Pediatric mass critical care in a pandemic*

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Objectives: **Previous simulation studies suggest that temporary pediatric mass critical care approaches would accommodate plausible hypothetical sudden-impact public health emergencies. However, the utility of sustained pediatric mass critical care responses in prolonged pandemics has not been evaluated. The objective of this study was to compare the ability of a typical region to serve pediatric intensive care unit needs in hypothetical pandemics, with and without mass critical care responses sufficient to triple usual pediatric intensive care unit capacity.**

Design, Setting, Patients, and Interventions: **The Monte Carlo simulation method was used to model responses to hypothetical pandemics on the basis of national historical evidence regarding pediatric intensive care unit admission and length of stay in pandemic and nonpandemic circumstances. Assuming all ages are affected equally, federal guidelines call for plans to serve moderate and severe pandemics requiring pediatric intensive care unit care for 457 and 5,277 infants and children per million of the population, respectively.**

Measurements and Main Results: **A moderate pandemic would exceed ordinary surge capacity on 13% of pandemic season days but would always be accommodated by mass critical care approaches. In a severe pandemic, ordinary surge methods would accommodate all the patients on only 32% of pandemic season days and would accommodate 39% of needed patient days. Mass critical care approaches would accommodate all the patients on 82% of the days and would accommodate 64% of all patient days.**

Conclusion: **Mass critical care approaches would be essential to extend care to the majority of infants and children in a severe pandemic. However, some patients needing critical care still could not be accommodated, requiring consideration of rationing. (Pediatr Crit Care Med 2012; 13:e1–e4)**

Key Words: disaster; Monte Carlo simulation; public health emergency; rationing; surge capacity; triage

Mass critical care approaches have been proposed to accommodate surges in critically ill or injured patients during public health emergencies (1–3). Mass critical care would extend intensive care to much larger than usual numbers of patients by limiting interventions to immediately lifesaving therapy only and delaying or forgoing less urgent routine care. Elements of mass critical care were used temporarily in the successful response to a major fire (4). Quantitative modeling studies have demonstrated that temporary mass critical care approaches would be essential in accommodating large numbers of pediatric patients in a sudden-impact emergency (5), with a likelihood of improved population outcomes (6). However, no published evidence has evaluated the potential benefit of sustained mass critical care in a prolonged public health emergency. This quantitative simulation study used Monte Carlo modeling to compare the ability of a typical region to serve pediatric critical care needs during hypothetical pandemics, with and without sustained mass critical care responses. Such evidence may help to justify a regulatory basis, operational plans, and stockpiles necessary to provide mass critical care.

METHODS

Typical Region

This quantitative modeling study analyzed pediatric critical care needs and resources in a typical region, whose population was assumed to be 1.7 million (all ages). The typical regional population size was postulated on the basis of the following evidence. Across the United States, the national population of 281,421,906 (7) is served by 174 level I or II pediatric intensive care units (PICUs) (8) and 170 verified pediatric trauma centers (9), resulting in average regional populations of 1.6–1.7 million. National averages are consistent with data for specific regions (10, 11). In the present study it was assumed that the typical regional population of 1.7 million includes 460,700 children of 0–18 yrs of age, inclusive (7). Also, on the basis of national averages, it was assumed that the region is served by 24 PICU beds (8).

Usual Nonpandemic Patients

A typical PICU bed provides care to 58.6 patients annually (12). Thus, four nonpandemic admissions each day were assumed for the typical region's 24 beds. It was assumed that 60% of nonpandemic PICU admissions are unscheduled emergencies (within the reported range of 43% to 91% [13]), with an equal probability of arriving on any day of the week. Scheduled elective admissions were assumed to account for the other 40% of admissions, with elective admissions occurring only on Mondays through Fridays. The length of stay for nonpandemic PICU patients, representing both survivors and nonsurvivors, was assumed to be 3.9 days (8), with no distinction between emergency and scheduled patients.

Hypothetical Pandemics

Pandemic scenarios were considered in daily detail over hypothetical 36-wk (252-day) pandemic seasons. The numbers of pandemic patients were postulated on the basis of federal assumptions calling for national preparations to admit 128,750 (457 per million) or 1,485,000 (5,277 per million) critically ill patients in moderate or severe pandemics, re-

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*See also p. 106.

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spectively (14). Assuming pediatric and adult populations are equally affected, the typical region would be faced with a total of 211 and 2,431 children needing PICU care during the pandemic season in moderate and severe scenarios, respectively.

