ORIGINAL RESEARCH

Geographical Maldistribution of Pediatric Medical Resources in Seattle-King County

Mary A. King, MD, MPH;[1] Kathryn Koelemay, MD, MPH;[2] Jerry Zimmerman, MD, PhD;[3] Lewis Rubinson, MD, PhD[4]

1. Seattle Children's, Pediatric Critical Care Medicine, Harborview Medical Center, Seattle, Washington USA; University of Washington, Seattle, Washington USA
2. Public Health-Seattle and King County, Communicable Disease Epidemiology, University of Washington, Department of Health Sciences, Seattle, Washington USA
3. Seattle Children's, Pediatric Critical Care Medicine University of Washington, Seattle, Washington USA
4. University of Washington, Seattle, Washington, USA; Pulmonary and Critical Care Medicine, Harborview Medical Center, Seattle, Washington USA

Correspondence:
Mary A. King, MD, MPH
M/S W-8866 PO Box 5371
Seattle, Washington 98105 USA
E-mail: maryking@u.washington.edu

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Abbreviations:
ICU = intensive care unit
NICU = neonatal intensive care unit
PACU = pediatric post-anesthesia care unit
PICU = pediatric intensive care unit
SKC = Seattle-King County

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Abstract

Objective: Seattle-King County (SKC) Washington is at risk for regional disasters, especially earthquakes. Of 1.8 million residents, >400,000 (22%) are children, a proportion similar to that of the population of the State of Washington (24%) and of the United States (24%). The county's large area of 2,134 square miles (5,527 km^2) is connected through major transportation routes that cross numerous waterways; sub-county zones may become isolated in the wake of a major earthquake. Therefore, each of SKC's three sub-county emergency response zones must have ample pediatric medical response capabilities. To date, total quantities and distribution of crucial hospital resources (available in SKC) to manage pediatric victims of a medical disaster are unknown. This study assessed whether geographical distribution of hospital pediatric resources corresponds to the pediatric population distribution in SKC.

Methods: Surveys were delivered electronically to all eight acute care hospitals in SKC that admit pediatric patients. Quantities and categories of pediatric resources, including inpatient treatment space, staff, and equipment, were queried and verified via site visits.

Results: Within the seven responding hospitals of eight queried, the following were identified: 477 formal pediatric bed spaces (pediatric intensive care unit, neo-natal intensive care unit, general wards, and emergency department), 43 informal pediatric bed spaces (operating room and post-anesthesia care unit), 1,217 pediatric nurses, 554 pediatric physicians, and 252 infant/pediatric-adaptable ventilators. The City of Seattle emergency response zone contains 82.1% of bed spaces, 83.5% of nurses, and 95.8% of physicians, yet only 22.8% of all SKC children live in that zone.

Conclusions: The majority of hospital pediatric resources are located in the SKC sub-region with the fewest children. These resources are potentially inaccessible and unable to be redistributed by ground transportation in the event of a significant regional disaster. Future planning for pediatric care in the event of a medical disaster in SKC must address this vulnerability.

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Introduction

Located in the Pacific Northwest, Seattle-King County (SKC), Washington is situated in an active volcanic zone and the region is vulnerable to numerous types of large-scale disasters created by earthquakes, volcanic eruptions, terrorist attacks, pandemics, and wind-induced power outages. The large county area of 2,134 square miles (5,527 km^2) makes long distance vehicular transportation a necessity.[1] However, major transportation routes are vulnerable to closure since bridges may become impassable or road conditions may become too dangerous to permit their use. In such cases of sub-county, regional isolation, SKC residents seeking medical care must do so in their immediate locales.

