Estimating medical capacity required to administer mass prophylaxis: A hypothetical outbreak of smallpox virus infection in the Republic of Korea

Running title: estimation of medical surge capacity for smallpox outbreak

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Introduction

Smallpox used to be a major scourge of humankind with high infection and mortality rate. History shows that one smallpox contagious individual can infect 3.5-7 people naive to the virus [1]. This high infectiousness prompted communities requiring to attain as low as 70% of vaccination coverage for effective herd immunity. Killing almost a-third of infected people with severe hemorrhage and dehydration, smallpox had been the leading cause of death posing the greatest threat to public health until its eradication (WHO, 2014). As a result of intensified global eradication program led by WHO from 1967 to 1980, smallpox was declared to be eradicated [2]. Due to the cessation of immunization programs across the world, the majority of the population across the world has now become vulnerable to this virus. Smallpox may pose a threat to public health given that the possibility of an intentional or accidental release of the smallpox virus still exists [3]. So far, vaccination is considered as the most effective way to stop the smallpox outbreak [4]. Before its eradication, there were two types of smallpox vaccination: Ring vaccination and mass vaccination during and after the incident. Ring vaccination was done to prevent further exposure to the virus among those who are at risk of exposure and ranged from 1 to 70,000 per case [5]. It is usually done for household members of those who were symptomatic or exposed to the virus. Mass vaccination is a strategy to vaccinate all eligible people who have no immunity and hence are vulnerable to the disease. Although there is no one-size-fits-all planning for a smallpox outbreak when it comes to vaccination it has been proven that achieving high vaccination coverage was a key to eradicating the virus during the outbreaks [4]. Therefore, if, for any reason, smallpox reemerges regardless of its nature, either intentional or accidental release, mass vaccination may be the optimal option to attain high coverage of immunization among the population, preventing further spread of the disease. The mass prophylaxis covering tens of millions of people is only able to afford a short time to complete. Given the dire urgency, once the event of smallpox outbreak occurs, the distribution and dispensing plan of such medical supplies should be implemented effectively. Without properly trained medical personnel and supporting facilities, successful response to smallpox outbreak is not guaranteed.

Stockpiled smallpox vaccines were available in only a few countries before 2001 when the anthrax attack event occurred in the US. Additional production of smallpox vaccination and others were begun to meet any major demand on vaccine supply in case of an intentional release of smallpox virus [6]. A few countries have stockpiled smallpox vaccine to cover 100% of their population [7]. The Republic of Korea is one of the countries where an intentional release might occur as a few publications point out [8]. In response, the Korean government has been working to stockpile smallpox vaccines for at least 80% of the population. The most recent announcement indicated that the stockpile of smallpox vaccines including 1st and 2nd generation vaccines would cover 33% of the population in Korea [9].

Even if the smallpox vaccine is fully available when the outbreak occurs, however, still needed is the medical personnel that can administer prophylactic measures nationwide in an organized manner. Because of the significance of the disease, clinicians may volunteer to help respond to medical surge during the outbreak. As it is known that at least a week is needed to acquire protection against the virus after vaccination [10], an important question arises; how quickly millions of people who needed the vaccination can be effectively protected against the virus while garnering volunteer clinicians during the outbreak and afterward? To meet the demand for administering mass vaccination, medical personnel should be trained ahead of time. While conducting a national training program for emergency
responders to biological events including bioterrorism attacks, the Korean government has been diligent in promoting medical personnel and emergency responders to be vaccinated against smallpox and other potential bioterrorism agents. However, only a small fraction of medical personnel so far is vaccinated and completed the training to handle medical surge during a smallpox outbreak.

Like most other developed countries in Europe and North America, the Republic of Korea is implementing a plan to enhance its capacity to respond to a potential outbreak of smallpox. However, there is a lack of information on the estimated need for medical staff for prophylaxis which is likely to be the most effective intervention in case of a large smallpox outbreak in Korea. In preparing for medical surge during the potential outbreak and afterward, quantitative assessment of medical resource for large-scale vaccination should be in order. Hence, we aim to generate quantitative estimates of the response capacity needed for medical surge during and after a hypothetical smallpox outbreak in the Republic of Korea. Specifically, this study focuses on the number of core medical staff and dispensing clinics and duration needed for successful mass prophylaxis strategies.

