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Incremental costs of introducing jet injection technology for delivery of routine childhood vaccinations: Comparative analysis from Brazil, India, and South Africa

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ABSTRACT

Background: Disposable-syringe jet injectors (DSJIs) have the potential to deliver vaccines safely and affordably to millions of children around the world. We estimated the incremental costs of transitioning from needles and syringes to delivering childhood vaccines with DSJIs in Brazil, India, and South Africa.
Methods: Two scenarios were assessed: (1) DSJI delivery of all vaccines at current dose and depth; (2) a change to intradermal (ID) delivery with DSJIs for hepatitis B and yellow fever vaccines, while the other vaccines are delivered by DSJIs at current dose and depth. The main advantage of ID delivery is that only a small fraction of the standard dose may be needed to obtain an immune response similar to that of subcutaneous or intramuscular injection. Cost categories included were vaccines, injection equipment, waste management, and vaccine transport. Some delivery cost items, such as training and personnel were excluded as were treatment cost savings caused by a reduction in diseases transmitted due to unsafe injections.
Results: In the standard dose and depth scenario, the incremental costs of introducing DSJIs per fully vaccinated child amount to US$ 0.57 in Brazil, US$ 0.65 in India and US$ 1.24 in South Africa. In the ID scenario, there are cost savings of US$ 0.11 per child in Brazil, and added costs of US$ 0.45 and US$ 0.76 per child in India and South Africa, respectively. The most important incremental cost item is jet injector disposable syringes.
Conclusion: The incremental costs should be evaluated against other vaccine delivery technologies that can deliver the same benefits to patients, health care workers, and the community. DSJIs deserve consideration by global and national decision-makers as a means to expand access to ID delivery and to enhance safety at marginal additional cost.

1. Introduction

Injection is the most conventional method of vaccine administration. Almost all vaccines are currently delivered by injections; exceptions are oral polio, rotavirus, cholera, and salmonella vaccines. Unsafe injections have been linked to around 23 million new hepatitis B, hepatitis C, and HIV infections each year [1], and concern has frequently been raised about the safety of vaccine delivery with injections, especially in low-income countries [2–4]. While the expansion of autodisabled syringes for vaccination has reduced the problem of reuse of needles and syringes, needlestick injuries and unsafe disposal of sharps waste still leave health care workers, patients, and the community at risk [5].

Injections of vaccines can be delivered in three ways; intradermally (ID) (into the skin), subcutaneously (SC) (into fatty tissue), or intramuscularly (IM) (into a muscle). All the injectable childhood vaccines except the Bacille Calmette-Guérin (BCG) vaccine should be administered by deep subcutaneous or intramuscular routes in either the deltoid region of the arm or the anterolateral thigh [6]. BCG is injected intradermally and, therefore, requires a smaller dose than other vaccines [7].

An alternative to needles and syringes is jet injector technology. A jet injector is a needle-free system where a fine, high-pressure stream of liquid is used to penetrate the skin and deposit vaccines or medication into the tissues by either ID, SC or IM [8]. Jet injectors can deliver any liquid vaccine or medication and do not require reformulation of the drug or vaccine. Since the 1940s, millions of doses of vaccine have been delivered with jet injectors. However, early jet injectors had a multiple-use nozzle design and were found to transmit blood borne pathogens between injections due to splash back of body fluids into the nozzle orifice [9]. In order to alleviate safety concerns the current generation of DSJIs have been specifically developed to avoid contamination by using a sterile, single-dose needle-free syringe which is discarded after each injection. Several DSJI devices are commercially available in

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high-income countries for a variety of applications, including vaccine delivery. Some of these are however not suitable for low- and middle-income country immunization programs because of their high cost and inappropriate design features, such as the need for an external power source. Low-cost designs of DSJIs that meet international public health safety standards have recently been developed by multiple industry players and are expected to be commercially available to low- and middle-income country vaccination programs by 2011 [10].

