ORIGINAL RESEARCH

Regional Variation in Critical Care Evacuation Needs for Children After a Mass Casualty Incident

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ABSTRACT

Objectives: To determine the ability of five New York statewide regions to accommodate 30 children needing critical care after a hypothetical mass casualty incident (MCI) and the duration to complete an evacuation to facilities in other regions if the surge exceeded local capacity.

Methods: A quantitative model evaluated pediatric intensive care unit (PICU) vacancies for MCI patients, based on data on existing resources, historical average occupancy, and evidence on early discharges and transfers in a public health emergency. Evacuation of patients exceeding local capacity to the nearest PICU center with vacancies was modeled in discrete event chronological simulations for three scenarios in each region: pediatric critical care transport teams were considered to originate from other PICU hospitals statewide, using (1) ground ambulances or (2) helicopters, and (3) noncritical care teams were considered to originate from the local MCI region using ground ambulances. Chronology of key events was modeled.

Results: Across five regions, the number of children needing evacuation would vary from 0 to 23. The New York City (NYC) metropolitan area could accommodate all patients. The region closest to NYC could evacuate all excess patients to PICU hospitals in NYC within 12 hours using statewide critical care teams traveling by ground ambulance. Helicopters and local noncritical care teams would not shorten the evacuation. For other statewide regions, evacuation of excess patients by statewide critical care teams traveling by ground ambulance would require up to nearly 26 hours. Helicopter transport would reduce evacuation time by 40%-44%, while local noncritical care teams traveling by ground would reduce evacuation time by 16%-34%.

Conclusions: The present study provides a quantitative, evidence-based approach to estimate regional pediatric critical care evacuation needs after an MCI. Large metropolitan areas with many PICU beds would be better able to accommodate patients in a local MCI, and would serve as a crucial resource if an MCI occurred in a smaller community. Regions near a metropolitan area could be rapidly served by critical care transport teams traveling by ground ambulance. Regions distant from a metropolitan area might benefit from helicopter transport. Using local noncritical care transport teams would involve shorter delays and less expert care during evacuation.

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Key Words: pediatric intensive care, interhospital transport, regional resources, discrete event simulation, quantitative model

Pediatric hospital services within a region may be unable to accommodate surges of patients associated with a large mass casualty incident (MCI).[1] While emergency stabilization and temporary mass critical care are likely to be provided at a hospital near the event, it may be necessary to transfer critically ill or injured children who exceed local capacity to pediatric intensive care units (PICUs) in neighboring regions to accommodate all those who need definitive PICU services.

The need for evacuation would depend on the number of patients needing critical care services and the number of vacant PICU beds available within each region. The duration necessary to complete a mass evacuation would depend on the transportation resources and travel times.

Making assumptions based on publicly available evidence, this study was conducted to determine the ability of PICU services within each of five statewide regions in New York to accommodate all the patients after a hypothetical MCI in that one region. For each region that would not be able to accommodate all the patients, the duration necessary to complete interhospital evacuation was estimated in a discrete event simulation.

METHODS

Hypothetical Mass Casualty Incident

A hypothetical MCI of unspecified type, occurring in each of five statewide regions of New York State, was quantitatively modeled for 30 children needing intensive care. Numbers and proportions of patients requiring intensive care would be plausible relative to historical MCIs[2] and federal planning assumptions.[3] It was assumed that initial patient distribution by emergency medical services was well controlled, such that children needing intensive care were initially taken to hospitals with PICUs near the scene of the MCI. For any region with adequate numbers of PICU beds at multiple nearby hospitals, it was assumed that patients were distributed evenly to take advantage of available regional resources.

It was assumed that temporary mass critical care[4,5] could be provided to all who need it, even at hospitals caring for many more than their usual capacity. For purposes of this study, facilities temporarily caring for large surges of MCI patients exceeding the usual capacity were referred to as mass critical care hospitals. Subsequently, patients were evacuated from mass critical care hospitals to vacant PICU beds at facilities in other regions, referred to as receiving hospitals.