Materials and Methods
We used the Weil/Cornell bioterrorism and epidemic outbreak response model (BERM version 2.0) to estimate the medical surge. BERM is a mass prophylaxis planning tool which is developed by researchers in the Department of Public Health at Weil Medical College of Cornell University. It calculates the estimates of staff and clinic sites needed to respond to a major disease outbreak or bioterrorism attack on a given population [11]. We reiterated estimations with varying the number of days for vaccination campaign, medical staff required and dispensing clinics as well as some predetermined parameters, such as characteristics of campaign and clinics. Campaign characteristics included population size for mass prophylaxis and length of the campaign. In this study, we assumed 35 million people (70% of total), which is the lowest coverage for herd immunity, as the target population for prophylaxis out of 50 million residing in South Korea will be required for immediate intervention to control the smallpox outbreak [12]. Duration of the campaign is the time frame to complete the prophylaxis campaign. The range of campaign duration was set from 10 to 1,080 days. Clinic characteristics included hours of clinic operation, shifts per day, downtime, per-clinic flow rate, crisis/isolation counseling, and patient testing. Hours of clinic operation is the hours of operation for the campaign’s dispensing clinics. Shifts per day are the number of anticipated work-shifts per day. Downtime is defined as the percentage of time used for breaks or lunch for the average staff worker. We assumed that the dispensing clinic will operate for 24 hours with 3 work-shifts, and downtime is assumed to be 15% as recommended. Per-clinic flow rate is the rate at which patients enter each dispensing clinic and is calculated to the patient/minute/clinic. It is the combined outcome of briefing characteristics using briefing plan in dispensing clinics with variables, such as the number of briefing rooms, each room’s capacity, and length of briefing. There is no research conducted in Korea that examined patients flow or health facilities capacity to handle mass vaccination in the context of healthcare environment of Korea. Hence, we used the CDC recommended values for those characteristics; CDC recommended the average patient flow rate to be 10 patients (pts) per minute for each dispensing clinic based on the number of briefing rooms (3-5 rooms), capacity of each room (50-75 patients), and length of briefing (20 minutes). We varied the rates a priori from 7.5 to 18.5 pts/min/clinic to examine the changes in the number of medical personnel and the duration of campaign, accordingly. In this study, crisis/isolation counseling that is to provide on-site assistance and referral information for individuals is considered. Our simulation did not include time and procedure for patient testing that is to evaluate potential contraindications to the vaccine. Event characteristics
included process time scenario, event scenario, and biological agent. Process time scenario is the amount of time required to process and individual at each of dispensing clinic stations. We selected the biological agent to be communicable and chose a fast process time and large-scale event scenario to reflect the surging demand during a hypothetical outbreak of smallpox. The core staff is defined as those individuals trained to work in direct contact with patients. Core staff includes triage and medical evaluation staff, forms distributors, collectors, vaccinators, etc. The number of core staff available ranged from 50 to 1200. The minimum number of core staff is based on the number of medical personnel have been vaccinated among health professionals in Korea until recently. The maximum number of core staff is indicative of the number of medical personnel that should be vaccinated before responding to the smallpox outbreak. We chose 1200 as the largest input for core medical staff after a series of iteration because it allowed a range of reasonable patient flow for various inputs.

To find the optimal range of the number of core staff and dispensing clinics and the duration of the campaign, firstly, we computed the total size of the population to be vaccinated given various length of campaign and numbers of core staff. The results are calculated by following formula:

\[ R_{\text{campaign}} = \frac{\text{Pop}}{T} = \frac{\text{Average campaign flow rate (pts/min)}}{\text{Average clinic flow rate (pts/min)}} \]  
\[ \text{(Eq. 1)} \]

Where,

\( \text{Pop} = \text{Total size of population,} \)
\( T = \text{Length of Time for campaign} \)

We then calculated the number of dispensing clinics needed given some selected durations of campaign and per-clinic patient flow rate. The number of dispensing clinics (\( N_{\text{DVC}} \)) is calculated by dividing the average campaign flow by the average clinic patient flow, as follows:

\[ N_{\text{DVC}} = \frac{R_{\text{campaign}}}{R_{\text{DVC}}} \]  
\[ \text{(Eq. 2)} \]

Where,

\( R_{\text{campaign}} = \text{Average campaign flow rate (pts/min)} \)
\( R_{\text{DVC}} = \text{Average clinic flow} \)

More detailed information on the parameters and equations used in this simulation can be found from the manual published alongside the calculation worksheets in the Microsoft Excel (BERM v.2).