The key advantage of using jet injection is the elimination of sharps and their associated disposal [9]. Moreover, jet injectors can facilitate the administration of consistent ID injections, if indicated for the vaccine [11]. Vaccines delivered intradermally have the potential to be delivered in smaller doses with an equal immune response to a full dose delivered subcutaneously or intramuscularly [12]. At the global level, a smaller dose could prevent vaccine shortages of capacity-constrained vaccines and at the national level vaccine costs could be reduced. Furthermore, smaller doses could potentially reduce the space required in the cold chain, thereby reducing storage and transportation costs.

While the potential health benefits of needle-free injection are multifold, it is likely that costs will be a critical factor for DSJI adoption. The objective of this study is thus to estimate the incremental costs of using DSJIs instead of needles and syringes for routine childhood vaccinations. The incremental costs of the following two scenarios were estimated:

1. All routine childhood vaccines delivered by DSJI at standard depth and dose.
2. Hepatitis B and yellow fever vaccines delivered by DSJI at ID depth and reduced dose and all other routine childhood vaccines delivered by DSJI at standard depth and dose.

Hepatitis B and yellow fever vaccines were chosen for the ID scenario, as a recent study has demonstrated the dose-sparing potential of delivering yellow fever vaccine by the ID route [13] and hepatitis B vaccine is one of the most-studied vaccines in terms of ID delivery [14,15]. It should however be emphasised that neither of these vaccines are currently recommended for ID administration; the scenario was mainly included to guide the ID research agenda.

2. Methods

2.1. Study settings

Brazil, India, and South Africa were chosen for the analysis. These three countries represent different geographical regions, income levels, health systems, and immunization schedules. The India analysis was limited to three states: Uttar Pradesh, Andhra Pradesh, and Madhya Pradesh.

2.2. Model design and data collection

The estimates were calculated with demographic data for year 2011, but costs estimated in 2009 US$ values. Cost items were divided into capital costs (items and activities lasting for more than one year) and recurrent costs [16]. To reflect the opportunity costs of committing resources for capital items, a discount rate of 5% was used when annualizing these [17,18]. Average exchange rates to the US$ were 2.03 Brazilian real, 49.03 Indian rupees, and 8.49 South African rand (www.oande.com).

Cost items included in the two scenarios are summarised in Table 1. Since only the incremental costs of DSJIs were assessed, cost items not likely to be markedly affected by the switch were excluded. A study from USA has concluded that it takes the same time to administer a vaccine with DSJI as with needles and syringes [19], so personnel costs were excluded along with costs of dry storage of DSJIs when first arriving in country, vaccine cold storage and disease surveillance. Due to the difficulty of arriving at accurate estimations, the initial costs of training staff as well as monitoring and supervision were not included. More importantly, averted treatment also costs from diseases such hepatitis and HIV caused by needlestick injuries and needle reuse were excluded. Without including this negative externality, the overall costs to society of introducing DSJIs are likely to be overestimated in our analysis.

Table 1
Cost items included in the two vaccine delivery scenarios.

Needles and syringes	Disposable-syringe jet injectors
Vaccines	Vaccines
Vaccine transport	Vaccine transport
Injection syringes and needles	Jet injector device
Reconstitution syringes	Jet injector disposable syringe
Safety boxes	Jet injector vial adapter
Waste management of used syringes	Reconstitution syringes
	Plastic bags for used DSJI disposables
	Safety boxes
	Waste management of used DSJI disposables and reconstitution syringes

In each country, the ministry of health provided guidance as to the most likely scenario for DSJI introduction, and a local researcher was engaged to collect vaccination program data using a standardised questionnaire. Demographic data were collected from the Brazilian Institute of Geography and Statistics, the India Registrar General and Census Commissioner, and the South African Government Statistics [19].

