JPPT | Administrative Practice

Drug Shortage and Critical Medication Inventory Management at a Children's Hospital During the COVID-19 Pandemic

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Drug shortages have significantly affected the ability to provide care at pediatric institutions, particularly in the inpatient and critical care settings. The coronavirus disease 2019 (COVID-19) pandemic highlighted additional challenges with drug supply chains. A working group consisting of pharmacy management, clinical pharmacists, and pharmacy buyers met regularly at the beginning of the COVID-19 pandemic. In collaboration with medical staff leadership and the Pharmacy and Therapeutics Committee, we developed a pediatric critical drug list to track essential medications for targeted monitoring. We created an inventory model with easily modifiable input variables related to patient and hospital data. This model was aligned across affiliate health care systems to increase transparency of our hospital's surge capacity for managing patients with COVID-19. Here, we share our framework for modeling drug inventory management at a freestanding children's hospital during a global pandemic.

ABBREVIATION COVID-19, coronavirus disease 2019

KEYWORDS COVID-19; inventories, hospital; medication systems, hospital; pediatric; surge capacity

J Pediatr Pharmacol Ther 2021;26(1):21–25

DOI: 10.5863/1551-6776-26.1.21

Introduction

National and international drug shortages have affected the ability to provide high quality care in the inpatient setting. Possible reasons for shortages include raw material shortages, disruptions in manufacturing, recalls, insufficient manufacturing incentives, lack of recognition for good manufacturing practices, and regulatory barriers.[1,2] The American Society for Health-Systems Pharmacists listed 210 active shortages in April 2020, not including medications that were permanently discontinued.[3] A substantial portion of drug shortages include sterile injectable medications, which are essential for the care of critically ill patients.[1] Guidelines exist related to drug shortage management[2] and surge capacity planning[4] in health care systems; however, these documents may lack sufficient consideration for the pediatric patient and provide little guidance to individual pediatric institutions for drug inventory preparation in the setting of limited resources such as a global pandemic.

Drug shortages may disproportionately affect pediatric patients. Children have unique diseases and may use specific medications for which therapeutic alternatives may not exist. Furthermore, evidence to support the use of alternative products may be limited in various pediatric populations and alternative therapies may cause more severe adverse events in children.[5] Forced changes to practice resulting from drug shortages have led to adverse outcomes.[6] Pediatric specialists have developed recommendations and models to address allocation of specific drugs or medication classes during shortages.[7,8] However, limited resources are available to aid children's hospitals in addressing drug shortages.

Medication inventory management during a regional, national, or global emergency poses additional challenges to the pediatric health care system. Previously published guidelines suggest that hospitals have the capacity to increase critical care resources by at least 20% above baseline in the event of pandemic or disaster.[4] Increased demand on a disrupted supply chain during a global pandemic may exacerbate drug shortages. Other resources provide little specific guidance on medication management.[9] Recently published tools for medication inventory management recommend data accountability and transparency, discussion at medication committees, and tracking drug utilization and projections, including in special populations such as pediatrics.[10] Additional challenges unique to the pediatric population, such as difficulty with utilization estimates due to fractionating vials and availability of multiple concentrations, are not addressed. Other resources for surge capacity are tailored to pediatrics but also fail to specifically mention the challenges with medication supplies.[11,12]

Drug Shortage Task Force

Lucile Packard Children's Hospital Stanford is a 397-bed standalone women and children's hospital that includes 72 pediatric and cardiovascular intensive

Table 1. Pediatric Critical Medication List

Acetaminophen	Esmolol	Phenylephrine
Albuterol	Fat emulsion	Potassium chloride
Alprostadil	Fentanyl	Propofol
Amino acids	Furosemide	Racemic epinephrine
Amiodarone	Ganciclovir	Rocuronium
Aspirin tabs	Heparin	Sodium acetate
Atropine	Insulin	Sodium bicarbonate
Calcium gluconate	Intravenous immunoglobulin	Sodium chloride
Caspofungin	Lidocaine	Sodium phosphate
Clevidipine	Magnesium sulfate	Surfactant
Cytarabine	Meropenem	Tacrolimus
Dextrose 70%	Methylergonovine	Water for injection
Empty Bags, sterile	Methylprednisolone	Vancomycin
Epinephrine	Midazolam	Vasopressin
Epoprostenol	Oxytocin	Vincristine