Given their higher risk of environmental exposure and inability to recognize and remove themselves from dangerous situations, children are more vul-

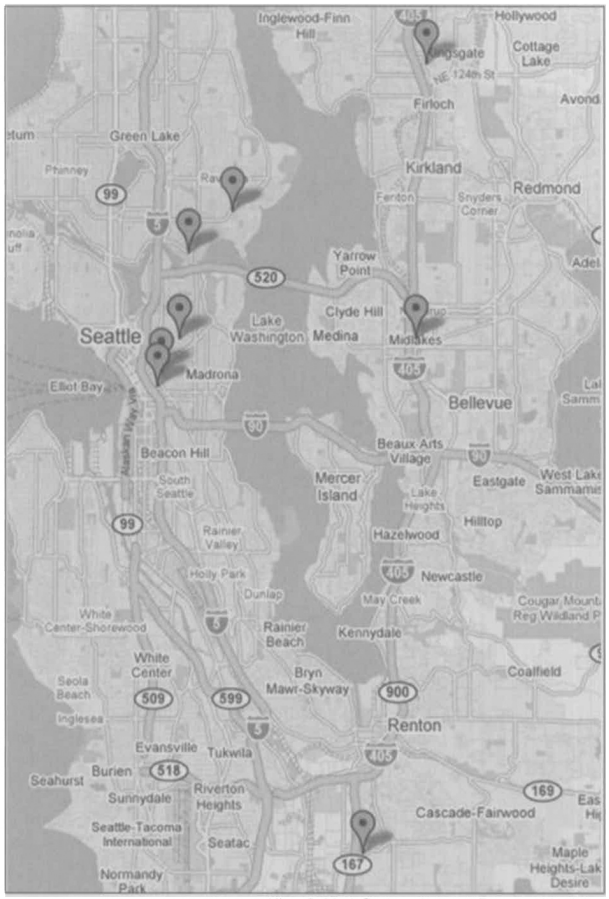

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Figure 1—Map of Seattle-King County (SKC) and all hospitals that regularly admit neonatal or pediatric patients (noted by balloons)

nerable during some medical disasters than are most adults.[2] For example, a windstorm in SKC, during December 2006, resulted in widespread and prolonged power outages during protracted freezing weather conditions. Unfortunately, to provide heat, many SKC families used charcoal grills inside their homes or generators that were improperly ventilated. These unsafe practices resulted in a large number of carbon monoxide (CO) poisoning cases and children made up a disproportionate share of the victims; 82 of 259 (32%) CO poisoning victims were children <12 years of age, although census data suggests that only 22% of the SKC population was 0–18 years of age.[3,4]

Much of pediatric inpatient hospital care in the United States is delivered at large, regional, pediatric centers, given the benefits of regionalized pediatric care for non-disaster scenarios.[5] In view of this trend, children may become more vulnerable when routine access to hospital care is interrupted during a disaster. Ample pediatric medical resources may be required within each geographical sub-region (between geographical barriers) to appropriately care for children during a regional medical disaster. Given that pediatric diseases, medical expertise, and medical supplies differ from those of adults, and in light of SKC transportation vulnerabilities, the geographical availability of pediatric-specific resources for disaster response was determined.

Prior to this study, the distribution of hospitals that admit children ages 0–18 years in SKC was known to be concentrated in the City of Seattle (Figure 1). However, additional details such as the total quantities and geographical distribution of crucial hospital resources available to manage pediatric victims of a medical disaster in SKC were unknown. The objectives of this study were to quantify pediatric-specific hospital resources available in all SKC hospitals that admit children, and analyze the regional distribution of these resources.

Methods

Study Setting

Seattle-King County is subdivided into three local emergency response zones that are designated Zone 1, 3, and 5. These sub-county zones have been established for emergency 9-1-1 call routing and dispatch of first responders (Figure 2) and roughly correspond to the county areas commonly referred to as the East Side (Zone 1), the South End (Zone 3), and the City of Seattle (Zone 5). The East Side (Zone 1) is separated from Seattle (Zone 5) by a large body of water (Lake Washington) that is traversed by two bridges, the northern Evergreen Point Floating Bridge (Highway 520) and the southern Interstate 90 Floating Bridge. These two bridges accommodate >150,000 cars per day and generate daily bottlenecks during peak traffic times. The 520 bridge must be closed during conditions of high wind velocity and is in need of significant seismic retro-fitting.[6] Similarly, the South End (Zone 3) is isolated from other areas of the county by long highway distances and roadways that have been identified as potentially impassable during a sizeable earthquake. Any event that significantly impacts highway transportation, such as the rerouting of cars from failed bridges or loss of infrastructure, may impede the ability of residents of the South End to travel in adjacent zones.