2.3. Model parameters and assumptions

2.3.1. Disposable-syringe jet injectors

A DSJI consist of three parts: the DSJI handpiece, a DSJI disposable syringe and a DSJI vial adapter (see pictures in Fig. 1). In addition to a handpiece, some manufacturers' devices require reset stations, which recharges the spring in the handpiece for each injection. For purposes of this model, the costs of the DSJI handpiece include any additional components needed to power the device. There are no spare parts to account for; if the device breaks a replacement is necessary. The disposable syringe is a sterile plastic syringe that has a capacity to contain a single dose of vaccine and has an auto-disabling feature to prevent reuse. The vial adapter is a plastic spike that penetrates the septum of a vial to allow for the vaccine to be drawn into the disposable syringe. One DSJI vial adapter is needed per vial, and it can work with any size vial. Therefore, if a 10-dose vial is used, 10 DSJI disposable syringes and one vial adapter are needed to give 10 injections. If the vaccine requires reconstitution, this should be done with reconstitution syringes and needles commonly used to reconstitute freeze-dried vaccines in multi-dose vials.

Parameter assumptions used for the DSJI cost estimates are summarised in Table 2. Prices of the handpiece, disposable syringes, and the vial adapter are preliminary estimates obtained from DSJI manufacturers. These prices are uncertain as the products are not yet sold at the volumes required for routine immunization. Various pricing models are under consideration by device manufacturers with the aim of making the technology affordable to developing countries.

In Brazil and South Africa, the number of handpieces was determined based on the average number of staff in each vaccine delivery facility plus one additional handpiece as a reserve. Therefore, three handpieces per facility were assumed for South Africa and Brazil. In

Table 2
Disposable-syringe jet injector assumptions.

Parameter	Base case assumption
Disposable-syringe jet injector (DSJI) device price	US$ 55
Freight charge per DSJI device	US$ 5
Useful life years of DSJI device	5 years
DSJI disposable price	US$ 0.12
DSJI vial adapter price	US$ 0.15
Wastage of DSJI disposable syringes	5%
Reduced volume of DSJI disposable syringes as compared to needle and syringe	50%
Intradermal vaccine dose size compared to subcutaneous and intramuscular dose size	20%

India, the feedback from public health officials was that since vaccination to a large extent is delivered by outreach services, each immunization health worker should have their own handpiece, rather than keeping them in facilities. No reserve handpieces were assumed in India.

According to manufacturers, the DSJI handpiece lasts for approximately 20,000 injections before it needs replacing. We divided the number of health workers with the total number of doses delivered per year and found that health workers on average deliver two, four, and eight vaccine doses per day in India, Brazil, and South Africa, respectively. If the devices were fully utilized for routine use only, the DSJI handpiece could last up to 31 years in India, 17 years in Brazil and 7 years in South Africa. To be more realistic and conservative, we assumed a life expectancy of five years in all the countries and varied the assumption in sensitivity analysis.

Fig. 1. Disposable-syringe jet injectors.

2.3.2. Vaccines

All injectable vaccines in the 2009 childhood vaccination schedules of the three countries were included in the analysis (Table 3). For each vaccine, total annual vaccine costs (TVC) were estimated as [15]:

$$\mathrm{TVC} = p \times c \times b \times d \times w$$

where, p is the vaccine costs per dose (including freight expenses), c is the vaccination coverage rate, b is the target population, d is the number of doses per child, and w is the wastage factor. Parameter values for 2009 for the three countries are summarised in Table 3. Two of these parameters are predicted to be affected by DSJI adoption: Vaccine wastage and, in the scenario of DSJI with ID delivery, the vaccine price.

2.3.2.1. Vaccine wastage. Vaccine wastage can be classified into wastage that occurs with unopened and opened vials [20]. While wastage of unopened vials, which is caused by expiry, heat exposure, freezing, vial breakage, missing inventory, and theft, will not change due to a transition to DSJI, opened vial wastage is predicted to decrease. Wastage of opened vials occurs due to six reasons [20]. While the first five types of wastage will not change with DSJI introduction, the last type would be impacted.