Regions

Five statewide regions were considered (Table), according to the New York State Office of Emergency Management classification.[6] Regions include (1) New York City/Long Island (NYC/LI), (2) Hudson Valley (HV), (3) Northeast (NE), (4) Central, and (5) Western. In the NYC/LI and Western regions, each with more than one PICU hospital, the MCI was considered to occur near NYC or Buffalo, respectively. In other regions, the MCI was assumed to occur near the only PICU hospital.

PICU Hospitals, Beds, and Pediatric Critical Care Transport Teams

Hospitals were considered to be PICU facilities if they appeared both on hospital profiles provided by the New York State Department of Health,[7] as well as a listing of major pediatric teaching programs.[8] PICU bed numbers were obtained from the Department of Health hospital profiles, supplemented by hospital Web sites where available. Twenty of 25 statewide PICU hospitals were located in the NYC/LI region. As standard information on availability of pediatric critical care transport teams is not publicly available, it was assumed that pediatric critical care transport teams were available from hospitals having 10 or more PICU beds; these were referred to as source hospitals for transport teams. These same hospitals were assumed to serve as receiving hospitals for evacuated patients from mass critical care facilities near the MCI. Six of 11 statewide transport team source and receiving hospitals were located in the NYC/LI region.

PICU Bed Availability

The number of vacant PICU beds at mass critical care and receiving hospitals was estimated as follows. Baseline PICU occupancy was assumed to be 61%.[9] Approximately 15% of occupied PICU beds could be made available by early discharges and transfers.[1] Therefore, the vacancies for MCI patients at each mass critical care or receiving hospital were assumed to be 50% of the hospital's total PICU bed number.

Evacuation

Transport teams were assumed to evacuate one critical care patient per vehicle. Three evacuation scenarios were considered in discrete event chronological simulations: pediatric critical care transport teams originating from other hospitals statewide, (1) using ground ambulances or (2) using helicopters, and (3) noncritical care teams from the local MCI region using ground ambulances. Statewide pediatric critical care transport teams were assumed to arrive at the mass critical care hospital after a delay associated with travel from statewide source hospitals. It was assumed that a maximum of 10 pediatric critical care transport teams were available for each scenario, with the mass critical care hospital in each scenario unable to provide a team because all staff would be involved in providing on-site mass critical care. Alternatively, 10 noncritical care transport teams were assumed to be immediately available from within the MCI region. Patients were always assumed to be transported from mass critical care hospitals to the nearest receiving hospital having vacant PICU beds.

Discrete Event Chronological Simulation of Evacuation

The simulation clock was assumed to begin at time zero at the onset of the MCI. Key events were modeled to occur at specified times, lasting specified durations. Durations were based on publicly available data, where available, or on specified plausible assumptions. Simulated durations were rounded up to the nearest 15 minutes. Simultaneous travel of multiple transport teams and evacuation of multiple patients were modeled in the chronological simulation. Chronology for evacuations was modeled for a hypothetical MCI in each of the regions unable to accommodate all MCI patients. The chronological model is similar to a federal mass evacuation model[10] that, however, does not provide any pediatric-specific analysis of resources.

It was assumed that during the first four hours after the MCI, all 30 children needing critical care were taken to a nearby mass critical care hospital, stabilized, and provided with temporary mass critical care. During the first four hours, arrangements for evacuation would be made. At the four-hour time point, pediatric critical care transport teams would depart from each of 10 statewide source hospitals, arriving at the mass critical care hospital after a period of air or ground travel. Alternatively, local noncritical care transport teams would begin arriving at the four-hour time point at mass critical care hospitals from within the local community.