Study Design

A cross-sectional survey instrument was developed to assess pediatric resources for medical disaster care on-site at SKC hospitals where children are admitted regularly. An electronic format of the survey was distributed to the eight acute care hospitals in SKC that admit neonatal and/or pediatric patients. Categories and quantities of pediatric resources were queried in three main areas: (1) bed spaces; (2) staff; and (3) equipment. Pediatric bed spaces were categorized as: (1) pediatric intensive care unit (PICU), neonatal intensive care unit (NICU); (2) pediatric general ward; (3) pediatric emergency department; (4) pediatric post-anesthesia care unit (PACU); or (4) pediatric operating room. Pediatric staff were categorized as: nurse, physician, or respiratory therapist, then further subcategorized by ward (for nurses) and by subspecialty training (for physicians). Pediatric equipment queried included: neonatal or pediatric-adaptable mechanical ventilators, non-invasive pediatric-adaptable positive pressure mechanical ventilatory devices, pediatric manual ventilation devices and face masks, pediatric tracheal intubation supplies, pediatric intravenous tubing, incubators, and cribs. The SKC pedi-

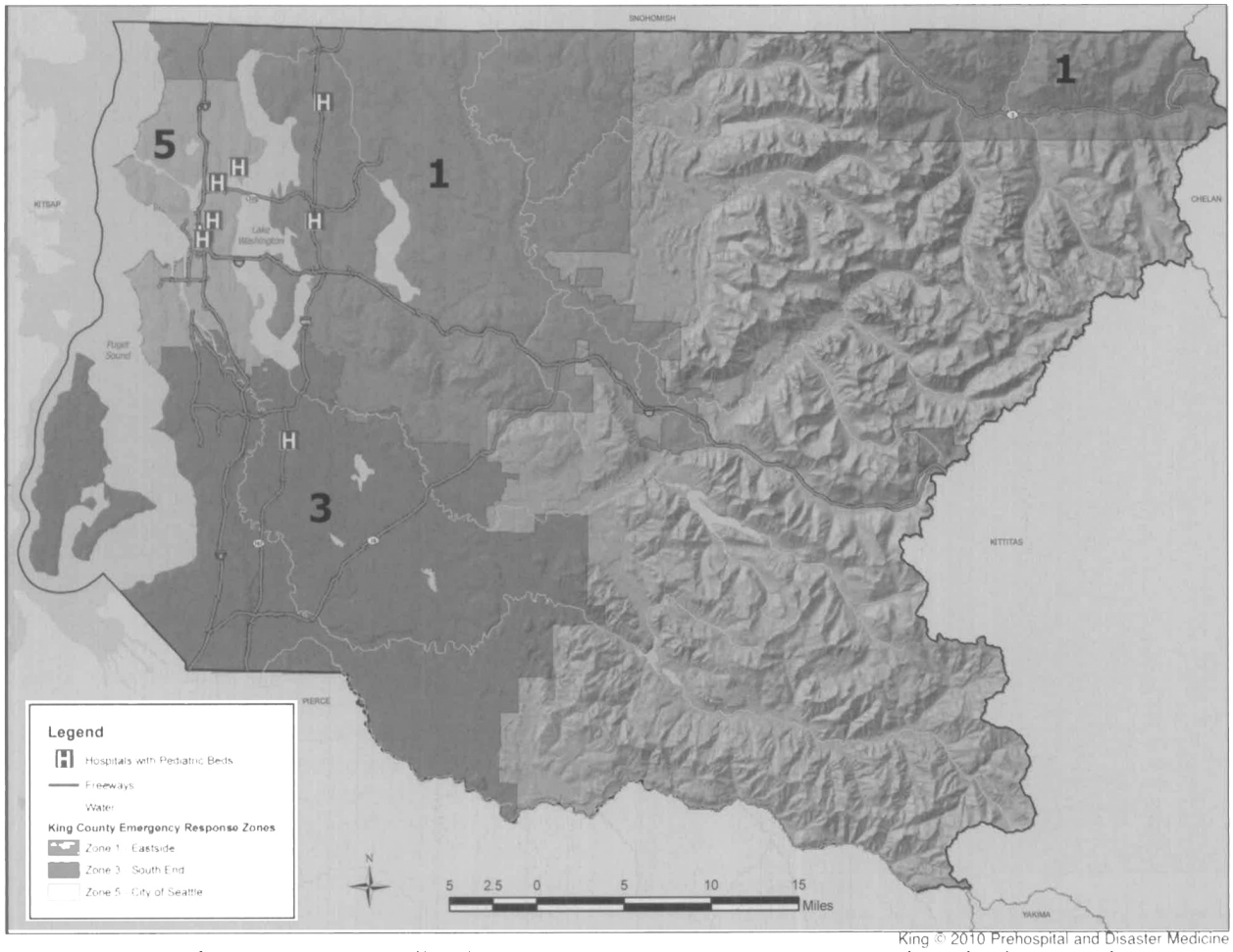

Figure 2—Map of Seattle-King County (SKC) and Emergency Response Zones: Zone 1 (East Side), Zone 3 (South End), and Zone 5 (City of Seattle)

atric population (0–18 years of age) was obtained via US Census 2000 data, including the distribution of pediatric-aged persons specifically in SKC. The distribution of pediatric resources and pediatric population were compared geographically by emergency response zone.

Data Collection

