Pediatric Hospital and Intensive Care Unit Capacity in Regional Disasters: Expanding Capacity by Altering Standards of Care
Robert K. Kanter and John R. Moran
*Pediatrics* 2007;119:94-100
DOI: 10.1542/peds.2006-1586

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://www.pediatrics.org/cgi/content/full/119/1/94
Pediatric Hospital and Intensive Care Unit Capacity in Regional Disasters: Expanding Capacity by Altering Standards of Care

Robert K. Kanter, MD, John R. Moran, PhD

*Department of Pediatrics, State University of New York Upstate Medical University, Syracuse, New York; †Department of Health Policy and Administration, Pennsylvania State University, University Park, Pennsylvania

The authors have indicated they have no financial relationships relevant to this article to disclose.

ABSTRACT

BACKGROUND. Federal planners have suggested that one strategy to accommodate disaster surges of 500 inpatients per million population would involve altering standards of care. No data are available indicating the extent of alterations necessary to meet disaster surge targets.

OBJECTIVE. Our goal was to, in a Monte Carlo simulation study, determine the probability that specified numbers of children could be accommodated for PICU and non-ICU hospital care in a disaster by a set of strategies involving altered standards of care.

METHODS. Simulated daily vacancies at each hospital in New York City were generated as the difference between peak capacity and daily occupancy (generated randomly from a normal distribution on the basis of empirical data for each hospital). Simulations were repeated 1000 times. Capacity for new patients was explored for normal standards of care, for expansion of capacity by a discretionary 20% increase in vacancies by altering admission and discharge criteria, and for more strictly reduced standards of care to double or quadruple admissions for each vacancy. Resources were considered to reliably serve specified numbers of patients if that number could be accommodated with a probability of 90%.

RESULTS. Providing normal standards of care, hospitals in New York City would reliably accommodate 250 children per million age-specific population. Hypothetical strict reductions in standards of care would reliably permit hospital care of 500 children per million, even if the disaster reduced hospital resources by 40%. On the basis of historical experience that as many as 30% of disaster casualties may be critically ill or injured, existing pediatric intensive care beds will typically be insufficient, even with modified standards of care.

CONCLUSIONS. Extending resources by hypothetical alterations of standards of care would usually satisfy targets for hospital surge capacity, but ICU capacity would remain inadequate for large disasters.
Federal targets for hospital surge capacity recommend accommodating 500 adult and pediatric patients per million population in a disaster. Recent observations in New York indicate that existing resources will often fall short of this target, especially for an incident involving large numbers of children. Planners have suggested that one strategy to extend resources would involve altering standards of care to expand numbers of patients who could receive essential interventions. Disaster planning for hospital and critical care has lagged behind that for prehospital and emergency care. Mass casualty hospital care is receiving increasing attention from professional organizations, government agencies, and clinical investigators. However, no evidence is available on the additional capacity that must be provided to reliably meet surge targets. Unique needs of children have been anticipated, but no publications, to our knowledge, have analyzed the matching of projected needs and extension of existing pediatric hospital resources.

Our study was performed by using New York City as a model to determine the likelihood that specified numbers of children in disasters could be accommodated for PICU and non-PICU hospital care. A set of strategies was explored to extend resources by altering standards of care in a graded fashion. Simulation methodology was used to investigate situations seldom previously encountered. The simulations were based on historical observations, as well as federal and professional planning assumptions. This analysis of hospital emergency capacity provides planners with a population-based approach that may assist disaster preparedness in metropolitan areas.

METHODS

Data, Assumptions, and Simulations

Hospitals’ capacity to accommodate a surge of new inpatients depends on peak capacity and the number of patients already occupying hospital beds, as well as the ability to extend staff to care for larger than normal workloads. Hospital surge capacity was estimated by a Monte Carlo simulation method, as follows:

Step 1

Our study of disaster surge capacity in New York City was based on known numbers of hospitals, as well as the known peak, mean, and standard deviation of daily occupancy counts at each hospital from 1996–2002.

Step 2

For each hospital, a simulated daily occupancy count was specified by drawing samples randomly from a normal distribution calibrated with the mean and standard deviation of each hospital’s actual daily occupancy count during 1996–2002. Random occupancy samples were truncated within the range of 0 to peak for each hospital. Each sample provided 1 hypothetical occupancy count, distributed probabilistically, from empirically plausible occupancies.

Step 3

Daily vacancies for new admissions at each hospital were calculated as the difference between known peak capacity (Step 1) and simulated daily occupancy count (Step 2), with fractions rounded down to the nearest whole number.

