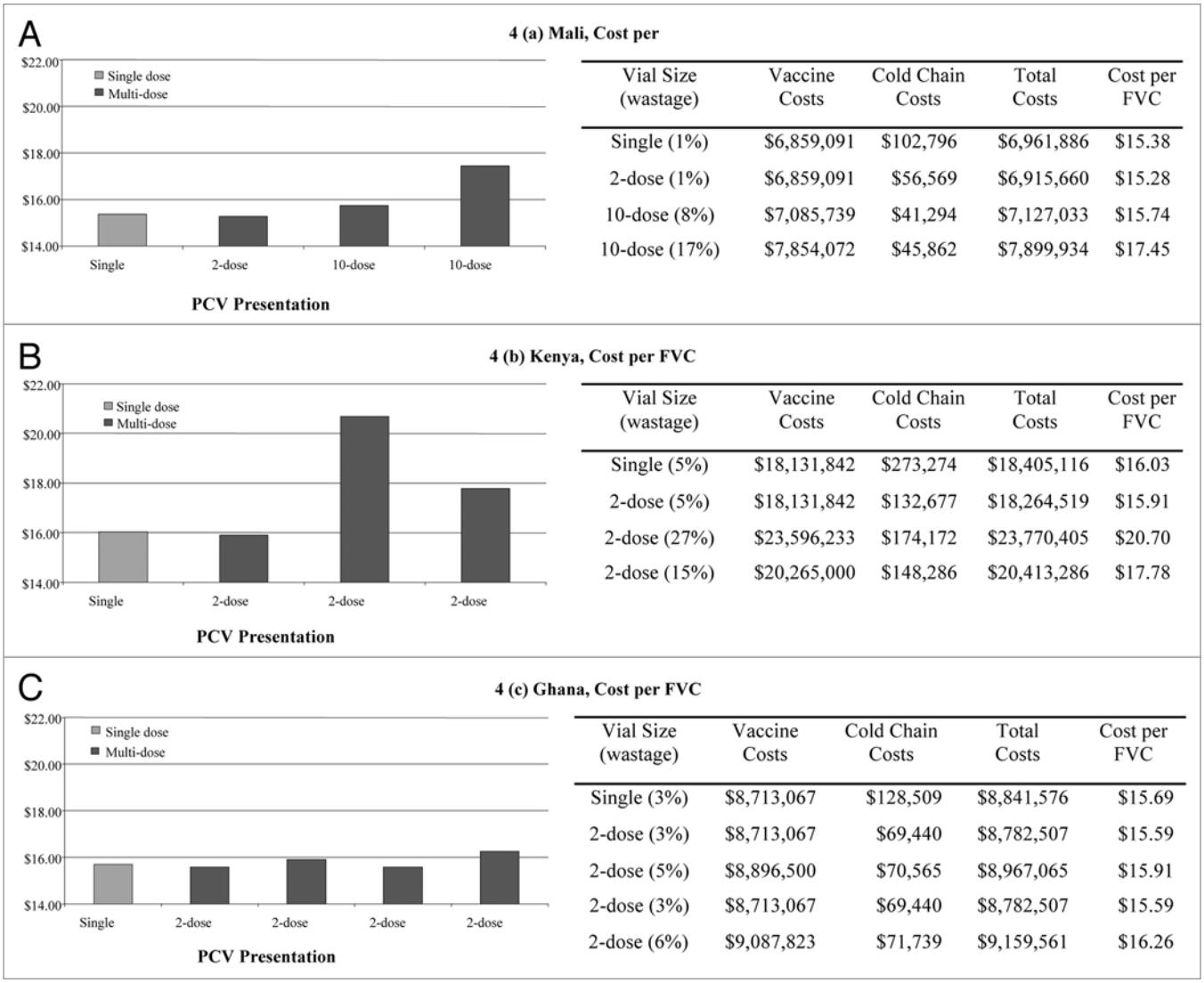
Materials and Methods

Empirical wastage rates. Vaccine wastage rates for 19 GAVI eligible countries were available from WHO Headquarters, Geneva. Vaccines were categorized according to their formulation: liquid (L), lyophilized (Ly) or liquid + lyophilized (LLy) and vial size. This information was cross-references from the WHO Vaccine