This study was approved by the participating members of the King County Healthcare Coalition, a regional hospital planning and response group affiliated with Public Health-Seattle and King County. The survey was sent via e-mail to each hospital emergency manager via a contact list previously created by the King County Healthcare Coalition. The emergency manager, who is in charge of facilitating county disaster compliance as well as internal hospital disaster planning, is designated as the primary liaison between the hospital and the Healthcare Coalition. Follow-up contact was attempted with non-responding hospitals by both e-mail and telephone. The emergency manager at each hospital was instructed to identify appropriate hospital staff members to complete each unique aspect of the survey, since hospitals vary in pediatric staffing composition and staff responsibilities. The data were compiled by the emergency manager and returned to the first author. Data were entered into an Excel spreadsheet (2003, Microsoft Inc., Redmond WA) and transferred to STATA 9.0 (Stata Corp., College Station, TX) for data processing.

An on-site, hospital pediatric team meeting was convened at each of the responding hospitals for survey clarification and data validation. Participants in the site meeting survey review included those who completed the survey at their respective hospital: emergency managers, pediatric nurses, pediatric physicians, respiratory therapists, pharmacists, and supply managers. This multi-disciplinary pediatric team meeting typically included about 10 hospital participants and lasted approximately two hours. Survey and site visits were completed between September 2006 and April 2007.

Study Assumptions

Several assumptions were made to compare these resources among hospitals. For hospitals without specific pediatric-designated ward bed spaces, the number of pediatric bed spaces was assumed to be equal to the average daily pediatric occupancy. Similarly, for hospitals with nurses who cared for both adult and pediatric patients, the number of pediatric nurses for a given ward was assumed to be equal to the average percent pediatric occupancy multiplied by