1. Vial remnant discarded due to discarding of vaccine remaining in a multi-dose vial after completion of one or more immunization sessions [21].
2. Poor reconstitution practices.
3. Submergence of open vials due to melting or wet ice.
4. Suspected contamination.
5. Patient reaction requiring more than one dose.
6. Unable to draw the number of doses indicated on the label of a vaccine vial due to two sub-types of wastage caused by syringes. "Dead space" wastage is vaccine remaining in the syringe after full delivery of the dose. All syringes have a dead space and vaccine manufacturers are expected to overfill vials to ensure that the number of doses indicated on the label can be drawn from the vial [20]. However, many syringes do not adhere to WHO standards on the maximum allowable dead space. The second type is "syringe overfill" wastage, which occurs when vaccine is expelled from the syringe in an attempt to eliminate excess vaccine and remove air bubbles.

Since dead space and overfill wastage occur because of the syringe, a transition to DSJI will change this wastage. To compare the number of doses that can be withdrawn from a vial with DSJI versus needles and syringes, we conducted bench testing between selected DSJI disposable syringes and Beckton Dickinson (BD) SoloShot syringes, which are designed to have a minimal amount of dead space (www.bd.com).

Furthermore, it is possible that wastage would be reduced with DSJI due to less patient reaction caused by fear of needles. This impact has however not been included in the analysis due to the difficulty in arriving at an accurate estimate.

2.3.2.2. Intradermal vaccine price. If vaccine is delivered intradermally, the dose size will be reduced, which could lead to a reduction in the vaccine price. The majority of the clinical ID trials conducted so far used a dose size which represented an 80% reduction from the standard dose [13], so we assumed a 0.10 ml dose for ID delivery of hepatitis B and yellow fever vaccines instead of the current size of 0.50 ml. It is however uncertain to what extent a decreased dose size would result in a similar lower price, as vaccine prices are not necessarily based on a fixed mark-up on production costs [20]. To be conservative and to allow for additional profit per vial even

Table 3
Childhood vaccination schedule for injectable vaccines,[a] vaccine prices, vial sizes, and vaccine wastage in Brazil, India, and South Africa (2009).

Country	Vaccines in schedule	Number of doses per child	Price per dose including freight, tax, etc. (US$)	Vial size	Vaccine wastage rate
Brazil	BCG	1	0.32	10	37%
	DTwP-Hib	3	4.34	10	25%
	Hepatitis B	3	0.63	10	22%
	MMR	2	3.34	10	15%
	Yellow Fever	1	0.50	5	10%
India	BCG	1	0.03	10	63%
	DT	1	0.02	10	39%
	DTwP	4	0.03	10	34%
	Hepatitis B	3	0.28	10	40%
	Measles	1	0.20	5	41%
South Africa	BCG	1	0.11	20	75%
	DTaP–Hib/IPV	4	8.80	1	25%
	Pneumococcal	3	27.00	1	25%
	Hepatitis B	3	0.67	10	25%
	Measles	2	0.44	10	40%
	Tetanus	2	3.80	1	25%

BCG—Bacille Calmette-Guérin; DT—diphtheria-tetanus; DTwP—diphtheria-tetanus-whole cell pertussis vaccine; DTaP—diphtheria-tetanus-acellular pertussis vaccine; MMR—measles-mumps-rubella; IPV—inactivated polio vaccine.

[a] Oral polio vaccine and oral rotavirus vaccine (part of the South African vaccination schedule) are excluded from the analysis.

if the dose size were reduced, we assumed a 20% price decrease for each dose delivered intradermally. The ID hepatitis B vaccine prices per dose were thus US$ 0.45 in Brazil, US$ 0.20 India, and US$ 0.53 in South Africa. The yellow fever ID price in Brazil was US$ 0.35 per dose. We varied this assumption in the sensitivity analysis.

