Vaccine 30 (2012) 5637–5643

Contents lists available at SciVerse ScienceDirect

Vaccine

journal homepage: www.elsevier.com/locate/vaccine

The impact of making vaccines thermostable in Niger's vaccine supply chain

Bruce Y. Lee[a,*], Brigid E. Cakouros[a], Tina-Marie Assi[a], Diana L. Connor[a], Joel Welling[b], Souleymane Kone[c], Ali Djibo[d], Angela R. Wateska[a], Lionel Pierre[e], Shawn T. Brown[b,f]

[a] Public Health Computational and Operations Research (PHICOR), University of Pittsburgh, 200 Meyran Ave., Suite 200, Pittsburgh, PA 15213, USA
[b] Pittsburgh Supercomputing Center, 4400 Fifth Avenue, Pittsburgh, PA 15213, USA
[c] World Health Organization (WHO), Avenue Appia 20, 1211 Geneva 27, Switzerland
[d] Niger Ministry of Health (MOH), Ministère de la Santé Publique BP, 623 Niamey, Niger
[e] Logistics for Health, 9536 S.W. 156th Place, Miami, FL 33196, USA
[f] Department of Biostatistics, University of Pittsburgh, 130 DeSoto Street, Pittsburgh, PA 15261, USA

ARTICLE INFO

Article history:
Received 6 December 2011
Received in revised form 26 June 2012
Accepted 29 June 2012
Available online 10 July 2012

Keywords:
Thermostable
Vaccines
Supply chain

ABSTRACT

Objective: Determine the effects on the vaccine cold chain of making different types of World Health Organization (WHO) Expanded Program on Immunizations (EPI) vaccines thermostable.
Methods: Utilizing a detailed computational, discrete-event simulation model of the Niger vaccine supply chain, we simulated the impact of making different combinations of the six current EPI vaccines thermostable.
Findings: Making any EPI vaccine thermostable relieved existing supply chain bottlenecks (especially at the lowest levels), increased vaccine availability of all EPI vaccines, and decreased cold storage and transport capacity utilization. By far, the most substantial impact came from making the pentavalent vaccine thermostable, increasing its own vaccine availability from 87% to 97% and the vaccine availabilities of all other remaining non-thermostable EPI vaccines to over 93%. By contrast, making each of the other vaccines thermostable had considerably less effect on the remaining vaccines, failing to increase the vaccine availabilities of other vaccines to more than 89%. Making tetanus toxoid vaccine along with the pentavalent thermostable further increased the vaccine availability of all EPI vaccines by at least 1–2%.
Conclusion: Our study shows the potential benefits of making any of Niger's EPI vaccines thermostable and therefore supports further development of thermostable vaccines. Eliminating the need for refrigerators and freezers should not necessarily be the only benefit and goal of vaccine thermostability. Rather, making even a single vaccine (or some subset of the vaccines) thermostable could free up significant cold storage space for other vaccines, and thereby help alleviate supply chain bottlenecks that occur throughout the world.

1. Introduction

The dearth of reliable methods of keeping vaccines adequately cool or cold in many parts of the world has motivated calls for the development of thermostable vaccines, i.e., vaccines that do not degrade under heat or excessive cold exposure. To reach its destination, a vaccine travels through a country's vaccine supply chain (i.e., the series of storage locations and transport vehicles needed to get vaccines from manufacturers to vaccine recipients), and can traverse great distances and different climates. Many locations do not have reliable refrigerators or freezers (i.e., cold storage) or reliable means of monitoring temperatures in these devices [1,2]. Even when cold storage is present, space within cold storage may be limited or power availability may be intermittent and capricious [3]. One study in particular conducted in Indonesia found that 75% of vaccine lots shipped from the central level to peripheral levels were exposed to adverse temperatures [4]. Currently, thermostable formulations of a number of vaccines are under development including hepatitis B; diphtheria, tetanus and pertussis (DTP); and pentavalent (DTP, hepatitis B and haemophilus influenza type b) vaccines [3].

However, some have raised concerns that unless all vaccines in a country's immunization program become thermostable, the benefit of making individual vaccines thermostable will be limited since the country will still have to maintain a cold chain for the non-thermostable vaccines [5]. In other words, unless technological advances can make all vaccines thermostable, developing individual thermostable vaccines may not be worth the effort. This

* Corresponding author. Tel.: +1 412 246 6934; fax: +1 412 246 6954.
E-mail addresses: BYL1@pitt.edu (B.Y. Lee), bec16@pitt.edu (B.E. Cakouros), tina-marie.assi@mail.mcgill.ca (T.-M. Assi), diana_connor@hotmail.com (D.L. Connor), welling@psc.edu (J. Welling), kones@who.int (S. Kone), ali_djibo@yahoo.fr (A. Djibo), arw38@pitt.edu (A.R. Wateska), lionel@logisticsforhealth.com (L. Pierre), stbrown@psc.edu (S.T. Brown).