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Bedspaces	PICU	NICU	Floor	ED	PACU	OR		Total	Population 0–18 yrs
Zone 1	0	35	9	5	0	0		49	124,753
Zone 3	0	34	10	0	0	0		44	190,797
Zone 5	37	112	213	22	25	18		427	93,299
Total	37	181	232	27	25	18		520	408,849
Nurses	**PICU**	**NICU**	**Floor**	**ED**	**PACU**	**OR**		**Total**	
Zone 1	0	104	18	24	0	0		146	124,753
Zone 3	0	55	*	*	0	0		55	190,797
Zone 5	161	286	434	56	41	38		1,016	427
Total	161	445	452	80	41	38		1,217	408,849
Physicians	**PICU**	**NICU**	**Peds**	**ED**	**Anesth**	**Surg**	**Spec**	**Total**	
Zone 1	0	7	35	9	3	0	1	18	124,753
Zone 3	0	5	*	0	0	0	0	5	190,797
Zone 5	22	20	159	37	51	41	201	531	427
Total	22	32	166	37	54	41	202	554	408,849
Ventilators	**Convent + HIFI**	**CPAP + BIPAP**	**Portable Vent**	**Anesth Vent**					**Total**
Zone 1	31	20	11	17				79	124,753
Zone 3	6	*	*	*				6	190,797
Zone 5	215	134	52	92				493	427
Total	252	154	63	109				578	408,849

Table 1—SKC pediatric bedspaces, pediatric nurses, pediatric physicians and pediatric-adaptable ventilators by hospital pediatric ward type or specialty and by SKC emergency response zone. (* = missing; PICU = pediatric ICU, pediatric ICU RN, or pediatric intensivist; NICU = neonatral ICU; neonatal ICU RN, or neonatologist; Floor = pediatric general medicine ward or pediatric floor RN; Peds = pediatric hospitalist; ED = pediatric ED physician; Anesth = pediatric anesthesiologist; Surg = pediatric subspecialty surgeon; Spec = pediatric subspecialties not listed; Convent = conventional ventilator; HIFI = high-frequency oscillator; CPAP = continuous positive pressure machine; BIPAP = biphasic positive pressure machine; Portable Vent = portable ventilator (in house or transport); Anesth Vent = anesthesia machine ventilator Total per 100K children = total resources per 100,000 pediatric population age 0–18 yrs

the number of nurses for that ward. In order to be consistent about counting staff and to avoid the problem of double counting, staff was only counted once at the hospital of primary employment and staffing agency personnel were not included. Physician group members were divided among their hospitals of employment per their FTE (full time equivalent) allotment. Physicians who were participating in an accredited pediatrics residency or pediatric subspecialty fellowship training program were counted as part of their respective specialty. Family practice doctors, internal medicine doctors, and surgeons without specific pediatric sub-specialty training were not counted.

Results

Six of eight total eligible hospitals (75%) completed a survey and the multi-disciplinary site meeting for data verification. Of the two non-respondents, one hospital provided partial survey information by phone. The other hospital that provided no response maintains only an 8–10-bed Extended Stay Nursery with mother-baby service and is located in the zone with the majority of pediatric resources (Zone 5). The SKC pediatric population ages 0–18 years old and hospital pediatric bed spaces, nurses, physicians and ventilators were compared by SKC emergency response zone. The data are summarized in Figure 3 and presented in detail in Table 1. Of the approximately 409,000 children living in SKC, only a minority of them (22.8%), live inside the city limits of Seattle (Zone 5). Far more children in SKC live outside of Seattle, with 30.5% of children on the East Side (Zone 1) and 46.7% of children in the South End (Zone 3.) However, the vast majority of SKC hospital pediatric resources (82.1% of pediatric bed spaces, 83.5% of pediatric nurses, and 95.8 % of pediatric physicians) are located in Seattle (Zone 5).