2.3.3. Syringes and needles

Annual injection syringe costs (SC) were calculated as [16]:

$$SC = ps \times c \times b \times d \times ws$$

where *ps* is the price per syringe, *c* is the vaccination coverage, *b* is the target population, *d* is the number of doses per child, and *ws* is the syringe wastage factor. In 2004, the Government of India required that all vaccinations should be given with autodisabled syringes to minimize the risk of reuse of syringes. The price of autodisabled syringes in India is US$ 0.059. In Brazil and South Africa, disposable syringes are used and are priced at US$ 0.065 and US$ 0.08 per syringe, respectively. If DSJIs are used for immunization, these syringes and needles are no longer needed.

Reconstitution syringes and needles are needed to reconstitute freeze-dried vaccines in multi-dose vials, both with traditional syringes and with DSJIs. In Brazil, DTP-Hib, MMR, and yellow fever vaccines are freeze dried, while in India and South Africa, this is the case for BCG and measles vaccines. The price of one reconstitution syringe is US$ 0.071 in Brazil, US$ 0.030 in India and US$ 0.150 in South Africa. For both injection and reconstitution syringes, wastage rates were reported as 5% in Brazil and South Africa and 10% in the three Indian states.

2.3.4. Health care waste disposal

Safe and environmentally friendly management of sharps and infectious health care waste is crucial when ensuring the overall quality of health services [21]. The change in waste management processing costs due to a switch to DSJI was estimated by adjusting the total cost of current waste management by the estimated percentage change in waste volume. With a switch to DSJIs, injection syringes and needles for vaccination will be eliminated, but reconstitution syringes still need to be disposed of as sharps waste. Hence, the quantity of safety boxes will decrease with the introduction of DSJI as these will only be needed for reconstitution syringes. According to WHO guidelines [22], the DSJI vial adapter should be disposed of while still attached to the vial ensuring that the spike is encapsulated and therefore not a sharp. We thus assume that DSJI disposable syringes and vial adapters will be disposed of as hazardous waste in colour-coded plastic bags with the international infectious substance symbol [23]. The cost of one plastic bag for hazardous waste was assumed as US$ 0.08 in all three countries based on the price in South Africa. The waste volume of a DSJI disposable syringe is approximately 50% less than the waste volume of a standard disposable syringe.

In India, the official government policy is to use needle cutters followed by either safe disposal of the infectious material or pits for burying at the immunization facility. However, this policy has still not been successfully implemented in all places. A detailed

Table 4
Wastage rates divided into different types: assumptions for Brazil.

Type of wastage	BCG	DTP-Hib	Hepatitis B	MMR	Yellow fever
Unopened vial wastage	0.22%	6%	5%	0.17%	0.10%
Opened vial wastage					
Vial remnant discarded	31%	14%	13%	12%	8%
Poor reconstitution practices	1.9%	1.2%	0.0%	0.8%	0.5%
Submergence of opened vials in water	0.7%	0.5%	0.4%	0.3%	0.2%
Suspected contamination	0.7%	0.5%	0.4%	0.3%	0.2%
Patient reaction requiring more than one dose	0.4%	0.2%	0.2%	0.2%	0.1%
Overfill and dead space wastage	1.9%	2.5%	2.2%	1.5%	1.0%
Total	37%	25%	22%	15%	10%

Source: [22].

study is available on the costs of needle removal and safe disposal [24]. We used the mid-cost scenario of needle removal, large-scale incineration, and provincial collection system at an average cost of US$ 0.035 per syringe [24].

In Brazil, the municipalities are responsible for waste management, which is most commonly done by incineration by either private companies or their own public company. According to a quote from a private company the waste management cost is US$ 0.0162 per syringe. Similarly, in certain provinces in South Africa health care waste management is contracted out to private companies with an average price of US$ 4.20 per safety box incinerated, amounting to US$ 0.042 per syringe. In Brazil, a 13-l safety box containing 230 syringes is used; in South Africa, a 5-l safety box containing 100 syringes is used. The unit cost of one box is US$ 1.40 in Brazil and US$ 1.10 in South Africa.