Step 4

Regional daily vacancies were calculated as the sum of the simulated daily vacancies at each hospital (Step 3). Assuming normal standards of care (1 patient for each vacancy), the regional capacity for new patients is equal to the regional daily vacancies.

Step 5

Regional capacity for new patients with altered standards of care was estimated by assuming a 20% increase in vacancies (Step 4) by discretionary modification of admissions and discharges, as well as by doubling or quadrupling the number of patients who can be admitted into each vacancy.

Step 6

By performing steps 1 through 5 repeatedly (1000 times), a probabilistic distribution of hospital surge capacities was obtained for New York City.

Given a set of needs, resources, and assumptions regarding the incident, the likelihoods of specific outcomes were estimated. Results were expressed as the probability that specified total numbers of hypothetical patients could be accommodated in each scenario, at each standard of care, in any hospital pediatric bed (without regard to PICU or non-PICU status), or specifically in PICU beds. Regional hospitals were considered to reliably serve a specified number of patients if that number could be accommodated with a probability of at least 90%.

Empirical data on daily use of PICU beds are not available from publicly available sources. Therefore, it was assumed that overall percent occupancy of pediatric beds at each hospital serves as a proxy for PICU percent occupancy at the same facility for those hospitals with PICUs. Thus, the simulated daily number of vacancies in PICU beds was estimated as the difference between total PICU beds on hospitals’ operating certificates and simulated percent daily pediatric occupancy determined across all pediatric beds at each hospital, as described above (simulation steps 2 and 3). PICU resources were further classified as those in state-designated trauma centers and those in pediatric teaching hospitals lacking trauma center designation.

It was assumed that beds routinely used for pediatric...
care could provide appropriate and satisfactory care in disasters if patient severity and complexity were similar to the patients routinely served at each hospital. If patients’ treatment needs in a disaster differ substantially from the ordinary, then emergency capacity would be more difficult to estimate.

This study investigated existing publicly available information without patient identifiers. The institutional review board for the Protection of Human Subjects at State University of New York Upstate Medical University determined that the work does not constitute human subjects research.

Scenarios

Hypothetical scenarios were assumed to involve a single mass casualty incident with patient numbers as large as 500 per million age-specific population. This corresponds with 800 hospitalized children, 0 to 14 years of age, in the New York City region. The regional population in this age range is 1.6 million. For analysis of PICU resources, it was assumed that critically ill or injured patients accounted for up to 30% of the hypothetical total, consistent with historical reports of pediatric and adult mass casualty events. This would correspond with as many as 150 children per million, or a total of 240 hypothetical PICU patients for the region. In an “all-resources-available” scenario, it was assumed that all hospitals remained in operation, remained accessible, that information was available regarding vacant capacity, and that sufficient authority existed to distribute patients to an appropriate vacant bed. In a second “loss-of-resources” scenario, it was assumed that 40% of existing hospital resources had been lost as a result of the disaster. In this case, no attempt was made to consider redistribution of preincident inpatients. It is simply assumed that vacancies, estimated as previously described, are reduced by 40%. This assumption is consistent with disaster scenarios in which preincident patients at destroyed facilities become fatalities, whereas patients at operational but inaccessible hospitals continue to receive care at those facilities. If it were possible to transfer patients from nonfunctioning hospitals, the demands placed on the remaining functional hospitals would be more severe than suggested by our simulations.

Standards of Care

The likelihood of accommodating all patients was evaluated for each of the following standards of care. (a) Normal: An attempt would be made to provide usual standards of care to all patients. Peak capacity could not exceed that in ordinary use. (b) A 20% discretionary increase in capacity for new patients would be achieved through early discharges and cancellation of elective admissions. This is a slightly larger discretionary increase in capacity than was seen in New York City after the 9/11/01 attacks. After the discretionary increase in capacity achieved by modifying admissions and discharges, usual standards of hospital or PICU care would be provided, and peak capacity could not exceed that in ordinary use. (c) After discretionary increases in capacity, further double the number of new patients that could be admitted for each vacancy by reducing standards of care. (d) Quadruple the number of new patients that could be admitted for each vacancy by more strictly reducing standards of care and limiting interventions to essential lifesaving measures. With alteration of standards as in (c) and (d), capacity could substantially exceed the ordinary peak. The assumption that the number of new admissions per vacancy could be doubled or quadrupled is not supported by historical evidence; instead it is made to determine whether even such substantial extensions of resources would be sufficient to accommodate federal targets for disaster surges.