We varied the number of days for the mass vaccination campaign from 10 to 1082 to examine how many days will be feasible for the country to plan on. Burke et al. showed that the smallpox outbreak may go on for up to 1200 days without any interventions [13]. Other research (Meltzer et al.) applied 365 days as a target duration to stop the spread and control smallpox with mass vaccination and quarantine [5]. This iteration was conducted with an assumption that the country will have sufficient number of dispensing clinics installed by letting the parameter float in the model. Also varied are the number of dispensing clinics to show how many clinics would be reasonable to prepare for an effective campaign to be done. A few requirements for dispensing clinic such as 24 hours of operation, 3 shifts
per day, and 15% of downtime are considered in the model. Some requirements were not included, for example, the existence of separate building for quarantine and isolation and patients testing. Other parameters and variables are determined to reflect the current capacity of Korea and potential milestones for future goals. Table 1 shows the variables that were considered and predetermined before our estimation.

Table 1

Results

We estimated the total population that can be vaccinated with given days of the campaign and the number of core medical personnel assuming the number of dispensing clinics were optimal. We iterated the estimation to produce a total of 168 observations with 7 different lengths of the campaign (i.e., 10, 30, 90, 180, 360, 720, and 1080) and 24 different numbers of core medical personnel varying from 50 to 1,200.

Figure 1 shows the total size of the vaccinated population according to the duration of the campaign and the number of core staff at the flow rate of 10 pts/min/clinic. The total size of the vaccinated population is converted into log scale: log(Vaccinated Population). To vaccinated the target population, 35 million people in 180 days after the outbreak, at least 1,200 core medical personnel will be needed to complete the prophylaxis (Figure 1. N1). If the vaccination can be done within 360 days, at least 903 core staff will be needed. With only 452 core medical personnel, it will take at least 720 days to complete the target vaccination goal (Figure 1. N3).

Figure 2 shows the number of dispensing clinics required for vaccination varied by different patient flow rate per clinic at a given duration of the campaign. Assuming core medical personnel is fully available for the given number of dispensing clinics, the duration of campaign and flow rate inversely correlate with the number of dispensing clinics. At a flow rate of 14.5 pts/min/clinic or higher, less than 10 clinics are required to achieve 70% vaccination within 180 days. At a flow rate of 7.5 pts/min/clinic and within 365 days of the campaign, about 10 clinics will be sufficient to achieve 70% vaccination.

We also examined the effect of patients flow rate on the number of dispensing clinics and core staff per clinic when the number of days for campaign duration is fixed as 360 days with about 1,000 medical core staff (Table 2). Because we could not fix the number of medical core staff exactly to 1,000, the results are based on the closest estimate of medical staff to 1,000. Table 2 shows the number of dispensing clinic and per-clinic core staff requiring to meet the per-clinic patient flow rate, assuming that the duration of the campaign is 360 days. Flowrate is correlated with the number of core staff. As the flow rate increases, the number of dispensing clinics decreases while the number of core staff per-clinic increases. At a flow rate of 8.5 pts/min/clinic, the number of dispensing clinics required for campaigns is 8, the number of core staff per clinic is 114 estimated from a total of 912 core staff.
Discussion
Examing the potential surge of medical resource during a hypothetical outbreak of smallpox infection provides an important opportunity for decision-makers to re-evaluate the country’s current capacity to meet the demand. From our crude but conservative simulation using a well-established tool, we found that there is a gap to fill in medical surge capacity if, for any reason, immediate response to smallpox outbreak is needed. Among competing priorities, developing personnel capacity to administer mass prophylaxis for a communicable disease appears to be one of the top priorities.

During a medical surge, the availability of medical staff that is trained and prepared for responding to such an event is utmost critical for successful and timely response and recovery. When medical staff is not properly protected, infected medical personnel can be more than just a burden and could add more risk to the public during an outbreak. The US has implemented a program to vaccinate medical personnel and emergency responders to enhance preparedness for smallpox outbreak [1]. While the program addressed many current issues, it also suffered low participation in the smallpox vaccination campaign. Participants later reported that the concern over possible side effects after the vaccination kept them from getting vaccinated [14]. Although smallpox vaccination had been administered for many decades it was not always safe to administer due to possible side effects and medical complications especially among those who are immune-compromised [15, 16]. This aspect of smallpox vaccination adds complexity to its planning because it requires much more sophisticated arrangement of related logistics, such as transport, evacuation, and medical facilities for dispensing the vaccines and quarantine. The Republic of Korea may benefit from the lessons learned from the experience of the US in meeting many preparedness demands for a possible biological event, such as emerging infectious diseases. After the very last report of smallpox infection in 1961, the Republic of Korea ceased mass vaccination in 1978 becoming one of the countries that eradicated. Anyone who was born before 1966 would have completed smallpox vaccination and anyone who is born after 1978 has no vaccination history of smallpox vaccine and therefore vulnerable to smallpox infection [17].