Table 2. Wastage costs for pentavalent and hypothetical PCV introduction, using country's empirical wastage rate data

Country	Year	Vial size/ vaccine	Vaccine type/wastage (%)[1]	Coverage (%)	Birth cohort ('000)	Total cost of wastage ($)		Cost of wastage per FVC for PCV[2] ($)
						Penta	PCV[2]	
Bolivia	2006	1/Penta	L/1	88	251	12,416	16,555	0.08
Bolivia	2003	1/Penta	L/5	88	251	130,041	173,388	0.79
Guyana	2005	1/Penta	L/10	94	13	15,275	20,367	1.67
Honduras	2002	1/Penta	L/5	91	193	103,991	138,655	0.79
Honduras	2003	1/Penta	L/5	91	193	103,991	138,655	0.79
Honduras	2006	1/Penta	L/5	91	193	103,991	138,655	0.79
Nicaragua	2001	1/Penta	L/10	91	136	153,850	205,133	1.67
Benin	2005	2/Penta	LLy/13	96	322	484,999	692,855	2.24
Benin	2006	2/Penta	LLy/11	96	322	401,161	573,088	1.85
Burkina Faso	2006	2/Penta	LLy/6	97	573	379,123	541,604	0.97
Ghana	2002	2/Penta	LLy/6	86	659	377,628	539,469	0.96
Ghana	2003	2/Penta	LLy/3	86	659	182,974	261,392	0.46
Ghana	2004	2/Penta	LLy/5	86	659	311,378	444,825	0.79
Ghana	2006	2/Penta	LLy/3	86	659	182,974	261,392	0.46
Kenya	2004	2/Penta	LLy/15	85	1,351	2,127,825	3,039,750	2.65
Kenya	2005	2/Penta	LLy/27	85	1,351	4,459,688	6,370,983	5.55
Kenya	2006	2/Penta	LLy/5	85	1,351	634,614	906,592	0.79
Malawi	2004	2/Penta	LLy/4	99	513	222,193	317,419	0.63
Malawi	2005	2/Penta	LLy/4	99	513	222,193	317,419	0.63
Malawi	2006	2/Penta	LLy/5	99	513	280,665	400,950	0.79
Mali	2006	2/Penta	LLy/1	90	503	48,014	68,591	0.15
Mongolia	2006	2/Penta	LLy/11	99	47	57,928	82,755	1.78
Rwanda	2003	2/Penta	LLy/10	99	372	429,660	613,800	1.67
Rwanda	2004	2/Penta	LLy/12	99	372	527,310	753,300	2.05
Rwanda	2005	2/Penta	LLy/11	99	372	477,936	682,766	1.85
Rwanda	2006	2/Penta	LLy/6	99	372	229,395	327,707	0.89
Senegal	2006	2/Penta	LLy/5	94	406	210,906	301,295	0.79
Uganda	2003	2/Penta	LLy/10	85	1,294	1,275,668	1,822,383	1.67
Uganda	2004	2/Penta	LLy/11	85	1,294	1,419,002	2,027,146	1.85
Uganda	2005	2/Penta	LLy/10	85	1,294	1,275,668	1,822,383	1.67
Uganda	2006	2/Penta	LLy/10	85	1,294	1,275,668	1,822,383	1.67
Yemen	2005	2/Penta	LLy/7	89	788	551,155	787,365	1.13
Zambia	2006	2/Penta	LLy/6	87	425	247,811	354,016	0.96
Bangladesh	2005	10/DTP	L/44	92	3,783	-	40,034,084	11.50
Cameroon	2006	10/DTPHepB	L/12	84	591	-	991,075	2.00
Mali	2004	10/HepB	L/17	90	503	-	1,357,445	3.00
Mali	2005	10/HepB	L/8	90	503	-	576,307	1.27
Niger	2003	10/DTP	L/10	49	607	-	478,883	1.63
Niger	2004	10/DTP	L/9	49	607	-	426,258	1.45
Niger	2005	10/DTP	L/6	49	607	-	275,103	0.93
Niger	2006	10/DTP	L/4	49	607	-	179,581	0.61

[1]L, liquid; LLy, liquid + lyophilized; [2]Hypothetical cost of wastage for PCV calculated by using country specific estimates for coverage, wastage rate and birth cohort.