Travel times for ground ambulances were based on publicly available travel times to and from exact hospital addresses, using longest estimated urban traffic travel time where available, but assuming no other unusual travel obstacles.[11] Helicopters were assumed to travel at 150 miles per hour.[12] Helicopter flight times were calculated from straight-line flight distances,[13] based on zip codes of source, mass critical care, and receiving hospitals. New York statewide interhospital travel varies from straight-line distances of less than 5 miles, up to 350 miles, and ground travel time of several minutes, up to 7.5 hours.

Two ground ambulances were assumed to be able to begin loading at the same time, limited by scarce personnel at mass critical care hospitals. Loading of another two patients could begin 15 minutes later. Two helicopters were assumed to be able

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TABLE

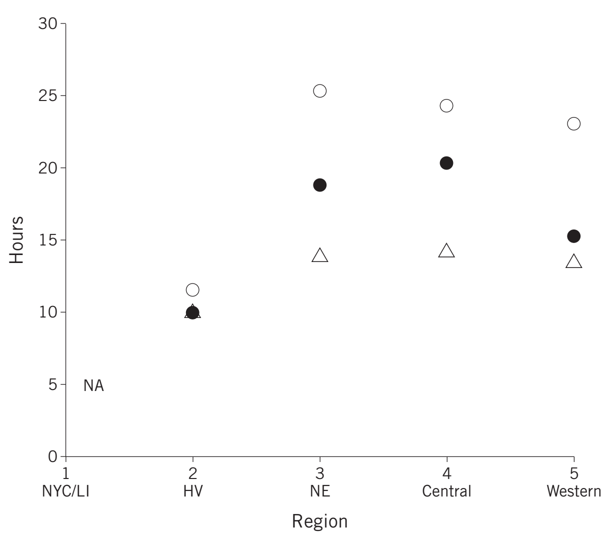
Regional Resources and Critical Care Evacuation Needs After a Hypothetical MCI in Any Single Region Involving 30 Children Needing Critical Care

	Regions				
Resources and Needs	I NYC/LI	II HV	III NE	IV Central	V Western
Population (millions)[14]	11.3	2.4	1.4	1.7	2.7
PICU hospitals (No.)	20	1	1	1	2
Transport source and receiving hospitals (No.)	6	1	1	1	2
PICU beds (No.)	207	18	17	15	42
Patients needing evacuation (No.)	0	21	22	23	20
Regions receiving evacuated patients	NA	NYC/LI	HV Central NYC/LI	Western NE	Western Central NE

Abbreviations: HV, Hudson Valley; MCI, mass casualty incidence; NA, not applicable; NE, Northeast; NYC/LI, New York City/Long Island; PICU, pediatric intensive care unit.

FIGURE

Simulated Time to Complete Evacuations After a Hypothetical Mass Casualty Incidence in Each Region.



Evacuation methods are critical care transport teams from statewide source hospitals traveling by ground ambulance (open circles) or helicopter (triangles) and local noncritical care transport teams traveling by ground ambulance (dark circles). Abbreviations: HV, Hudson Valley; NA, not applicable; NE, Northeast; NYC/LI, New York City/Long Island.

to occupy landing sites at the same time to load or unload patients. Patient loading was assumed to last 30 minutes for ground ambulance or helicopter. When necessary, transport teams and vehicles were assumed to wait at a nearby unspecified location until loading could begin. After transport from the mass critical care hospital to the receiving hospital, patient unloading was assumed to take 15 minutes. Restocking the transport vehicle was assumed to occur at the receiving hospital after unloading a patient, and to last 15 minutes. Refueling was always assumed to precede patient loading so that refueling never occurred with a patient on board. Refueling and maintenance for helicopters was assumed to be necessary every 300 miles,[12] requiring one hour, and for ground ambulances every 250 miles, requiring 30 minutes.