2.3.5. Vaccine transport

Any change in vaccine wastage should impact transport costs due to a change in vaccine volume. Transport costs per cm^3 were calculated by dividing transport costs per dose with packed volume per dose. In Brazil, costs per dose amount to between US$ 0.09 in the South East region and US$ 0.038 in the North region where vaccine transport is often done by aeroplane. In India, transport cost data were based on estimates from Andhra Pradesh amounting to US$ 0.07 per dose [25]. In South Africa, vaccine transport is contracted out to a private company which charges 3% of the vaccine value [26]. Hence, the transport costs in South Africa will only change in the ID scenario where it is assumed that the vaccine price will decrease by 20%.

3. Results

3.1. Vaccine wastage

Bench testing of the DSJI disposable syringe and the BD SoloShot syringe showed that for 0.50 ml syringes, DSJIs have an average of 78% less dead space and overfill wastage than the SoloShot syringes, but for the 0.10 ml syringes, which are used for BCG, DSJIs have an average of 17% more wastage than the SoloShots. Baseline wastage rates for each vaccine reported in Table 3 were divided into unopened vial wastage and the six different types of opened vial wastage. The percentages allocated to each type of wastage were based on conversations with immunization program managers and findings from a recent study in Bangladesh [27]. These percentages as applied to the baseline wastage rates for Brazil can be seen in Table 4. This calculation was similarly conducted for the other two countries. The dead space and the overfill wastage rates were multiplied by the percentage differences found in the bench study to generate the impact on vaccine wastage from transitioning from needle and syringe to DSJIs.

3.2. Incremental cost of DSJIs introduction

The number of DSJI handpieces needed to facilitate the transition to DSJI is 87,388 in Brazil, 13,320 in South Africa, and 93,475 in the three Indian States. At US$ 60 per handpiece, including shipment, the total initial investment cost is US$ 5.2 million in Brazil; US$ 799,200 in South Africa; and US$ 5.6 million in Uttar Pradesh, Andhra Pradesh, and Madhya Pradesh.

The annual cost difference between vaccine delivery with needles and syringes and the DSJI standard depth and dose scenario are summarised in Table 5. The transition will imply an overall cost increase in all three countries. While the percentage annual cost increase is relatively minor in South Africa and Brazil, at 0.9% and 3.9%, respectively, the increase is 25.9% in India, reflecting the considerably lower total vaccination costs in this country, thereby

Table 5
Annual total and incremental costs of current scenario with needles and syringes and with DSJIs (2009 US$).

Item	Brazil			Three Indian states			South Africa		
	Needle and syringe	DSJI	Incremental costs	Needle and syringe	DSJI	Incremental costs	Needle and syringe	DSJI	Incremental costs
Vaccines	79,855,264	79,302,868	−552,397	17,227,330	16,475,044	−752,286	122,371,376	121,860,601	−510,775
DSJI devices	–	1,211,066	1,211,066	–	1,295,427	1,295,427	–	159,840	159,840
DSJI disposable syringes	–	4,486,877	4,486,877	–	12,221,918	12,221,918	–	1,530,079	1,530,079
DSJI vial adapters	–	733,715	733,715	–	2,829,923	2,829,923	–	1,181,481	1,181,481
Injection syringes	2,134,957	–	−2,134,957	6,101,680	–	−6,101,680	501,677	–	−501,677
Reconstitution syringes	149,541	145,052	−4489	263,342	260,072	−3269	71,674	71,076	−597
Safety boxes	248,879	14,409	−234,470	–	–	–	480,558	17,213	−463,345
Plastic bags	–	11,965	11,965	–	32,592	32,592	–	4080	4080
Transportation	972,496	1,001,567	29,070	1,180,177	1,148,268	−31,909	3,671,141	3,655,818	−15,323
Waste management	645,371	350,689	−294,683	4,139,351	2,140,674	−1,998,677	555,170	287,444	−267,726
Total	84,006,509	87,258,207	3,251,698	28,911,880	36,403,920	7,492,040	127,651,596	128,767,633	1,116,037
Percentage increase			3.9%			25.9%			0.9%

Table 6
Costs per fully vaccinated child[a] in the three scenarios (2009 US$).