care unit beds, a 40-bed level-IV neonatal intensive care unit and a level 1 trauma center designation. The Department of Pharmacy supplies medications for inpatient care, as well as ambulatory settings, home infusion, outpatient, and specialty pharmacy. Our institution created a drug shortage task force in 2019, in accordance with national guidelines for health care systems.[2] The task force consists of pharmacy buyers, pharmacy technicians, pharmacy management, and clinical pharmacist specialists representing various practice environments. We track possible and active drug shortages through a shared document (Microsoft Excel). The task force assigns an "owner" and further categorizes drug shortages based on the severity of the effect. The owner or their designee conducts inventory and utilization evaluation based on pharmacy purchase history and dispensing and administration data from the electronic medical record on a regular basis to provide estimates for month supply on hand. Smaller working groups that include affected pharmacy representatives, key stakeholders, and frontline staff manage the shortage item and report back to the task force. The task force communicates new, updated, and resolved shortages to medical staff through weekly emails, published summaries on the pharmacy department intranet page, and regular presentations at the Pharmacy and Therapeutics and Medical Executive Committees, via the Pharmacy and Therapeutics chairs.

Drug Shortages During COVID-19

The international coronavirus disease 2019 (COVID-19) pandemic raised additional issues related to drug shortages and critical medication inventory management. Unknown supply chain disruptions of active pharmaceutical ingredients and finished drug products due to global quarantines and production shifts led to uncertainty in the availability of critical medications.[13] In addition, increased purchasing by national and global health care systems contributed to decreased availability through distribution systems.[14] General frameworks have been suggested for mitigating drug shortage management during the COVID-19 pandemic.[15] Published "essential medications" lists were either not designed to address pediatric patients[16] or were not specific enough to inpatient and critical care on an institutional level to be used effectively during the COVID-19 pandemic.[17]

In addition to the volume of medications on shortage, the COVID-19 pandemic changed the paradigm for management of active shortages. Our historical approach has relied on reallocating or centralizing inventory, transitioning to alternative agents, or switching to a pharmacy-compounded product. During the COVID-19 pandemic, entire classes of medications—particularly sedatives, analgesics, and neuromuscular blocking agents—were largely unavailable. Purchasing all available inventory of the aforementioned classes, amongst others, was not feasible from a financial standpoint and would further contribute to ongoing shortages. In order to maintain adequate supply of critical drugs to care for our patients with and without COVID-19, we targeted only essential items and developed an adaptable model for inventory evaluation.

Critical Medication List Development and Inventory Modeling During COVID-19

The drug shortage task force served as a natural working group to address the aforementioned issues related to the COVID-19 pandemic. Pharmacists in the workgroup collaborated with unit medical directors to

Table 2. COVID-19 Surge Planning Model Using Cardiac Medications as an Example.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1							20*		20*			75%*	
2							x = patient weight (kg)		y = days/ admission			z = census adjustment Factor	
3	Formulas						=(E3*G1)/C3		=H3*G3*K1			=K3*(J1/30)*L1	MAX(0,(J3-L3)/I3)
4	**Category**	**Medication**	**Ref Product**	**Units**	**Input Dose***	**Units**	**Products used/day**	**Estimated Use***	**Qty consumed per admission for (y) days**	**Inventory***	**Use Per Month***	**Use for (X) days with Global Census Adjustment**	**[Surge Capacity over (x) days with Census Factor (z)]**
5	CARDIAC MEDICATIONS	Epinephrine	1	mg	0.05	mcg/kg/min	1.4	25%	7	2750	2500	1250	208
6		Norepinephrine	4	mg	0.05	mcg/kg/min	0.4	15%	1	100	65	33	63
7		Vasopressin	20	units	0.5	milliunits/kg/min	0.7	5%	1	195	91	45	208
8		Phenylephrine	10	mg	0.5	mcg/kg/min	1.4	10%	3	447	102	51	138
9		Alprostadil	500	mcg	0.05	mcg/kg/min	2.9	1%	1	80	43	22	102
10		Amiodarone	150	mg	5	mcg/kg/min	1.0	5%	1	259	207	104	162
11		Atropine	1	mg	0.02	mg/kg ONCE	0.4	1%	0	60	95	47	159
12		Clevidipine	50	mg	2	mcg/kg/min	1.2	10%	2	175	280	140	15
13		Esmolol	2000	mg	100	mcg/kg/min	1.4	5%	1	136	39	20	81
14		Lidocaine	50	mg	20	mcg/kg/min	11.5	5%	12	1369	1209	605	66
15		Sodium Bicarbonate	50	mEq	1	mEq/kg 3x/day	1.2	20%	5	534	319	160	78