Historical data do not reflect current intensive care practices. Thus, we lack historical data on the proportion of assumed total PICU admissions that would occur each day during the hypothetical pandemic seasons. Therefore, daily patterns of PICU pandemic admissions were modeled on the basis of proportions of deaths occurring each day in historical pandemic seasons as a proxy for severe illness needing PICU admission. Records of historical weekly or monthly variation in proportions of deaths were converted to daily variation for the purpose of modeling the timing of PICU admissions. Historical daily pandemic admission patterns were based on the moderate pandemic of 1968–1969 (15) and the severe pandemic of 1918–1919 (16). In each hypothetical scenario, the pandemic cases were considered to begin in the fifth week of the 36-wk season. The intensive care unit length of stay for pandemic patients, including survivors and nonsurvivors, was assumed to be 7.4 days on the basis of recent experience with critically ill 2009 H1N1 influenza patients (17).

Ordinary Surge Responses and Triage Rules

Ordinary care for the hypothetical typical region is usually provided in 24 PICU beds. However, most regions can modestly increase this number by using ordinary surge methods and still provide normal care. For the purposes of the modeling study, it was assumed that on the first day normal capacity is exceeded, early discharges would reduce occupancy by 15% below that accounted for by usual discharges (1, 18). On subsequent days, it was assumed that early discharges would reduce occupancy by an additional 5% each day below that accounted for by usual discharges. It was assumed that early discharges would shorten the PICU length of stay for both pandemic and nonpandemic patients. When normal capacity is exceeded, it was further assumed that elective scheduled admissions would be canceled. Finally, it was assumed that capacity could be modestly increased to 115% of the usual maximum to an ordinary surge capacity of 28 beds while normal care continued to be provided.

Mass Critical Care Responses and Triage Rules

Proposed mass critical care approaches would greatly increase the number of patients receiving essential lifesaving interventions. In addition to early discharges and cancellation of elective admissions, as described for ordinary surge, it was assumed that mass critical care methods would also triple capacity above the usual maximum of 24 PICU beds to a sustained mass critical care maximum of 72 beds.

Quantitative Model

Each day's number of patients needing PICU care was calculated by subtracting daily discharges and adding daily admissions relative to the previous day's patient number across the pandemic season for each scenario. The Monte Carlo simulation method accounts for uncertainty in assumptions, as well as random variation in daily events, by repeated random sampling. In this method, a quantitative model repeatedly calculated daily numbers of patients needing PICU care 100 times for each scenario. For each calculation, randomly selected values were assigned for the variables of interest. The random values were sampled from normal distributions around the evidence-based expected values of admission and discharge variables. The expected numbers of daily admissions and discharges were based on historical data, as outlined above. The sampling distribution around the expected values was specified as the standard deviation of variation in each variable. Since historical data are generally not available to describe the extent of variation or uncertainty in each variable, a coefficient of variation (the ratio of the standard deviation to the mean value of the variable) of 60% was assumed for each admission and discharge variable. Typical daily needs were estimated as the average of the repeated calculations across the pandemic season for each scenario. Extreme ranges of daily needs were estimated as ±2 SD from the average of the repeated calculations across the pandemic season for each scenario.

To evaluate assumptions made without historical evidence regarding uncertainty in admission and discharge variables, a sensitivity analysis was performed. All the above calculations were repeated with coefficients of variation in the variables changed from 60% to 30% and 90% to determine whether the results would be substantially altered.

Moderate and severe pandemics were modeled. In addition, intermediate scenarios were considered to determine the threshold of pandemic cases at which ordinary surge capacity and mass critical care capacity would be overwhelmed. Daily PICU admissions in the intermediate scenarios were based on timing of the 1918–1919 season (16).

Quantitative modeling was performed in Excel (Microsoft, Redmond, WA, 2004). The Institutional Review Board for the Protection of Human Subjects at the State University of New York Upstate Medical University determined that this modeling study based on publicly available data does not constitute human research and is therefore not subject to human research regulation.

RESULTS

Nonpandemic PICU Occupancy

Assumptions regarding usual nonpandemic PICU admissions and discharges estimate an average occupancy of 16 patients, well below the usual capacity of 24 beds. Ordinary surge responses to accommodate day-of-the-week and random variations in occupancy would be necessary an average of 3% of the time. An ordinary surge capacity of 28 beds would accommodate all the patients more than 99% of the time on average. In a nonpandemic situation, a PICU in an adjacent region would usually be able to accommodate the rare excess of patients above ordinary surge capacity. Nonpandemic day-of-the-week and random variations are shown in the first 4 wks of each of the hypothetical pandemic summaries (Figs. 1 and 2).

