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Major Article

Hospital influenza pandemic stockpiling needs: A computer simulation

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Background: A severe influenza pandemic could overwhelm hospitals but planning guidance that accounts for the dynamic interrelationships between planning elements is lacking. We developed a methodology to calculate pandemic supply needs based on operational considerations in hospitals and then tested the methodology at Mayo Clinic in Rochester, MN.

Methods: We upgraded a previously designed computer modeling tool and input carefully researched resource data from the hospital to run 10,000 Monte Carlo simulations using various combinations of variables to determine resource needs across a spectrum of scenarios.

Results: Of 10,000 iterations, 1,315 fell within the parameters defined by our simulation design and logical constraints. From these valid iterations, we projected supply requirements by percentile for key supplies, pharmaceuticals, and personal protective equipment requirements needed in a severe pandemic.

Discussion: We projected supplies needs for a range of scenarios that use up to 100% of Mayo Clinic–Rochester's surge capacity of beds and ventilators. The results indicate that there are diminishing patient care benefits for stockpiling on the high side of the range, but that having some stockpile of critical resources, even if it is relatively modest, is most important.

Conclusions: We were able to display the probabilities of needing various supply levels across a spectrum of scenarios. The tool could be used to model many other hospital preparedness issues, but validation in other settings is needed.

Of the 4 influenza pandemics during the past 100 years (1918, 1957, 1968, and 2009), only the 1918 influenza pandemic is considered severe in terms of morbidity and mortality. It was responsible for 50-100 million deaths worldwide.[1] Approximately one-third of the American population was infected, with a case fatality rate (CFR) of approximately 2.5%.[1] Such a pandemic today would no doubt overwhelm hospitals.[2] Hospital pandemic preparedness has been hampered by a lack of sufficiently specific planning guidance.[3] In large part, this is because differences among hospitals and between various pandemic scenarios make it difficult to provide useful guidance that is broadly applicable to all hospitals.

The US Department of Health and Human Services released its initial hospital pandemic guidance in 2006.[2] Although this guidance covered many important areas of hospital preparedness, there were significant gaps and generalities, such as advice to "stockpile enough supplies and medications" and "consider ways to increase surge capacity." How hospitals should best do this remains unclear.

The elements for consideration in hospital pandemic planning and health care surge capacity have been well described,[2,4] but the complex and dynamic interrelationships between these elements must be taken into consideration. For this reason several computer-based decision-making tools have been developed.[3,5-7]

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Conflicts of interest: MNA is principal, Interdisciplinary Solutions, LLC, New York, NY, which owns the rights to Panálysis. EST, AAA, and JCH were consultants to Interdisciplinary Solutions, LLC.

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Although useful, these tools were limited particularly with respect to dealing with the many uncertainties inherent in hospital pandemic planning and the operational interdependencies of response activities. For example, changing bed or ventilator capacity affects staffing, supply, and pharmaceutical needs and vice versa. Previous models also did not adequately account for operational chokepoints and bottlenecks, such as emergency department throughput and dynamic staffing patterns.

This report describes a detailed and nuanced computer-aided modeling tool that can enable rational resource-related decision making for hospital pandemic preparedness. The specific goals of this project were to develop a methodology to calculate influenza pandemic supply stockpile needs based on variable operational considerations in individual hospitals and then to test the methodology at Mayo Clinic Hospital–Rochester (Mayo Clinic), a major regional referral medical center with a large local population catchment area.

Previous research has provided pockets of information related to stockpiling, primarily pharmaceuticals, for pandemics.[8-13] Although cost is a factor in making stockpiling decisions, costs analysis was not included in our analysis. Additional analyses will be needed to determine the economic feasibility of preparing for a specified level of influenza pandemic scenarios based an organization's risk tolerance.

METHODS

A modified version of a previously described computer modeling tool, Panálysis (Interdisciplinary Solutions, LLC, New York, NY), was used for this study.[4] Inputs to the model were determined in several ways.