Vial Size (wastage)	Vaccine Costs	Cold Chain Costs	Total Costs	Cost per FVC
Single (1%)	$6,859,091	$102,796	$6,961,886	$15.38
2-dose (1%)	$6,859,091	$56,569	$6,915,660	$15.28
10-dose (8%)	$7,085,739	$41,294	$7,127,033	$15.74
10-dose (17%)	$7,854,072	$45,862	$7,899,934	$17.45

Vial Size (wastage)	Vaccine Costs	Cold Chain Costs	Total Costs	Cost per FVC
Single (5%)	$18,131,842	$273,274	$18,405,116	$16.03
2-dose (5%)	$18,131,842	$132,677	$18,264,519	$15.91
2-dose (27%)	$23,596,233	$174,172	$23,770,405	$20.70
2-dose (15%)	$20,265,000	$148,286	$20,413,286	$17.78

Vial Size (wastage)	Vaccine Costs	Cold Chain Costs	Total Costs	Cost per FVC
Single (3%)	$8,713,067	$128,509	$8,841,576	$15.69
2-dose (3%)	$8,713,067	$69,440	$8,782,507	$15.59
2-dose (5%)	$8,896,500	$70,565	$8,967,065	$15.91
2-dose (3%)	$8,713,067	$69,440	$8,782,507	$15.59
2-dose (6%)	$9,087,823	$71,739	$9,159,561	$16.26

Figure 4. Country summaries (A, Mali; B, Kenya; C, Ghana): Cost for a fully vaccinated child (FVC) with three doses of PCV (adjusted for wastage and cold chain costs).

Preventable Disease Monitoring System 2007 Global Summary, GAVI/VF shipment records and Financial Sustainability Plans. Wastage rates were available for DTP, Hib, HepB, measles, BCG, OPV, DTPHib, DTPHepBHib and yellow fever.

As the PCV under consideration is for administration to infants, wastage rates only for those vaccines that are administered to infant were introduced. Wastage rates for OPV were not included since it is an oral vaccine. For the Democratic Republic of Congo only combined wastage rates for 10 and 20-dose vials of DTP are available; we therefore did not include this wastage rate in the analysis.

The wastage rate for a pre-filled syringe presentation was set at 1%.[7]

Cold-chain costs. Cold-chain costs were calculated at three levels—central, provincial and district. It was assumed that the birth cohort is evenly distributed amongst provinces and districts. Therefore the vaccine storage requirement in each province and district will be the same. It was assumed that every year there will be 2 shipments to the central level, 4 shipments to the provincial level and 6 shipments to the district level. At the central level, cold room costs are calculated while at the provinces and districts, costs of ice-lined refrigerators are considered. Cold chain estimates ideally should include the costs of running the equipment, maintenance and other miscellaneous like transportation. We did not include these costs and have likely underestimated cold chain costs for both single and multi-dose vials. This underestimation favours single-dose vials as they have a greater impact on cold chain requirements.

Packaged volume estimates for future possible PCV presentations considered for this analysis are shown in **Table 3**.

The storage volume factors used to determine the size of cold rooms are also shown in **Table 3**. This factor is used to account for air circulation and movement.[11] Cost of refrigeration is taken as $11.50 per liter (1 liter: 1,000 cm^3) from the WHO Performance, Quality and Safety (PQS) standards.[12]

Table 3. Estimates for purchase price, packaged volume and cost of cold rooms for PCV

(A)

