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One size does not fit all: The impact of primary vaccine container size on vaccine distribution and delivery

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ABSTRACT

Background: While the size and type of a vaccine container (i.e., primary container) can have many implications on the safety and convenience of a vaccination session, another important but potentially overlooked consideration is how the design of the primary container may affect the distribution of the vaccine, its resulting cost, and whether the vial is ultimately opened.
Methods: Using our HERMES software platform, we developed a simulation model of the World Health Organization Expanded Program on Immunization supply chain for the Republic of Benin and used the model to explore the effects of different primary containers for various vaccine antigens.
Results: Replacing vaccines with presentations containing fewer doses per vial reduced vaccine availability (proportion of people arriving for vaccines who are successfully immunized) by as much as 13% (from 73% at baseline) and raised logistics costs by up to $0.06 per dose administered (from $0.25 at baseline) due to increased bottlenecks, while reducing total costs by as much as $0.15 per dose administered (from $2.52 at baseline) due to lower open vial wastage. Primary containers with a greater number of doses per vial each improved vaccine availability by 19% and reduced logistics costs by $0.05 per dose administered, while reducing the total costs by up to $0.25 per dose administered. Changes in supply chain performance were more extreme in departments with greater constraints. Implementing a vial opening threshold reversed the direction of many of these effects.
Conclusions: Our results show that one size may not fit all when choosing a primary vaccine container. Rather, the choice depends on characteristics of the vaccine, the vaccine supply chain, immunization session size, and goals of decision makers. In fact, the optimal vial size may vary among locations within a country. Simulation modeling can help identify tailored approaches to improve availability and efficiency.

1. Introduction

While the size and type of a vaccine container (i.e., primary container) can have many implications on the safety and convenience of a vaccination session, another important but potentially overlooked consideration is how the design of the primary container may affect the distribution of the vaccine, its resulting cost, and whether the vial is opened depending on the policies and session [1,2]. The primary container is the vial or bottle in which the vaccine antigen is directly placed for storage and transport and can vary by size, shape, the number of vaccine doses it carries, and the presence or absence of an integrated administration device (e.g., a needle and syringe). These characteristics can affect the amount of storage and transport capacity required as well as vaccine wastage

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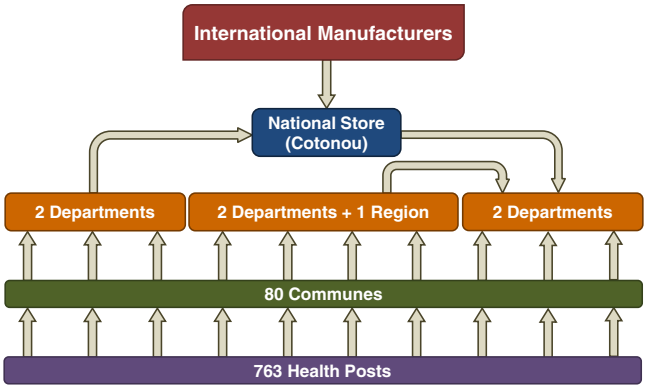

Fig. 1. Structure of Benin vaccine supply chain.

(i.e., if all doses in an opened container are not used during the same day, remaining doses may need to be discarded, depending on vaccine characteristics and program policies).

An immunization supply chain has three main objectives: making available the necessary vaccines and supplies, preserving vaccine potency, and utilizing resources efficiently [3]. Since a supply chain includes many different locations, storage devices, and transport vehicles, determining the combined effect of primary container characteristics on these supply chain objectives can be difficult without the use of computational simulation modeling. Therefore, using our HERMES (Highly Extensible Resource for Modeling Supply Chains) software platform, we developed a simulation model of the World Health Organization (WHO) Expanded Program on Immunization (EPI) supply chain for the Republic of Benin and used the model to explore the effects of different primary containers for various vaccines. In particular, we studied the impact of primary container choice on two major supply chain objectives: availability and efficiency.

2. Methods

2.1. HERMES model of the Benin vaccine supply chain

As described in a previous publication, a combined team of Agence de Médecine Préventive (AMP), PATH, and the HERMES Logistics Modeling Team developed a discrete-event simulation model of the Benin immunization supply chain [4]. Our HERMES model includes virtual representations of each vaccine vial, facility, storage equipment, transport device, route, and personnel in the supply chain as well as the anticipated demand at each immunization location. The model includes characteristics of the current EPI vaccines and one impending introduction [5,6], summarized in Table 1. National ordering and shipping policies govern the flow of vaccines through the country's four-level supply chain, shown in Fig. 1.

In Benin, the frequency of immunization sessions at each immunizing location is determined by the size of the population served, in order to maintain approximately uniform session sizes across all health posts and open vial wastage rates that conform to national guidelines. While policy dictates that health workers open a new vaccine vial, if necessary, to immunize any patient who arrives for vaccines, national policy also requires health workers to discard all open vials at the end of every immunization session. Our model follows these stated policies, but this study also includes experiments based on anecdotal evidence of health workers turning away patients whose immunizations would lead to the wastage of most doses in a vaccine vial.

Table 1
Vaccine characteristics in Benin supply chain model.

Vaccine	Presentation	Storage location	Doses per person	Baseline presentations			Experimental presentations		
				Doses per vial	Vaccine packed volume per dose	Diluent packed volume per dose	Doses per vial	Vaccine packed volume per dose	Diluent packed volume per dose
Diphtheria-tetanus-pertussis-hepatitis B-haemophilus influenza type B vaccine (DTP-HepB-Hib)	Liquid	Refrigerator (2–8 °C)	3	2	9.9 cm^3	n/a	10	2.6 cm^3	n/a
Oral polio vaccine (OPV)	Liquid	Preferably freezer (−15 to 0 °C)	4	20	0.7 cm^3	n/a	1 10	10.3 cm^3 1.0 cm^3	n/a n/a
Bacille Calmette–Guérin tuberculosis vaccine (BCG)	Lyophilized	Refrigerator (2–8 °C)	1	20	1.3 cm^3	0.6 cm^3	10	2.3 cm^3	1.0 cm^3
Yellow fever vaccine (YF)	Lyophilized	Refrigerator (2–8 °C)	1	10	2.5 cm^3	2.5 cm^3	2	7.2 cm^3	7.2 cm^3
Tetanus toxoid vaccine (TT)	Liquid	Refrigerator (2–8 °C)	2	10	2.6 cm^3	n/a	1	15.7 cm^3	n/a
Measles vaccine (M)	Lyophilized	Refrigerator (2–8 °C)	1	10	1.3 cm^3	2.5 cm^3	1	26.1 cm^3	15.7 cm^3
Pneumococcal conjugate vaccine (PCV)	Liquid	Refrigerator (2–8 °C)	3	1	12.0 cm^3	n/a	2	4.8 cm^3	n/a
Rotavirus vaccine (RV)	Liquid	Refrigerator (2–8 °C)	2	1	17.1 cm^3	n/a	n/a	n/a	n/a