Immunization with vaccinia-based vaccines involves inoculation of the skin using a bifurcated needle that holds a dose of the vaccine (a small drop) in its fork, and that is first used to release the liquid on the skin and then held perpendicular to the skin, to rapidly and vigorously puncture the skin in an area of about 5 mm diameter, making a trace of blood appears [12]. This practice would require a skill that is not likely to be taught in most of the medical schools in Korea, hence needs to be learned through a hands-on training. Even though the medical personnel (vaccinator) became available after an immunization, they need to be first trained to be capable of vaccinating patients using the bifurcated needles. This highlights again the importance of training proper medical personnel in advance to prepare for such an event.

As part of the national vaccination plan during an emergency, health centers (and possibly some health posts) across the country will be used for dispensing vaccines. This leads to the notion that training the medical staff properly should be the most urgent task to get done. In the Republic of Korea, doctors are predominantly located in a metropolitan area leaving those remote parts of country vulnerable to delayed response in case of a large-scale infectious disease outbreak. Nurses are less concentrated but still largely located in the metropolitan area. There are about 250 health centers across the country all of which are run by one or more physicians depending on the catchment area [18]. Mass vaccination using the health centers should be part of the national campaign plan of the Republic of Korea because it will be much easier to mobilize the facilities and personnel to respond to the event.
compared to private medical entities. Other medical facilities with certain equipment such as a negatively pressurized room for highly pathogenic patients could be used during a medical surge for mass prophylaxis. Such hospitals should have enough space for quarantine and isolation facilities ready for use. To get the prophylactic medications and vaccines to those affected, dispensing clinic should be equipped with several core functions, such as mass triage, medical evaluation of symptomatic individuals, pharmaco-therapeutic consultation for drug or dosage adjustment if needed, and provision of antibiotics or vaccination [19]. Depending on the clinic’s capacity, it may also perform health emergency surveillance, patient briefings and communication, and mental health counseling. Facilities for shelters and medical evacuation should be also designated for a large-scale smallpox outbreak. A possible option is to use some of the government training facilities across the country that could accommodate large crowd as well as those in need of isolated rooms for quarantine.

Despite the lessons we derived from the simulation, there are limitations in interpreting the results. BERM v2 is a well-organized tool to help preparing for dispensing medical counter measures during public health emergencies. Since this tool was designed to apply to the American healthcare setting, parameters used in the tool should not be taken for granted for different countries healthcare setting. Especially, core staff in BERM v2 was defined as those who interact with patients, such as greeters (screeners), forms distributors, medical evaluators, briefing supervisors, triage staff, testing staff, vaccinators, crisis counselors, exit educators, and transport (EMS). These roles in the clinic may be played differently in the Korean healthcare setting. Depending on the availability of trained staff, there may be a discrepancy in the simulation inputs in this regard. However, assignment of such core staff is based on the needs of services to provide at the clinic during the mass vaccination in order to assure that there is no back up of patients in the clinic. Inputs for core staff in this simulation study adhere to CDC’s recommendation that over 60% of core staff be assigned to medical evaluators, triage staff, and vaccinators, which will be crucial during a public health emergency [19]. Not all fixed parameters we used are validated from previous studies. For example, we assumed that the dispensing clinics will operate 24 hours a day with a 15% downtime. Although this is within the CDC’s recommended range, it never was field-tested. In reality, emergency operation of the facilities may encounter interruptions by many unforeseen mishaps and may result in longer downtime, which implicates more medical surge capacity needed than our estimation.