RESULTS

Hospitals and Beds

In the New York City region, 71 hospitals providing care during 1996–2002, still in operation in 2005, were included in the analysis. The regional peak capacity for all hospitals would allow usual standards of care for a maximum of 1478 children in pediatric beds (924 beds per million age-specific population). Six hospitals with trauma center designation provided a total of 62 PICU beds (39 per million age-specific population). Seven teaching hospitals lacking trauma center designation provided 46 PICU beds (29 per million age-specific population). Together, the trauma and nontrauma hospitals provided a total of 68 PICU beds per million population.

Hospital Disaster Care: All Resources Available

Hospitals in New York City could reliably accommodate >250 children per million (Fig 1: curve a) in a mass casualty event, corresponding with half the target number of 500 per million. If discretionary changes in admissions and discharge expand vacancies by 20%, then >300 per million could be reliably accommodated (Fig 1: curve b). Altering standards of care to double the number of new pediatric admissions per vacant bed would be necessary to reliably accommodate 500 children per million (Fig 1: curve c).

Hospital Disaster Care: 40% of Resources Lost

If disaster-related events reduced available pediatric hospital resources by 40%, then slightly >125 children per million could be reliably admitted for routine care, and 250 per million would virtually always exceed available resources (Fig 2: curve a). A 20% discretionary increase in vacancy by modifying admissions and discharges, coupled with a doubling of new patients for each vacancy, would often still fall short of the target of 500 per million (Fig 2: curves b and c). Only by quadrupling new inpa-
patients per vacancy could the surge of 500 per million be reliably accommodated (Fig 2: curve d).

**PICU Disaster Care: All Resources Available**

If an attempt was made to provide usual standards of intensive care, vacancies would not reliably accommodate as few as 25 children (total number) in trauma center PICUs (Fig 3: curve a), or in all regional PICUs, with or without trauma center designation (Fig 4: curve a). Increasing capacity through a discretionary modification of discharges and admissions and a reduction in care standards sufficient to quadruple the number of new patients admitted to each PICU vacancy would substantially improve the situation. As a result, intensive care could be reliably provided for 63 children per million (a total of 100 new children) (Fig 4: curve d). However, disaster scenarios involving 500 children per million age-specific population in which 30% require intensive care would almost always exceed available PICU resources despite alterations in standards of care (Figs 3 and 4).

**PICU Disaster Care: 40% of Resources Lost**

Fifty-five percent of PICU beds were concentrated at only 4 hospitals. If any of these hospitals were to become disabled, the loss of regional PICU capacity would be disproportionately large compared with the loss of non-

---

**FIGURE 1**
Probability of accommodating all patients in pediatric hospital beds if all resources are available: a Normal standards of care; b discretionary increase in vacancies by 20%; c double admissions for each vacancy. Numbers of patients are expressed per million age-specific population and total.

**FIGURE 2**
Probability of accommodating all patients in pediatric hospital beds if 40% of resources are not available: a Normal standards of care, b discretionary increase in vacancies by 20%, c double admissions for each vacancy, d quadruple admissions for each vacancy. Numbers of patients are expressed per million age-specific population and total.
PICU resources, which are not as highly concentrated. Results are not shown in the figures.

**DISCUSSION**

This simulation study analyzes the ability of New York City hospitals to expand pediatric hospital capacity by altering standards of care. No attempt was made to gain insight regarding the specific alterations in care that would be necessary or feasible, the resulting impact on survival, or the relative merits of other strategies.

The probabilistic representation of baseline hospital occupancy counts, based on recent historical experience, provides an evidence-based method for estimating emergency surge capacity. Reducing standards of care would reliably permit hospital care of 500 per million children in the New York City region in a disaster. Depending on the proportion of critically ill or injured patients, PICU beds may be insufficient even with modified standards of care.

Random selection of baseline occupancies from historical data takes into account both seasonal and day-of-the-week variation in the availability of beds. High hospital occupancy on winter weekdays contributes to the small probability that even small surges would exceed available capacity, whereas low occupancy on summer weekends contributes to the small probability that larger surges could be accommodated without expanding vacancies or modifying standards of care. An average of
268 vacant functional pediatric beds per million children are available, statewide, with a minimum of 193 per million available during high-occupancy periods in the winter and a maximum of 354 per million available during low-occupancy periods in the summer.2

The following considerations pertain to assumptions made in this study. We have analyzed 2 scenarios, each having historical and disaster-planning relevance. In the first, nearly all resources remain available, corresponding with the historical example of the 9/11/01 responses in New York City and Washington.19,20 A second scenario, in which 40% of resources are unavailable, was used in planning response strategies by the federal Agency for Healthcare Research and Quality.1 In considering a 40% reduction in resources, we assume that preincident inpatients in the unavailable hospitals may still be receiving care at the inaccessible hospitals or may have become fatalities at a destroyed facility. No consideration has been given to redistributing preincident inpatients at the remaining accessible facilities.