RESULTS

After a hypothetical MCI involving 30 children needing critical care, variation across New York State regions would accommodate between 7 and all 30 MCI patients. Thus, the number of children evacuated from overloaded mass critical care hospitals would vary across regions from 0 to 23 (Table). The NYC/LI region, with more than 200 PICU beds in 20 PICU hospitals, would be able to accommodate all the MCI patients within the region, with none requiring subsequent evacuation if the initial patient distribution were controlled to take advantage of existing vacancies. The other regions, each with no more than 20 PICU beds at a PICU hospital near the MCI, would have similar needs across regions for interhospital evacuation of 20 to 23 patients. Regional variation in time to complete evacuations (Figure) would be due to differences in PICU vacancies, geographical distance, and travel time between mass critical care hospitals from transport team sources and receiving hospitals.

In the Hudson Valley region, close proximity to the many transport teams and receiving hospitals in New York City would result in an evacuation time of less than 12 hours by ground ambulance. Little time would be saved by use of helicopters or local noncritical care teams.

The longest evacuation times would occur for the Northeast and Central regions. Long travel times for critical care transport teams, from statewide source hospitals, and to the nearest receiving hospitals, would prolong evacuations. Critical care transport teams from statewide sources traveling by ground would require slightly less than 26 hours to complete the evacuation. Helicopters would shorten durations for evacuation by 40%-44% compared with ground transport by critical care teams. Immediately available ground ambulances staffed by local

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noncritical care teams would reduce evacuation durations by 16%-26%, compared with critical care teams from statewide sources traveling by ground.

For an MCI in Buffalo (Western region), the relatively close proximity to a receiving hospital in the same region would result in evacuation durations intermediate between an MCI in the Hudson Valley, Northeast, and Central regions. For the Western region, critical care transport teams traveling by helicopters would provide a 40% reduction in evacuation duration compared with ground ambulances. Immediately available ground ambulances staffed by local noncritical care teams would provide a 34% time saving advantage compared with critical care teams arriving from statewide sources traveling by ground.

COMMENT

For a hypothetical MCI involving 30 children needing critical care, this model of existing resources and evacuations reveals the following generalizable conclusions. Assuming good coordination and communication, rapid preparation of patients for evacuation, availability of usual statewide resources, and normal travel conditions, an evacuation of all patients to receive definitive critical care could be complete within less than 26 hours after the MCI for any region in New York State.

Region-specific differences include the likelihood that large metropolitan regions could accommodate all the patients without evacuation of children to other regions. In addition, large metropolitan areas would provide crucial resources for interhospital evacuation and definitive critical care for patients transferred from smaller regions. For regions near a large metropolitan area, it would be effective to await pediatric critical care transport teams from nearby hospitals traveling by ground ambulance to carry out the evacuation. For regions distant from other pediatric critical care centers, pediatric critical care transport teams traveling by helicopter would substantially save time. For regions distant from other pediatric critical care centers, noncritical care transport teams immediately available from the local community would also shorten evacuation time, but decision makers would have to consider the trade-offs between faster evacuation time and less expert care provided by noncritical care teams. It is notable that after the 2011 Tuscaloosa tornado, noncritical care teams from the local community evacuated more than 20 critically injured children to the nearest children's hospital after their initial local emergency department stabilization, with no preventable adverse events.[15]

This study has the following limitations. It is possible to imagine larger patient numbers, worse limitations of resources, or travel obstacles that would cause much longer delays. Details of mass critical care clinical disorders and interventions are not modeled in the study. Noncritical care patients are not considered. Results modeled for New York State would not generalize to other states with much longer travel distances. In addition, some states depend on critical care resources in neighboring states, adding jurisdictional complexity to disaster management. However, the results provide insight for regional resource-sharing in other states having moderate travel distances and a mix of large metropolitan areas, smaller urban and suburban communities, and large rural areas.

CONCLUSIONS

Critical care evacuation after a large MCI is likely to be more effective with prior planning.[1,12] The present study provides planners with a quantitative evidence-based approach to estimate generalizable and region-specific pediatric critical care evacuation needs.

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