Vial Size	Purchase price per dose[1]	Packaged volume per dose (cm^3/dose)	Comparable vaccine presentation to estimate packaged volume per dose
1	$ 5.00	12.9[b]	Pentavalent (liquid) single-dose vial Berna Biotech Korea Corp.
2	$ 5.00	6.4[a]	Assumed same vial size as single-dose vial
5	$ 4.88	8.0[a]	Assumed same vial size as 10-dose vial
10	$ 4.80	4.0[b]	HepB (liquid) 10-dose vial WHO International Shipping Guidelines
Pre-filled Syringe	$ 5.95	55.4[b]	PVC-7 pre-filled syringe, Wyeth

(B)

Cold room size (m^3)	Volume factor[c]	Cost of cold room ($)
5	3.2	11,000
10	3.3	13,000
15	3.7	14,500
20	3.9	16,000
30	4.2	18,000
40	4.2	20,000

[a]GAVI's PneumoADIP estimates; [b]WHO Vaccine Volume Calculator 2005;[10] [c]WHO Guidelines for Establishing or Improving Primary and Intermediate Vaccine Store, 2002.[11]

Vaccine purchase price. The expected purchase price for pneumococcal vaccines is projected to be $5–$7 per dose.[3] **Table 3** lists the purchase price per dose for all vial sizes considered. Prices for a single and a 2-dose pentavalent vaccine are taken as $3.75 and $3.50 per dose, 2007 UNICEF prices.[13]

Methodology. The empirical data were used to determine a 'range' of wastage rates (with a lower bound at the 25th percentile and an upper bound at the 75th percentile) and median wastage rates. These bounds were estimated for Ly, L and LLy formulations.

Cost per fully vaccinated child. Doses of PCV required are calculated according to the WHO Guidelines:[10]

*No. of doses required = i * b * d * [1/(1 - w)]*
where,
i = immunization coverage rate;
b = birth cohort;
d = number of doses per fully vaccinated child (FVC);
w = wastage rate (%);

The average of the vaccine coverage rates for DTP1 and DTP3, WHO-UNICEF 2006 estimates were used.[14] WHO 2006 live birth estimate was used for birth cohort. It was assumed that a FVC would be one who has received 3 doses of PCV.

*Cost per FVC = (No. of doses required * Price per dose) ~ (Coverage * Birth Cohort).*

Sensitivity analysis. Since data on wastage rates was limited, we conducted two-way sensitivity analyses varying the wastage rates for all vial sizes. We compared the cost of purchasing PCV for a hypothetical country (Country A) with a birth cohort of 1 million infants and 100% coverage rate. The cost of vaccinating this cohort using PCV in a single-dose vial was compared with the cost of vaccinating using 2, 5 or 10-dose vials. Wastage for single-dose vials was varied from 0–10%, and 0–20% for multi-dose vials. In addition, sensitivity analyses were conducted to account for the fact that it is unclear at present what the level of discount in price per dose would be if PCV were to be available in a multi-dose vial.

Country specific analyses: vial size and cold chain capacity. Country specific analyses were conducted to estimate the impact of wastage and vial sizes on cost per FVC. For each country, cost of wastage, not adjusting for cold chain, was calculated by using country specific figures for wastage rate, birth cohort and immunization coverage. Wastage costs were estimated for hypothetical PCV presentation for all countries for which empirical wastage rates were available, assuming the country used the same vial as the one for which wastage rate was available. Wastage costs were also estimated for pentavalent vaccines for countries that were using this vaccine. Wastage rates for pentavalent vaccine were available for most of the countries analyzed here; therefore this vaccine was used for comparison.

For Mali, Ghana and Kenya empirical wastage rates were available for more than one year or vial size; we, therefore, compared the cost of using a single-dose vial of PCV with the costs of using the specific vial sizes for which the rates are available.

Conclusions

Prior to the introduction of PCV in GAVI eligible countries, there is an urgent need for more rigorous and systematic wastage monitoring. The optimal vial-size for PCV is dependent upon country specific wastage rates, coverage levels, current cold chain capacities and session sizes. The use of multi-dose vials can result in huge wastage, increasing the total vaccine costs and the savings associated with their lower volume per dose can only be realized in countries with very low wastage.

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Note

Two authors are staff members of the World Health Organization. The authors alone are responsible for the views expressed in this publication and they do not necessarily represent the decisions, policy or views of the World Health Organization

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