Our study considers only the patient numbers involved in the initial transition from ordinary hospital operations to a crisis response. Hospital functions in a protracted crisis are beyond the scope of this study. The rate-limiting steps in prehospital, emergency department, surgical, and radiologic services have been considered by other authors,18,21 and are not explored in this study. The assumption that vacant beds could be identified by a coordinating authority is consistent with existing information systems that provide real-time data on resource use, now available in some states.22

Federal targets for hospital surge capacity are intended to stimulate local planning efforts for all potential hazards and do not emphasize particular mechanisms of illness or injury. Traumatic or burn injuries, infections, or toxic exposures would all create unique patient care implications. Crises occurring as a result of terrorism would involve distinct considerations for authorities compared with accidents or natural disasters.

The target surge bed ratios of 500 patients per million population were derived from National Disaster Medical System projections, data from established trauma systems in the United States and other countries, and on the basis of expert judgment.1 Target proportions of pediatric and adult patients have not been specified, consistent with the view that incidents could involve large numbers of children or adults. Federal guidelines do not provide targets for intensive care bed availability.

Standards of care could be mildly altered by discretionary modification of admissions and discharges. The discretionary increase in vacancys of 20% assumed in this study is larger than the increase seen in New York City after the 9/11/01 attacks.2 It may be assumed that if larger numbers of beds had been needed after 9/11, additional beds could have been made available. Surveys of physicians and nurse managers indicate that up to 30% of inpatients typically could be discharged to accommodate surges of new patients in a disaster.21

More substantial alterations in standards of care to double or quadruple the capacity for new patients are assumed to be possible. Most historical experience with alteration of care in disasters has involved minute-by-minute matching of needs and resources, decided by individual clinician leaders. If alterations of care must be formalized over multiple institutions for many hours or days, the following practices have been suggested:7–10; temporarily increase the pool of providers by expanding the scope of professional practice; conserve supplies and equipment by reusing disposable supplies; increase reliance on clinical judgment if availability of laboratory and radiologic services are limited; reduce documentation, confidentiality, and informed consent; use standing template orders; and extend staff to care for many more than the usual number of patients by foregoing nonessential interventions. We have not specified specific alterations in bedside care and therapeutic interventions because no evidence is available on the workload and capacity implications of particular alterations.

It might be argued that an unprecedented expansion of hospital capacity would involve many factors not accounted for in our model. For example, it is likely that the least-severe casualties may arrive at hospitals first, with ambulatory patients choosing to bypass triage by emergency medical services. It is likely that hospitals near a mass casualty incident will receive large numbers of victims exceeding capacity even if standards are reduced, whereas more distant facilities will have unused capacity.24 However, we have addressed considerations of unused or unavailable resources in our “40%-loss-of-resources” scenario. If some hospitals were disabled, patients at those hospitals might require redistribution to functional hospitals, adding to the emergency surge numbers. Even making the stated optimistic assumptions, our data indicate population-based limits beyond which the system would likely be overwhelmed or would require other strategies to expand capacity. Some anticipated disasters would exceed targets of 500 per million. For example, a severe influenza pandemic might cause illness in 300,000 per million, with hospital care required for 33,000 per million, and mechanical ventilation for 2400 per million, over the course of the pandemic.23 Limited stockpiles of mechanical ventilators are likely to be a critical factor, which is not accounted for in the present study, in accommodating critically ill or injured patients.10

Pediatric patients were the focus of this study because hospital capacity for children is smaller and concentrated at fewer facilities than that for adults.2 More than half of all regional PICU capacity was concentrated in only 4 facilities. Geographical concentration of critical infrastructure may intensify vulnerability in disasters.26 Large numbers of pediatric patients might be encountered as...
part of a large incident involving all segments of a population, as an accident involving a facility for children, or as a result of the targeting of children in a terror-related event.27,28

The strength of this study lies in its population-based analysis of real resources in a real location using empirical data. The utility of the report for other regions may be to motivate quantitative analyses of local needs, resources, and response strategies, and to suggest an approach to such planning efforts. In particular, quantitative analysis of the expected survival trade-offs between lower standards and greater surge capacity versus normal standards and lower capacity would be necessary to guide the implementation of altered standards of care. Comparison with other strategies would be warranted. If patient surges in disasters are to be accommodated by altering standards of care, careful consideration must be given to specific rules and procedures formalizing such a transition.

REFERENCES