0264-410X/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.vaccine.2012.06.087

United Nations Map of Niger:
www.un.org/depts/Cartographic/map/profile/niger.pdf

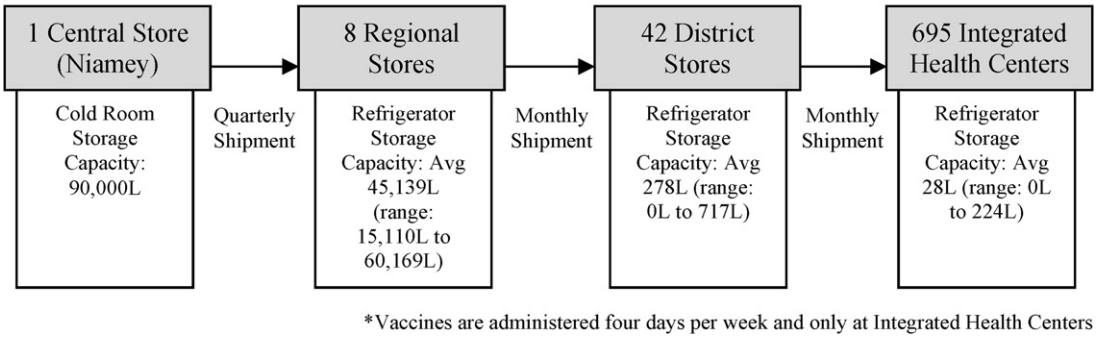

Fig. 1. The structure of Niger's vaccine cold chain.

is based on the belief that the greatest value of thermostable vaccines is the potential to eliminate the need for the cold chain, which is very costly and difficult to maintain.

Nevertheless, making individual vaccines thermostable could still have benefits if their removal from the cold chain could relieve bottlenecks in the vaccine supply chain. Therefore, our Vaccine Logistics Modeling team developed a computational model of Niger to simulate the effects of making different World Health Organization (WHO) Expanded Program on Immunizations (EPI) vaccines thermostable [6]. Many health centers in Niger have unreliable power or lack cold chain infrastructure, and therefore face difficulties in maintaining vaccines within 2–8 °C [7].

2. Methods

2.1. Niger vaccine supply chain model

Our team constructed a detailed discrete-event simulation computational model of the Niger vaccine supply chain utilizing our Highly Extensible Resource for Modeling Supply Chains (HERMES) framework. HERMES is programmed in Python and uses features provided by the SimPy package. Previously published studies detail the structure, data, and assumptions of our Niger supply chain model, which represents every storage location, refrigerator, freezer and transport device in the Niger supply chain as well as shipping schedules and policies and every EPI vaccine vial flowing through the supply chain (Fig. 1) [6,8]. This includes Bacille Calmette-Guerin (BCG), pentavalent, yellow fever (YF), oral polio virus (OPV), tetanus toxoid (TT), and measles (M). The model includes the type, make, model, age, and the specific capacity of every single cold room, refrigerator, and freezer at each location in the Niger supply chain with data collected by the 2008 WHO Cold Chain Inventory, verified and augmented by 2009 team visits. Each vaccine vial has a specified lifetime during which the vaccine remains effective. Exposure to temperatures beyond a vial's recommended range shortens this lifetime. Each immunization day, virtual patients arrive to be vaccinated based on census and birth data from Niger. Personnel at each location open and reconstitute (if necessary) a vaccine vial to immunize a child. Any reconstituted but unused doses are discarded at the end of the session.

2.2. Converting vaccines into thermostable formulations

The packaged volumes and temperature profile for each vaccine (Table 1) govern where (freezer versus refrigerator versus room temperature) each vaccine can and should be kept while in storage or transport [9,10]. It also determines the shelf-life of a vaccine. Converting a vaccine into a thermostable formulation means that the vaccine no longer requires cold storage or could be kept out of cold storage long enough to traverse locations and routes that may experience cold storage constraints resulting in bottlenecks and would have a shelf-life equivalent to established upper limits. Our experiments involved making various combinations of the EPI vaccines thermostable.