Moderate Pandemic

A moderate pandemic (Fig. 1) would result in a daily seasonal average occupancy

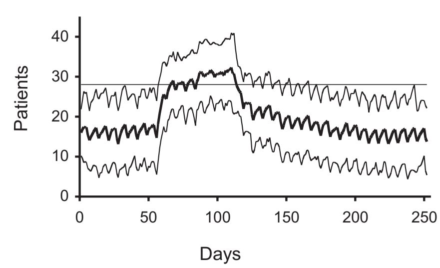

Figure 1. Daily number of patients needing pediatric intensive care unit care in a moderate pandemic. Daily results shown are the mean ± 2 SD for 100 repeated runs of a model season. The 28-bed ordinary surge capacity is shown (*thin horizontal line*).

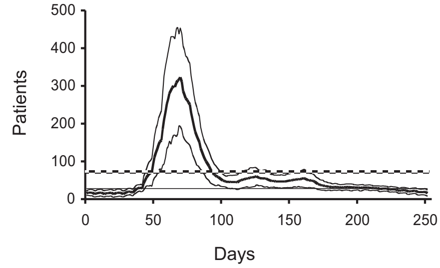

Figure 2. Daily number of patients needing pediatric intensive care unit care in a severe pandemic. Daily results shown are the mean ± 2 SD for 100 repeated runs of a model season. The 28-bed ordinary surge capacity (*thin horizontal line*) and the 72-bed mass critical care capacity (*thick horizontal line*) are shown.

of 20. Ordinary surge methods would accommodate all the patients 87% of the time and would accommodate 98% of patient days, on average. Mass critical care methods, needed for an average of 34 days, would always accommodate all patients. It is evident in Figure 1 that day-of-the-week variation in occupancy diminishes at the peak of the pandemic, as ordinary surge triage rules call for cancellation of scheduled weekday admissions.

Severe Pandemic

A severe pandemic would result in a much higher daily seasonal average of 65 patients needing PICU care. For a period of approximately 2 months, the need for PICU services in a typical region would exceed resources despite the implementation of ordinary surge and sustained mass critical care responses (Fig. 2). Ordinary surge methods would accommodate all the patients needing intensive care on only 32% of the days and would accommodate only 39% of patient days, on average. Mass critical care responses, needed on an average of 171 days of the 252-day season, would be essential in extending resources. With mass critical care approaches, all patients would be accommodated on 82% of the days, and 64% of patient days would be accommodated on average. However, rationing of PICU resources would be necessary over much of the pandemic peak despite mass critical care responses.

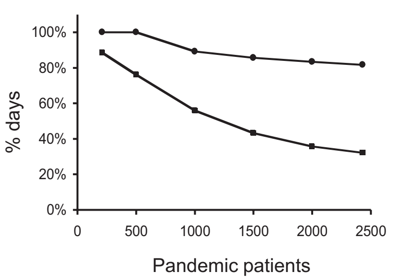

Figure 3. Average percentage of days on which all patients would be accommodated with (*circles*) and without (*squares*) mass critical care responses for pandemic patient number varying between moderate and severe.

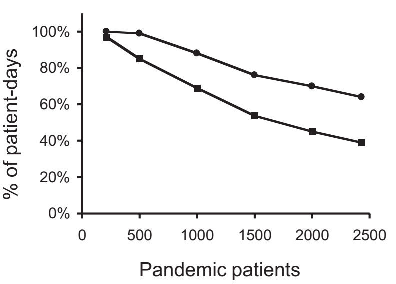

Figure 4. Average percentage of patient days accommodated with (*circles*) and without (*squares*) mass critical care responses for pandemic patient number varying between moderate and severe.

Scenarios Intermediate between Moderate and Severe Pandemics

In scenarios involving patient numbers intermediate between those of the moderate and severe pandemics described above, mass critical care approaches would play an increasingly important role as the size of the pandemic increased. For pandemics only slightly larger than the federal assumptions for a moderate pandemic (14), mass critical care responses would become crucial in increasing the percentage of days on which all patients would be accommodated (Fig. 3) and in increasing the percentage of needed patient days that would be accommodated (Fig. 4).