* Input variables
Column M (Surge capacity) was automatically highlighted in ☐ for <25 patinets, ☐ for 25-100 patients and ☐ for >100 patients.

develop a list of "critical" and life-sustaining medications in the pediatric population. This list was adjusted and approved by our institution's Pharmacy and Therapeutics and Medical Executive Committees. The final version consisted of 45 items that were deemed essential to the care of our pediatric patients (Table 1).

We adapted a forecasting model in order to project ability to support surge capacity for patients with COVID-19 (Table 2). We estimated how much a patient with COVID-19 might consume during an admission, with easily modifiable input variables including the following: weight-based dose administered per day (average patient weight, estimated utilization [as a percent of days of therapy during hospitalization]) and duration of hospitalization. Standard dose was converted to daily amount (i.e., mcg/kg/min to mg/day by multiplying by 24*60 and dividing by 1000). Baseline utilization for non-COVID-19 patients was calculated using monthly purchase history and dispensing reports from our electronic medical record. We also included a percentage adjustment for our census, which was reduced at the beginning of the COVID-19 pandemic due to a reduction in elective surgeries. Projected utilization was calculated for the average duration of hospitalization for a patient with COVID-19, and the difference between inventory and baseline utilization was used to calculate surge capacity for patients with COVID-19 over that same time period. Inventory was normalized to a reference product (epinephrine 30 mg/30 mL counted as 30 units of 1 mg/1 mL). Inventory was counted twice weekly by pharmacy staff and the status of active shortages or medications with a surge capacity of less than 100 COVID-19 patients (highlighted in red for less than 25 and yellow for 25–99 patients based on internal projections for hospitalizations) was discussed weekly with the drug shortage task force.

Similar versions of this model (without input variables to account for the variability in our pediatric population) were developed at our affiliate health care institutions that primarily care for adult patients. In order to align our models, we tracked medications that were not included on our pediatric critical medication list but were considered essential for the care of adult COVID-19 patients. This facilitated transparency of shared inventory and earlier identification of new or worsening shortages. It also allowed us to identify our ability to support adult patients, who may use different medications at much different rates, should our hospital experience a surge of adult patients as a result of the COVID-19 pandemic.

Our model aligns with previously published recommendations for surge capacity planning.[4,10] Our process promoted data transparency and reporting. Highlighting specific medications allowed for targeted interventions, such as conserving supply or promoting use of alternatives. A shared model with our affiliates permitted collaboration and regional planning. Overall, the goal of our critical drug list and inventory model was to allow our health care system to provide essential clinical care without stockpiling inventory.

Future Directions

The COVID-19 pandemic has forced adoption of mechanisms to ensure adequate supply of medications for pediatric patients, particularly those who are critically ill. Significant challenges include securing consensus on a short list of critical medications amongst different specialties, rapidly changing availability of medications, and feasibility of accurate evaluation of utilization due to weight-based dosing used in children. We believe that our approach aligns with recommendations for shortage management during COVID-19.[10] We plan to continue to maintain and update our critical drug list. We also aim to implement the model as part of our active shortage management, using the inputs to more accurately predict our supply. Our hope is to increase the transparency of drug shortage management solutions affecting pediatric patients and collaborate with other children's hospitals and health care systems to sustain and improve the quality of care.

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Disclosures. The authors declare no conflicts or financial interest in any product or service mentioned in the manuscript, including grants, equipment, medications, employment, gifts, and honoraria. The corresponding author had full access to all data and takes responsibility for the integrity and accuracy of the data analysis.

Ethical Approval and Informed Consent. Given the nature of this project, institution board/ethics committee review was not required.

Acknowledgment. The authors thank the drug shortage task force at Lucile Packard Children's Hospital Stanford, unit medical directors, and Stanford University School of Medicine.

Submitted. August 27, 2020

Accepted. October 14, 2020

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