In SKC, pediatric bed spaces are presented by hospital ward type and by emergency response zone. A total of 520 pediatric bed spaces were identified, including 477 formal pediatric bed spaces (designated PICU, NICU, pediatric floor, and pediatric emergency department), as well as 43 informal hospital pediatric bed spaces (pediatric PACU and operating room). Of the 477 formally designated pediatric bed spaces, 181 beds are neonatal ICU beds that traditionally are used solely for neonates who have not yet been discharged from a hospital (inborn neonates.) All pediatric

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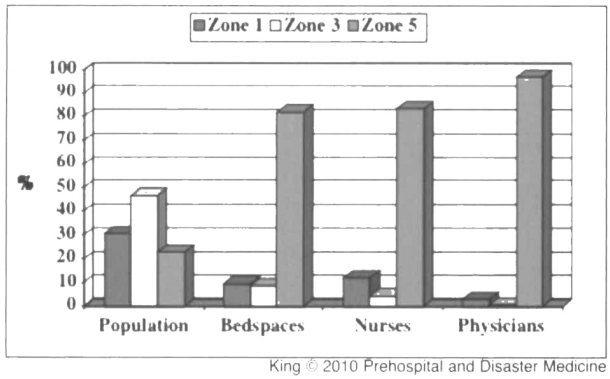

Figure 3—SKC pediatric population age 0–18 years old and total hospital pediatric resources (bedspaces, nurses, and physicians) by SKC emergency response zone.

ICU, OR, and PACU beds in SKC are located within a single zone (Zone 5, City of Seattle). Of the 232 total pediatric floor beds in SKC, there are few located outside of Zone 5 with just nine on the East Side (Zone 1), and just 10 in the South End (Zone 3). In contrast, there is more significant NICU bed space in Zones 1 and 3 relative to all the other pediatric bed space types.

Mirroring the geographical distribution of pediatric bed spaces, 1,217 total pediatric nurses were identified in SKC with 83.5% employed in Seattle hospitals in Zone 5. No pediatric ICU, PACU, or operating room (OR) nurses were identified as working in Zones 1 and 3, whereas a significant number of NICU nurses were identified as working in those two zones.

In comparison to pediatric bed spaces and pediatric nurses, the uneven distribution of employed pediatric hospital physicians was even more pronounced. Among 554 total pediatric-trained, hospital-based physicians employed in SKC, 531 of them (95.8%) are employed in Seattle (Zone 5) hospitals. All hospital-based pediatric subspecialist groups followed this trend except neonatologists; in Zones 1, 3, and 5 there were 7, 5, and 20 neonatologists employed, respectively. However, no PICU, pediatric ED, pediatric anesthesiologists or pediatric surgeons and only nine hospital-based general pediatricians were employed in hospitals outside of Seattle. Excluding ICU, ED, generalist, anesthesia, or surgery, 201 pediatric subspecialists are employed in Seattle who may not have designated specific roles during a medical disaster.

Pediatric ventilation equipment for a medical disaster proved difficult to measure because there is minimal pediatric-only ventilation equipment. Although most neonatal mechanical ventilation equipment is used only on children, pediatric, full-feature ventilatory equipment often is both pediatric and adult adaptable. A total of 252 mechanical ventilators (conventional or high-frequency) that are at least adaptable to children or infants, with the majority being adult-adaptable were tabulated. Another 172 pediatric-adaptable anesthesia machines and portable ventilators were identified. In times of high demand or resource scarcity, when mechanical ventilation machines may be a significant limiting factor, the allocation of these resources between children and adults is unclear. When neonatal or pediatric-only ventilation equipment was considered, 13 high-frequency oscillator ventilators (Sensormedics 3100A) were located in Seattle and two such machines were located both on the East Side and in the South End.

Discussion

During ordinary times, the benefits of regionalization of care have been demonstrated clearly. Both children and adults exhibit improved outcomes if they are treated at centers with expertise and ongoing, frequent practice exposures to certain patient populations. In this regard, Level-I Trauma Centers are perhaps the best known examples,[4–9] particularly when an intensivist is involved in coordinating care.[10] However, the same benefit has been demonstrated for critically ill adult,[11] pediatric,[12,13] and neonatal[14] patients. Regionalization of usual care, however, may be a vulnerability for disaster medical response.[15] Resources, like mechanical ventilators, at tertiary centers could quickly become depleted in the setting of need for mass critical care, such as a severe influenza pandemic.[16] Shortages of specialized resources, including critical care supplies, equipment, and personnel likely would become limiting in terms of providing critical care.[17,18] Even if resources are available at specialized centers, they may not necessarily be accessible. In this regard, the importance of developing additional community-based solutions/facilities has been suggested for surge capacity planning.[19] The current system functions under usual conditions, but would become a critical impediment to care delivery, if a disaster involved destruction of ground transportation routes, particularly bridges and major highways or loss of access to pediatric-centric healthcare facilities.