Sensitivity Analysis for Uncertainty in Assumptions

Models were recalculated assuming a coefficient of variation of 30% or 90% instead of 60% for admission and discharge variables. This results in smaller or larger day-to-day variation, respectively, in the numbers of children needing PICU care but has no effect on average critical care needs.

DISCUSSION

Mass critical care has been recommended to improve population outcomes when a large public health emergency threatens to overwhelm intensive care resources. In mass critical care, immediately lifesaving interventions would be provided to three times the usual number of intensive care unit patients by delaying or forgoing less urgent routine care and by substituting, adapting, conserving, and reusing resources (1–3). The resulting "altered" or "crisis" standards of care would provide a lower level of care to each patient to extend essential interventions to a larger number. Essential interventions would include mechanical ventilation, fluid resuscitation, vasopressors, antidotes and antibiotics, and analgesia and sedation.

The results of the present quantitative modeling study predict that even a moderate pandemic, as defined by federal planning definitions, would briefly exceed the PICU ordinary surge capacity in a typical region. The entire anticipated moderate pandemic surge could be accommodated by pediatric mass critical care approaches. In a severe pandemic, mass critical care would substantially improve the ability of existing resources to serve pediatric critical care needs. However, during a portion of a severe pandemic, mass critical care responses would be inadequate, and rationing would inevitably exclude some patients from intensive care.

The results of the present study may be compared with those of another recent quantitative pandemic model (19). Nap et al (19) modeled a pandemic involving 96-191 PICU patients in a region almost identical to that in the present study. Infants and young children could be accommodated for the pandemic smaller than the moderate pandemic modeled in the present study if children older than 7 yrs were admitted to adult units. However, options to transfer children to adult units may fail if capacity is filled across other hospital areas. Mass critical care approaches to increase pediatric capacity for larger pandemics were not explored in the Nap study.

It is also notable that intensive care needs for the 2009 H1N1 influenza pandemic were considerably smaller than the events modeled in the present study. In Australia and New Zealand, intensive care was required for 29 per million of the population (17), far below the 457 and 5,277 intensive care unit patients per million (14) modeled for moderate and severe pandemics in the present study. Thus, lessons learned in intensive care units during the 2009 H1N1 pandemic provide guidance in the utility of ordinary surge responses (20) but provide no evidence regarding mass critical care approaches.

The following limitations must be noted when considering implications of the present study to guide local operational planning. The present model examines a representative region, but the needs and resources of particular regions are more important for operational planning. Numerous variables not modeled in the present study would affect the balance between needs and resources, including population susceptibility, virulence and transmissibility of the pathogen, social distancing, vaccine and antimicrobial effectiveness, and the pandemic duration. If the mass critical care capacity was reduced by approximately 30% by staff absenteeism or other resource limitations (19), the present study predicts that moderate pandemics could still be accommodated by mass critical care approaches. However, such reductions in mass critical care capacity would impair responses to severe pandemics. No attempt has been made in the present study to model outcomes. In particular, the model provides a pessimistic overestimate of PICU patient day needs in a severe pandemic, as patients receiving mass critical care and especially patients excluded from care would have a higher mortality rate than those receiving normal care, tending to reduce PICU patient day needs below those shown. The model provides no insight into the details of bedside care, supply chain logistics, or limitations in capacity of other areas of the hospital. No gold standard exists to validate the performance of the model in a sustained mass critical care response. However, validity is supported by the model's reasonable representation of variation in typical intensive care unit occupancy in nonpandemic circumstances.

The present study adds to previous evidence that mass critical care responses, with or without rationing, would be an essential component in successful responses to a large public health emergency. Authority to implement temporary mass critical care in individual hospitals in a sudden-impact emergency may be implied by emergency triage procedures (1, 21). However, authority is ambiguous regarding the alteration of usual critical care standards in a sustained mass critical care response across a wide geographical area (1, 21). Lacking authority to initiate sustained mass critical care, neither operational plans nor stockpiles sufficient for mass critical care presently exist in most jurisdictions.

Public health emergency powers are defined on a state-by-state basis (22). Therefore, it is essential that state departments of health and other relevant agencies develop crisis standards of care protocols that reaffirm ethical norms, define legal authority, and provide liability protection. Only with a consistent framework across jurisdictions will it be possible to develop local operational plans, stockpiles, and public and professional education necessary for mass critical care in public health emergencies (21, 23, 24). Lack of preparation guarantees failure. Because regional pediatric critical care resources are more limited than those for adults, it is essential that operational plans for mass critical care include components necessary to extend intensive care for infants and children.

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