Our simulation assumed that each dispensing clinic has the same capacity to handle the same number of patients. This allows us to treat dispensing clinics as a function of core medical staff. A dispensing clinic with 200 core staff can be considered equivalent to two small clinics with 100 core staff each. We also assumed that government will have designated facilities ahead of time for mass vaccination with minimum requirements for point of dispense, such as security, crowd control measures, quarantine and isolation room, and so on. Adding these complexities to medical surge capacity may require more sophisticated simulations including, for example, a gradual increase of participating dispensing clinics and variation in the patient flow rate between clinics. There are many other factors that are not included in the simulation: 1) transportation from communities to dispensing clinics, 2) administrative burden for managing crowd control near the clinics, and 3) risk communication during the outbreak and promotion for vaccination afterward. Requirements of health facilities administering mass prophylaxis are comprehensive and well documented in a previous report [19]. The guidelines are based on the US healthcare environment, however, a caution should be paid when applying them to the healthcare system in Korea. Distribution of patients across the country may have influence on the
number of clinics required to meet the goal of vaccinating a majority of population in a short time period. We recognized that the design and staffing of a clinic may differ depending on its characteristics, such as private vs. public facility. Reaching out to various facilities in the private sector could be an option to fulfill the need for providing prophylaxis in a timely manner during mass vaccination campaign. One possible protagonist assumption is that many clinicians, doctors, and nurses will have volunteered to participate in the mass vaccination campaign if such an event occurs. Medical volunteers will certainly help reduce the burden of mass vaccination. Identifying and vaccinating potential volunteers as well as training specifically for mass vaccination event would be a crucial step to enhance the current medical surge capacity. To promote those organizations and individuals volunteer for mass vaccination, Korean government may consider establishing a regulation that provides protections from liability for potential adverse outcomes in responding to medical surge. US has a regulation that authorizes the top health official to provide immunity from tort liability for those who respond to public health emergencies [20].

There is a concern that the genomes of the smallpox virus are even possible to build from a small lab with the necessary equipment [21]. No one ever imagined this possibility during the time of the smallpox eradication campaign. With a certain motivation and resource, any rogue state or organization could try to build a virus and use it to leverage their political agenda. Given its disfiguring impact and high fatality, smallpox is something that mankind should always look out for. Despite the very low likelihood, the detrimental impact of smallpox infection outweighs the burden of maintaining the smallpox vaccine stockpile given the high efficacy of the vaccine. To justify and fulfill such a significant commitment, it is absolutely crucial to train the medical personnel and responders properly and plan for successful implementation of mass prophylaxis.

Acknowledgement
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References


Table 1. Simulation inputs and parameters

<table>
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<tr>
<th>Inputs</th>
<th>Range</th>
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<tr>
<td>No. of core medical personnel</td>
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<tr>
<td>Per-clinic flow rate (pts/min/clinic)*</td>
<td>7.5-18.5</td>
</tr>
<tr>
<td>Duration of campaign (day)</td>
<td>10-1080</td>
</tr>
<tr>
<td>No. of dispensing clinic</td>
<td>2-325</td>
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</tbody>
</table>

Simulation parameters

| Population size                             | 35,000,000 people         |
| Hours of clinic operation                   | 24 hours                  |
| Shifts per day                              | 3 shifts                  |
| Downtime                                    | 15%                       |
| Crisis / Isolation counseling               | Included                  |
| Patient testing                             | Not included              |
| Process time scenario                       | Fast process times        |
| Event scenario                              | Large-scale event         |
| Biological agent                            | Communicable (Smallpox)   |

* CDC recommendation is 10 patients / min / clinic
Table 2. The Number of Dispensing Clinic and Per-clinic Core Staff according to Per-clinic Patient Flow Rate, when Duration of Campaign is fixed as 360 days

<table>
<thead>
<tr>
<th>Flow rate (patients/minute/clinic)</th>
<th>Dispensing clinic (A)</th>
<th>Core staff per clinic (B)</th>
<th>Total core staff (A) x (B)</th>
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Figure 1. Distribution of the size of vaccinated population based on various duration of campaign and numbers of core medical personnel (Note: N1: Core Medical Personnel=1200, Duration of Campaign=180, N2: Core Medical Personnel=903, Duration of Campaign=360, N3: Core Medical Personnel=452, Duration of Campaign=720)
Figure 2. The Number of Dispensing Clinics Needed according to The Duration of Campaign and Per-clinic Patient Flow Rate (Note: C1: Per-clinic Patient Flow Rate=14.5, Duration of Campaign (day)=180, C2: Per-clinic Patient Flow Rate=7.5, Duration of Campaign (day)=360)