	Brazil			India			South Africa		
Cost item	Needle and syringe	DSJI standard depth	DSJI ID	Needle and syringe	DSJI standard depth	DSJI ID	Needle and syringe	DSJI standard depth	DSJI ID
Vaccines	25.17	24.95	24.33	1.80	1.72	1.53	117.54	117.04	116.58
Syringes	0.60	–	–	0.61	–	–	0.51	–	–
Reconstitution syringes	0.06	0.06	0.06	0.02	0.02	0.02	0.08	0.08	0.08
Jet injector device	–	0.05	0.05	–	0.01	0.01	–	0.01	0.01
Vial adapters	–	0.21	0.21	–	0.27	0.27	–	1.08	1.08
DSJI disposable syringes	–	1.26	1.26	–	1.26	1.26	–	1.52	1.52
Safety boxes	0.07	0.01	0.01	–	–	–	0.48	0.02	0.02
Plastic bags	–	0.003	0.003	–	0.003	0.003	-	0.38	0.38
Waste management	0.19	0.10	0.10	0.42	0.21	0.21	0.55	0.29	0.29
Vaccine transport	0.28	0.29	0.25	0.11	0.11	0.10	3.53	3.51	3.48
Total costs	26.37	26.93	26.26	2.96	3.60	3.41	122.69	123.93	123.45
Incremental costs per child		0.57	−0.11		0.65	0.45		1.24	0.76

[a] Only injectable vaccines and only cost items that will be affected by DSJI are included in the estimates. For a full estimate of costs per fully vaccinated child, oral polio vaccine and rotavirus vaccines should be included, as well as items such as salaries and disease surveillance.

making the cost of injection devices a larger portion of the total costs. In all three countries, the jet injector disposable syringes are the most important incremental cost category.

Costs per vaccinated child with injectable vaccines in the three countries are seen in Table 6. The costs vary among the countries with South Africa spending considerably more on fully vaccinating each child than the other two countries. This is primarily due to two relatively expensive vaccines introduced during 2009, the pneumococcal conjugate vaccine and the combined DTaP–IPV–Hib vaccine. Injectable vaccine costs are substantially less in India than in the two other countries because Hib, rubella, pneumococcal and IPV are not part of the schedule. In the scenario with standard depth and dose, the incremental costs per vaccinated child amount to US$ 0.57 in Brazil, US$ 0.65 in India, and US$ 1.24 in South Africa. In the scenario with ID delivery, DSJIs are cost-saving in Brazil, but not in India and South Africa. In Brazil, both yellow fever and hepatitis B vaccines were assumed delivered with ID, but yellow fever vaccine is not part of the schedule in the other two countries.

In South Africa, the cost of the vial adapter results in a high per injection cost because several vaccines are presented in single-dose vials. This is not the case in India and Brazil where multi-dose vials are the norm.

3.3. Sensitivity analysis

In the base case scenario, the jet injector device was assumed to last five years, which resulted in an average of 1541 injections delivered per device in Brazil, 5405 in India, and 4558 in South Africa. When changing the assumption to a lifetime of 20,000 injections, the annual costs of the device decrease considerably. The jet injector device costs per fully vaccinated child decreases from US$ 0.05 to US$ 0.01 in Brazil, from US$ 0.01 to US$ 0.003 in South Africa, and from US$ 0.01 to US$ 0.005 in India. However, as seen in Tables 5 and 6, the jet injector device constitutes a relatively small percentage of the incremental costs, so varying this assumption does not change the overall conclusion. Total incremental costs amount to US$ 0.55 in Brazil, US$ 0.56 in India, and US$ 1.23 in South Africa, which is hardly different from the figures seen in Table 6.