In the current investigation, significant geographical mal-distribution of various medical resources was identified for the pediatric population of Seattle-King County, Washington. A disaster that impacts transportation may prevent pediatric patients from receiving pediatric-appropriate life-saving medical care. This transportation vulnerability must be addressed by future planning for pediatric hospital care in the event of a medical disaster in SKC by considering alternative forms of pediatric care delivery and enhancing capabilities to redistribute both resources and patients. This study is directly applicable only to the single region of SKC and the results do not directly apply to other regions of the US. However, given the trend of regionalized pediatric care, these results should compel disaster planners and pediatric providers in other regions to assess their own geography and its potential effects on pediatric care delivery during a disaster.

This study was limited by lack of a 100% response rate. However, the one non-responding hospital had minimal pediatric capacity and is located in the City of Seattle (Zone 5), which contained the vast majority of pediatric resources. This non-responder introduced a conservative bias to the results. Additionally, the one pediatric-admitting hospital that exists in the South End (Zone 3) provided only partial information via telephone; the data on non-neonatal nurses and physicians and non-neonatal ventilators from that zone is incomplete, but likely does not impact the overall results, given the known bed space number

and types. Finally, this survey did not include an assessment of family medicine doctors or other health professionals with training in pediatric care that should be considered in response planning for medical management of children in a large-scale emergency.

In addition to identifying pediatric medical resources and care providers, it is clear that disaster planners also must consider how to effectively match the pediatric healthcare resources with the affected children. Evacuation of pediatric patients to appropriate facilities outside of the exposed area is ideal when usual local capability is exhausted. However, such evacuation may not offer timely or sufficient capacity to accommodate large numbers of pediatric patients. During the response to Hurricane Katrina, initial inadequacy of supplies for pediatric patients was noted by the pediatricians in Baton Rouge and Houston.[20,21] To prevent similar future inadequacies locally, SKC disaster planners must consider: (1) creating caches of pediatric medical supplies and equipment within or near to the areas of highest population density of children; (2) identifying local facilities where these medical supplies and equipment could be utilized; and (3) developing a plan for mobilizing pediatric healthcare providers from areas of over-abundance to the affected pediatric population.

Future studies and community disaster planning should include developing alternative modes of pediatric inpatient and critical care delivery outside of the tertiary centers and backup transportation plans to and from these tertiary centers. The suggestion of extending PICU capability from the PICU, post-anesthesia recovery areas, and emergency departments to step-down units to procedure suites to telemetry units to hospital general wards[22] may need to include extension to primary hospitals. The specific type and number of non-pediatric nurses and physicians best-suited to care for children during times of disaster likely will vary from hospital to hospital as a function of staff comfort, experience, and accessibility to pediatric subspecialty consultant input. An additional resource that should be explored to geographically extend the role of pediatric specialists in a mass disaster setting is telemedicine. This modality already has been shown to be beneficial in supervision of the critical care of adults[23,24] and children[25] residing in underserved regions. Of course, such technology would require that communication systems remain functional.

Water is an asset and liability for SKC residents. In the event of a regional disaster such as an earthquake, portions of this corner of the Pacific Northwest could become relatively isolated from each other. Data from the present study indicate that tertiary care pediatric facilities must partner with other regional pediatric facilities and perhaps traditional adult-only facilities in order to plan for pediatric patient-medical resource matching in the setting of a disaster. The methods presented in this manuscript of: (1) sub-regional determination of specialty medical resources; and (2) comparison of sub-regional resources to population density can be applied to other regions with identified geographical barriers to delivery of specialty care during disaster.