The range of likely epidemiologic variables (eg, clinical attack rate, hospitalization rate, hospital length of stay by unit type, percent requiring mechanical ventilation, and case fatality rate) for a local US portion of a severe influenza pandemic was determined by review of the literature and/or expert consensus of the project team (Table 1). The shape of the epidemiologic curve was taken from the second wave of the 1918 influenza pandemic in London, England.[17]

Table 1
Ranges of disease profile variables used in the simulation

Disease profile characteristics	Low end of range	High end of range	Range in literature	Reference
Clinical attack rate	22	38	30	7
			30	14
			30	8
Infected seeking care at hospital (triaged)	5	55	39	15
Triaged requiring hospitalization on a non-ICU unit	15	40	85	7
Average time spent in a non-ICU bed (d)	3	12	5	8
			11	15
Admitted to the hospital that require ICU admission	20	50	25	14
			15	8
			26	15
Average time spent in an ICU bed (d)	4	14	10	8
			10	15
ICU patients requiring mechanical ventilation	30	80	60	14
			50	8
Average time ventilated (d)	3	12	10	8
Non-ICU fatality rate assuming no shortages	3	6	N/A	—
ICU fatality rate assuming no shortages	10	60	N/A	—
CFR for the nonhospitalized population	0	0.3	0.11	16

NOTE. Values are presented as % unless otherwise noted.
CFR, case fatality rate; *ICU*, intensive care unit; *N/A*, not available.

It was selected because it is the most relevant historical example we could find and it is consistent with epidemiologic curves used in other influenza pandemic modeling efforts.

Mayo Clinic provided catchment population data. We assumed Mayo Clinic would provide care for its entire geographic catchment population. Age distribution was determined through US census data.

CFR was used as a proxy of severity. So that the effect of various shortages could be explored, we used 3 different CFRs, which together comprised the population-based rate:

- The CFR of patients who died outside the hospital,
- The CFR in a nonintensive care unit (ICU) bed, and
- The CFR for ICU patients and for patients on a ventilator.

These CFR values were determined by expert opinion of the investigators and normalized to collectively equal the expected population-based CFR of 0.93% ± 0.23%. To determine this value, we estimated that if an influenza pandemic of the same severity as occurred in 1918 occurred today the CFR would be reduced from the historic 2.5% to 0.93% due to advances in medical technology. See supplemental information for more details. This value falls within the midrange of those used by other researchers for modeling a severe pandemic (0.25%-2.1%).[8,16] We used a ±25% tolerance range of 0.93% ± 0.23% to account for uncertainty.

Key pharmaceuticals and supplies needed for hospitalized influenza patients, including those patients requiring critical care services and mechanical ventilation, were determined by expert opinion of the investigators. We only included supplies without which there would likely be a significant degradation in patient outcome and which could not be shared. Our list of essential pharmaceuticals and supplies is available in online supplemental information.

We surveyed Mayo Clinic to determine the total number of existing beds, potential surge beds, physicians, nurses, and patient care assistants that could be available by nursing unit and then estimated the occupancy of these beds by noninfluenza patients during a pandemic for each nursing unit. Out-of-state patients were excluded from our calculation under the assumption that in the context of a severe pandemic travel from out of state would be significantly reduced for elective hospital admissions because of public fear, travel warnings, or Mayo Clinic's operational decisions to postpone elective admissions.[18,19] From this, we projected the number of available influenza beds and categorized available beds by whether they could support a ventilated patient or not.

To project the number of ventilators and anesthesia machines that could be available at Mayo Clinic during an influenza pandemic, we counted the total number of ventilators and anesthesia machines in the hospital and determined their normal use rates. We then adjusted the use rates to account for the cancelation of elective surgeries and for absence of out-of-state patients to determine the number that could be available during a pandemic. We also took into account the number of respiratory therapists at Mayo Clinic and the number of patients they could care for to assess whether personnel or machines were the limiting factor. Nursing staffing was also modeled and will be reported elsewhere.

These data and assumptions were incorporated into a version of Panálysis[4] that was modified to incorporate Monte Carlo simulation, enabling thousands of scenarios each with slightly different assumptions to be modeled. Panálysis runs on Excel (Microsoft Corp, Redmond, WA) and the Monte Carlo simulations were performed with @Risk version 6 for Excel (Palisade Corp, Ithaca, NY).

Various response options were analyzed in the iterative model runs. Constraints were applied to the model to exclude iterations which violate logic or predefined parameters. For example: