Cost, health impacts and cost-effectiveness of ice-less refrigeration in India's vaccine cold chain

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Introduction

- The WHO Expanded Program on Immunization (EPI) launched in 1974 with the goal to vaccinate every child <1 year against 6 childhood diseases (TB, polio, diphtheria, pertussis, tetanus, measles) – now preventing ~3 million deaths/year.
- High levels of vaccine preventable diseases (VPD) continue to be observed worldwide, with an estimated mortality of 1.5 million deaths annually.
- "Last mile" immunization cold chain in remote, low-income settings reliant on ice-based technologies face problems of compliance, accidental freezing and/or warming, and lack of temperature monitoring during transport.
- Ice-based products and technologies exposing vaccines to sub-zero temperatures is potentially endemic. A recent study found that ~65% of vaccine vials showed evidence of freezing in vaccine stores and peripheral health facilities across 10 states in India.[1]
- Vaccines damaged due to cold chain failings will be either identified pre-administration and be replaced, incurring higher costs, or inadvertently administered to children resulting in higher risk of contracting VPDs, which could erode hard-won confidence in national and multilateral vaccination programs.
- The cost-effectiveness of iceless, battery-powered, portable cold storage devices for vaccine delivery in LMICs, in terms of wastage costs avoided and disability-adjusted life years gained, is poorly defined.

Objectives

1. To estimate the cost of wastage in ice-based cold chains and wastage costs averted in an iceless, battery-powered vaccine delivery cold chain
2. To calculate the incremental cost per vaccine dose delivered with iceless, battery-powered carriers
3. To model the health gains and cost-effectiveness of an iceless, battery-powered carrier for 'last mile' vaccine delivery cold chain, using the example of rotavirus vaccination in rural India.

Methods and Materials

To estimate the cost of wastage due to ice-based cold chain vaccine delivery, we compiled data on the number of eligible children for EPI vaccinations in rural India, the coverage rates in 2017, vaccine wastage rates, the estimated price per dose and the total number of doses for full vaccination.

To calculate the incremental delivery cost per dose for the iceless, battery-powered carrier we used the number of doses of each of the 6 routine vaccines to be delivered per year per health centre, and used these to estimate the number of devices and costs that would be required per health-centre catchment area using their volume capacity, and unit and maintenance costs.

To estimate the cost-effectiveness of iceless, battery-powered carriers for rotavirus vaccine we used a simplified Markov model that was validated by comparison with a more detailed published model, generating similar results.[2] The model is comprised of three health states – well, symptomatic rotavirus gastroenteritis (with a proportion of these becoming severe), and dead. We fit the model incidence of rotavirus gastroenteritis using recent data from India showing an annual risk of 8,394/100,000 in children under 5 years of age.[3] We then modelled the added benefit of an iceless, battery-powered device to reduce wastage rates in vaccine delivery. Key parameter estimates in the model are shown in **Table 1**. We carried out a sensitivity analysis on the incremental cost of the iceless, battery-powered device per vaccine delivery and their wastage rate in cold chains.

Table 1. Parameter estimates used in cost effectiveness analysis

Key parameters	Estimate and source
Incidence of rotavirus gastroenteritis	0.29* (2)
Probability of episode being severe	0.28** (1)
Mortality in severe cases	0.068 (1)
Protective effect of vaccine	48% (3)
Wastage rate in ice based cold chain	25%
Wastage rate in iceless based cold chain	10% - conservative estimate
Incremental cost per vaccinated child for iceless cold chain	$0.1

*The model was fit to the reported rate of 8,394/100,000 in children <5 using this incidence at 6 months and declining exponentially with age. **At 6 months, declines exponentially with age reaching <1% at 30 months.

Results

The number of eligible children and women in 2017 for routine vaccination in rural India is shown in **Table 2.**

Table 2. Number of vaccine doses for routine vaccination and number of eligible individuals in 2017

Target Population	# of vaccine doses required by demographic**						Number of eligible individuals
	BCG	DPT	TT	Hepatitis B	OPV	Measles	
At birth	1	--	--	1	1	--	18,645,600
Age in 1 year	--	--	--	--	3	1	17,897,736
Age in 5 years	--	2	--	--	1	1	63,362,264
Pregnant women	--	--	2	--	--	--	20,508,800
Women of child bearing age	--	--	1	--	--	--	163,964,320

**http://www.searo.who.int/entity/immunization/data/india.pdf?ua=1

Results

The costs of wastage in the context of rural India of the ice-based cold chain system is **7,512,930 USD,** as detailed in **Table 3.**

Table 3. Vaccine cost/dose, wastage rates, coverage and costs of wastage using ice-based delivery

Vaccine	Cost /dose (USD)	Wastage rate	Current Coverage	Cost of avoidable vaccine wastage (USD)	Total cost of wastage (USD)*
BCG	0.05	25%	95%	22,1417	1,328,499
DPT	0.04	25%	100%	1,900.868	13,781,292
TT	0.02	25%	85%	237,731	11,760,383
Hepatitis B	0.05	25%	100%	233,070	1,398,420
OPV	0.06	25%	90%	1,831,964	9,465,150
Measles	0.16	25%	95%	3,087,880	7,912,693
Total				**7,512,930**	**45,646,891**

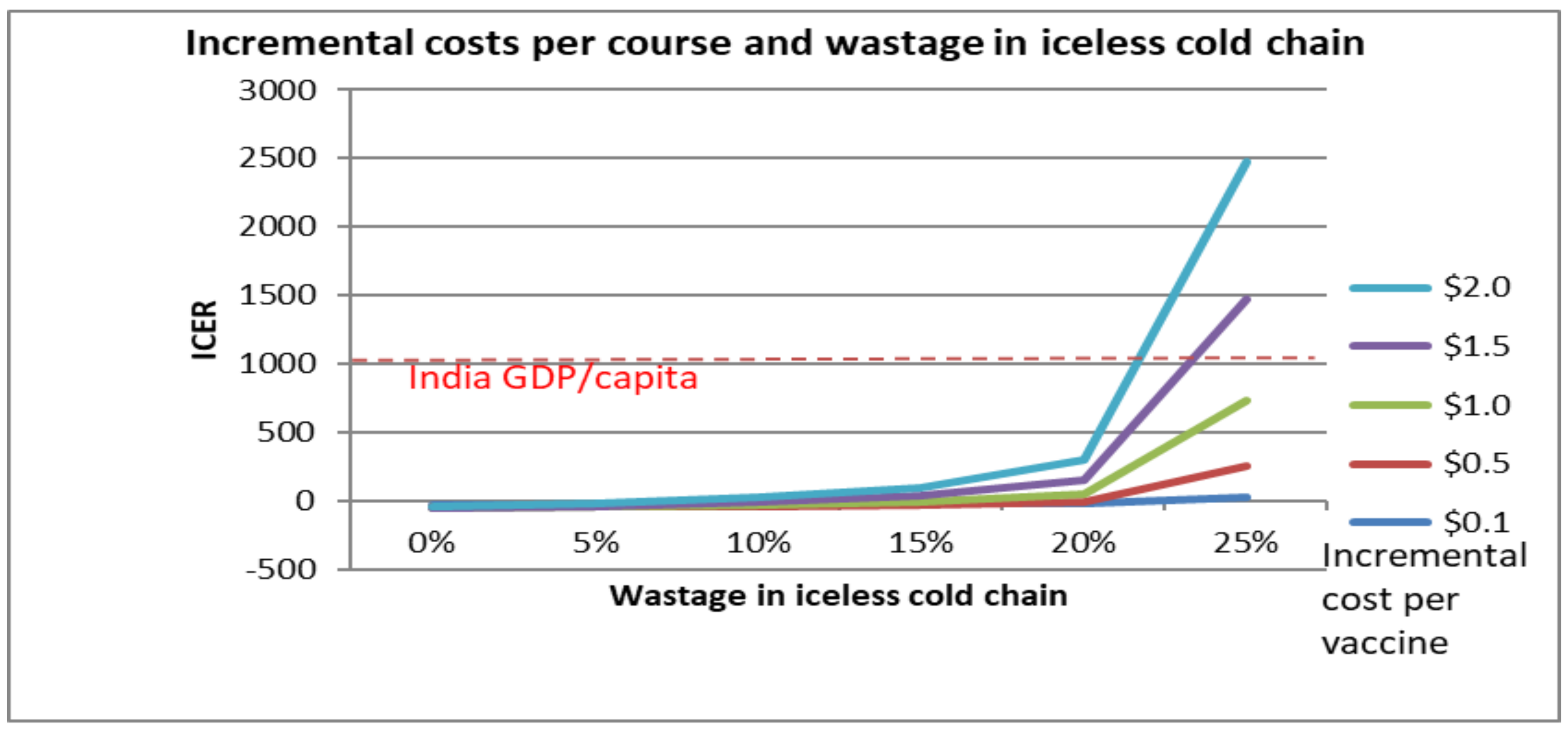
*Includes $0.25 program costs per dose.[5]

The incremental cost per vaccine dose delivered with an iceless, battery-powered carrier is **USD 0.026**. On average, a health center serves a 4,554 target population for routine vaccination for about 18,358 doses of vaccines. The total cost of an iceless, battery-powered carrier per 5 years of use is USD 2,375, equal to USD 475 per year (**Table 4**). This compared with an annual wastage of USD 1,726 per health center, therefore the **cost-benefit ratio for an iceless, battery-powered cold chain that avoided this wastage would be 0.28**, indicating that this is cost-beneficial.

Table 4. Incremental costs of vaccine delivery using iceless, battery-powered device

Target population	Individuals/ centre	Doses/ vaccine	Subtotal # of doses	Cost of iceless carrier (USD)	
At birth	705	3	2,116	Unit cost (5 year est. shelf life)	2,000
In 1 year	677	4	2,708	5 year maintenance cost	375
In 5 years	2,397	5	11,983	Cost per year	475
Pregnant women	776	2	1,551		
Total	**4,554**		**18,358**	**Cost per dose:**	**0.026**

Using the current ice-based cold chain the vaccines were cost-effective with a cost per DALY averted of USD 216, slightly higher than prior estimates due to the lower incidence in our model. **Switching to the iceless, battery-powered device would avert a further 0.03 DALYs per child with cost savings of USD 0.80 per child vaccinated**. The sensitivity analysis suggested that even at a much higher incremental delivery cost of, for instance, USD 2 per vaccinated child and with higher wastage rates in the iceless device of up to 20% (as compared with 25% in the ice-based system) the iceless, battery-powered cold chain would still be cost-effective.



Conclusions

- Vaccine wastage in ice-based cold chains incurs high human and economic costs, whereas the per-dose incremental delivery cost for an iceless, battery-powered device to reduce or eliminate such wastage is negligible.
- Compared with a scenario in which spoiled vaccines are identified and replaced, the use of an iceless, battery powered device would result in large cost savings.
- Compared with a scenario where spoiled vaccines are administered to children the iceless, battery-powered device would be cost-saving and provide additional health gains.
- These conclusions are robust to variation in the incremental cost of vaccine delivery with the use of the iceless, battery-powered device and more modest gains in wastage avoided.

References

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