Conclusions

The majority of hospital pediatric resources are located in the Seattle-King County, Washington sub-region that is the least populated by children. These resources potentially are inaccessible by ground transportation in the event of regional disaster. Future planning for pediatric care in the event of a medical disaster in Seattle-King County must address this vulnerability.

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Editorial Comments—Surge Capacity Implications and Geographic Maldistribution of Pediatric Medical Resources in Seattle-King County

Samuel J. Stratton, MD, MPH

UCLA School of Public Health, Center for Public Health and Disasters and The Orange County California Health Care Agency, Los Angeles, California USA

Correspondence:
E-mail: strattos@ucla.edu

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Dr. King and co-authors' research showing the maldistribution of Seattle-King County pediatric acute care resources is an important addition to the disaster medical literature. The authors report that in the event of a regional disaster, there is a lack of access to medical services for children because of the location of acute care pediatric resources relative to the predominate areas of the local pediatric population. Most likely, many urban and rural areas also reflect the problems of Seattle-King County in that specialty hospitals are located so that access during disasters is not possible for vulnerable populations.

The findings of King and co-authors are important when considering concepts of disaster medical surge capacity. Current surge capacity development is based on four key components as described by the US Government Accounting Office. These components include: (1) increasing hospital capacity; (2) identifying alternate care sites; (3) registering medical volunteers; and (4) altering established standards of care.[1] In review of extensive work done in the US on development of surge capacity, there is little recognition of the limitations of physical access to medical care resources during disasters and the impact of this lack of access to providing medical surge capacity for affected populations.[2] A lack of recognition of the relationship of physical access to health care and effective provision of surge capacity is well-illustrated with the multi-million dollar (US) Pricewaterhouse Coopers, LLP project in California to define and develop standards for surge capacity development.[3] This extensive project, which included emergency management and academic consultants from throughout the US, fails to address within the >1,000 pages that resulted from the project, the issue of geographic isolation of populations from surge resource locations.

As described by King and co-authors, much of the pediatric inpatient hospital care in the US now is delivered at regional pediatric centers. In fact, pediatric regional centers encourage the referral of pediatric patients to regional locations rather than outlying community hospitals. The centralization of pediatric care is driven by economic conditions and sub-specialization of pediatric services. In addition to pediatric acute care, centralization of trauma, cardiac, and stroke care also is common.

In disaster medicine, pediatric populations usually are considered vulnerable. In disaster settings, children are vulnerable because they are less likely to understand how to keep themselves safe, have less access to and understanding of emergency information, and are prone to illness (gastrointestinal) and injury (lacerations from broken glass). While many disaster medical problems can be managed by those who have general medical knowledge, children who suffer symptomatic dehydration, serious infection, and significant trauma often require the resources available at a pediatric center. As noted by Dr. King and co-authors, during a disaster, pediatric acute care resources in Seattle-King County may not be accessible by ground transportation to 73% of the pediatric population. Failure to appreciate the challenge of access to surge resources for affected populations can result in a mismatch of surge resources and the target populations.

While not a part of the Seattle-King County study, another issue is the ability of healthcare providers to be physically present for disaster response

duties at hospitals. It is probable that many physicians, nurses, and medical support staff live in residential areas that are removed from healthcare sites. During disasters, lack of transportation access routes may result in challenges for healthcare providers to be at hand to provide health care. Considering this potential, it is not inappropriate to assume that due to site access, many healthcare providers may not be able to staff acute care centers in support of surge efforts.

The authors of the Seattle-King County paper are to be congratulated for their contribution to the disaster medical science knowledge base. They have shown that regionalization of specialty care for pediatric patients may result in lack of access of care during disaster events because there is "cut off" of ground transportation routes. This important concept has not been addressed in large projects designed to develop medical surge capacity. Access for populations to medical surge resources is an important component of providing medical surge capacity.

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