The jet injector disposable syringe was found to be the most important incremental cost category. The price of the jet injector disposable syringes was varied from the base case price of US$ 0.12 until the point where the DSJI scenario becomes cost saving. A unit price for the disposable syringe of US$ 0.06 in Brazil and India and US$ 0.04 in South Africa allows the incremental costs of introducing DSJIs to be cost neutral.

In the ID scenario, it was conservatively assumed that a dose-volume reduction of 80% would only lead to a price decrease of 20%. When the price of hepatitis B vaccine with ID delivery is reduced by 60% in India and by 50% in South Africa, the ID scenario also becomes cost saving in these countries, as is the case for Brazil with a 20% price reduction.

4. Discussion

We found a marginal increase in the costs per vaccinated child in all three countries when transitioning to DSJI from needle and syringe in the standard dose and depth scenario. In the ID scenario, the introduction of DSJIs resulted in cost savings in Brazil and marginally higher cost in South Africa and India. The cost of the DSJI disposable syringe was the most important cost item. For a transition to DSJI to be cost saving, DSJI developers should consider pricing the DSJI disposable near the current price of disposable and AD syringes for developing-country immunization programs.

We found that percentage cost increases of transitioning to DSJIs vary considerably among countries. Since India is currently spending less per fully vaccinated child than the two other countries, introduction of DSJIs would be a relatively larger investment in this country. In Brazil and South Africa, the percentage increase in total vaccine delivery costs is relatively small.

Another factor for ministries of health to consider when adopting DSJIs for immunization program use is the effect on capital and recurrent health budgets. Currently, budgeting is solely driven by the quantity of needles and syringes needed in a given budget period. The shift to DSJIs would involve an upfront capital costs and replacement costs after the lifetime of the jet injector device expires. Although the cost of the jet injectors may be a small factor in total costs of moving to DSJIs over time, it needs to be assessed in each country how budgeting would be affected and how financing would be obtained. It should be noted that device developers are considering various pricing models that could improve the fit of the DSJI technology within current budget constraints.

Ekwueme and colleagues compared the costs of seven different injection devices for sub-Saharan Africa and DSJIs were one of these technologies [28]. While the costing methodology used in this study is comparable to ours, widely different parameter values were used. Ekwueme et al., assumed a DSJI device price of US$ 250 while we used US$ 55. Similarly, the price of the vial adopter and the DSJI disposable were 0.55 and 0.25, respectively, in the Ekwueme paper, while we used US$ 0.12 and US$ 0.15. Compared to disposable syringes, the incremental costs per DSJI injection was found to be US$ 0.26, which is considerably more than in our analysis where the incremental costs per child (who receives numerous injections depending on the country in question) are between US$ 0.57 and US$ 0.76.

A limitation of our analysis is the uncertainty on the impact of vaccine costs per dose when changing from standard depth and standard dose to ID delivery. It is important to note that changing the depth of dose will require the involvement of the vaccine manufacturers, clinical trials, and a vaccine label change, as well as possible modification in vial size.

Another limitation of our analysis is exclusion of future cost savings resulting from a decrease in blood-transmittable diseases, such as hepatitis and HIV, which occur due to needle reuse and needlestick injuries. Attempts to quantify the incidence of diseases transmitted due to unsafe injections are rare, so inclusion of these costs would be surrounded by great uncertainty. However, exclusion of this negative externality underestimates the benefits of DSJIs. Ekwueme and colleagues included the direct medical costs of treating diseases transmitted from unsafe injections and found DSJIs to be cost saving when treatment cost savings were included in the analysis [28].

Other needle-free technologies are currently in the development phase for delivery of vaccines, such as aerosol inhalation devices, nasal sprays, oral formulations, and transdermal patches. We believe that an early cost analysis is crucial to understanding their feasibility for delivering vaccines in low- and middle-income countries. The incremental costs should be evaluated against other vaccine delivery technologies that can deliver the same benefits to patients, health care workers, and the community. DSJIs deserve consideration by global and national decision-makers as a means to expand access to ID delivery and to enhance safety at marginal additional cost.

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