Mapping US Pediatric Hospitals and Subspecialty Critical Care for Public Health Preparedness and Disaster Response, 2008

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ABSTRACT

Objective: The objective is to describe by geographic proximity the extent to which the US pediatric population (aged 0-17 years) has access to pediatric and other specialized critical care facilities, and to highlight regional differences in population and critical resource distribution for preparedness planning and utilization during a mass public health disaster.

Methods: The analysis focused on pediatric hospitals and pediatric and general medical/surgical hospitals with specialized pediatric critical care capabilities, including pediatric intensive care units (PICU), pediatric cardiac ICUs (PCICU), level I and II trauma and pediatric trauma centers, and general and pediatric burn centers. The proximity analysis uses a geographic information system overlay function: spatial buffers or zones of a defined radius are superimposed on a dasymetric map of the pediatric population. By comparing the population living within the zones to the total population, the proportion of children with access to each type of specialized unit can be estimated. The project was conducted in three steps: preparation of the geospatial layer of the pediatric population using dasymetric mapping methods; preparation of the geospatial layer for each resource zone including the identification, verification, and location of hospital facilities with the target resources; and proximity analysis of the pediatric population within these zones.

Results: Nationally, 63.7% of the pediatric population lives within 50 miles of a pediatric hospital; 81.5% lives within 50 miles of a hospital with a PICU; 76.1% lives within 50 miles of a hospital with a PCICU; 80.2% lives within 50 miles of a level I or II trauma center; and 70.8% lives within 50 miles of a burn center. However, state-specific proportions vary from less than 10% to virtually 100%. Restricting the burn and trauma centers to pediatric units only decreases the national proportion to 26.3% for pediatric burn centers and 53.1% for pediatric trauma centers.

Conclusions: This geospatial analysis describes the current state of pediatric critical care hospital resources and provides a visual and analytic overview of existing gaps in local pediatric hospital coverage. It also highlights the use of dasymetric mapping as a tool for public health preparedness planning.

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Key Words: pediatric critical care, regionalization, dasymetric mapping

Planning for pediatric mass critical care must be based on a foundation of information about existing resources so that they can be organized effectively in a public health emergency. Unfortunately, national information about existing pediatric emergency and critical care resources is limited.

Children are not miniature adults. They have unique physical, physiological, and emotional needs, and when ill or injured, require specialized care and equipment. Because of these unique needs, there may be more children than expected in mass critical care scenarios. Pediatric needs may predominate in an epidemic involving pregnant or postpartum women, a disaster or epidemic affecting schools or child-related activities, a pathogen that mainly infects children, or if children are intentional targets of terrorism.[1-3]

Evidence demonstrates that access to risk-appropriate care reduces mortality and morbidity.[4] However, in spite of the evidence that specialized pediatric services are beneficial,[5-9] gaps in service locations[10,11] still exist and often interfere with use of existing pediatric critical care resources. Effective use of resources across entire regions is essential to maximize pediatric population outcomes. In a major public health emergency, regions defined on the basis of jurisdictional decision-making authority may need to be larger for pediatric than adult services and require more overlap in preparation for mass casualty events.

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Our study uses geospatial analyses to describe the current state of pediatric critical care resources and to plan for future regionalization of these resources. It provides a visual and analytic overview of existing hospital resources to serve as the basis for the regionalization of these resources in preparation for disasters.

METHODS

Pediatric hospitals and pediatric and general medical/surgical hospitals with specialized critical care units were targeted for the analysis. The specialized units include pediatric intensive care units (PICU), pediatric cardiac ICUs (PCICU), level I and

TABLE

Number and Percent of Pediatric Population Living Within 50 Miles of Selected Pediatric Critical Care Resources by State

State	Pediatric Hospital, No.	(%)	Hospital with PICU, No.	(%)	Hospital with PCICU, No.	(%)	Trauma Centers, No.	(%)
United States	**47 126 358**	**(64.1)**	**60 249 067**	**(82.0)**	**56 286 769**	**(76.6)**	**59 270 895**	**(80.7)**
Alabama	350 212	(31.2)	768 742	(68.5)	465 808	(41.5)	484 700	(43.2)
Arkansas	267 827	(38.1)	245 174	(34.9)	242 420	(34.5)	40 124	(05.7)
Arizona	1 067 652	(62.5)	1 375 260	(80.6)	1 375 252	(80.6)	1 372 884	(80.4)
California	7 701 280	(82.2)	8 029 112	(85.7)	7 641 152	(81.6)	7 958 940	(85.0)
Colorado	935 838	(77.5)	760 461	(63.0)	758 737	(62.9)	1 067 299	(88.4)
Connecticut	810 289	(99.8)	801 017	(98.6)	801 017	(98.6)	810 389	(99.8)
District of Columbia	107 897	(96.3)	107 968	(96.4)	107 968	(96.4)	107 978	(96.4)
Delaware	156 903	(76.1)	159 438	(77.3)	159 438	(77.3)	159 384	(77.3)
Florida	2 689 193	(67.2)	3 525 472	(88.0)	3 454 383	(86.3)	3 268 246	(81.6)
Georgia	1 770 695	(69.5)	2 111 359	(82.8)	2 019 954	(79.2)	2 303 162	(90.4)
Iowa	37 645	(05.3)	481 447	(67.6)	477 454	(67.0)	412 810	(57.9)
Idaho	38 443	(09.3)	272 655	(66.1)	272 655	(66.1)	119 380	(28.9)
Illinois	2 596 828	(81.7)	2 899 406	(91.2)	2 898 390	(91.2)	2 550 475	(80.2)
Indiana	915 765	(57.8)	1 425 867	(90.0)	1 400 154	(88.4)	1 419 291	(89.6)
Kansas	245 021	(35.0)	426 177	(60.8)	425 988	(60.8)	499 537	(71.3)
Kentucky	592 299	(58.8)	708 930	(70.3)	708 333	(70.3)	699 817	(69.4)
Louisiana	641 275	(57.9)	827 933	(74.7)	544 219	(49.1)	461 772	(41.7)
Massachusetts	1 383 946	(97.0)	1 363 634	(95.6)	1 363 634	(95.6)	1 393 744	(97.7)
Maryland	1 187 817	(88.6)	1 225 587	(91.4)	1 201 419	(89.6)	1 221 296	(91.1)
Maine	12 790	(04.7)	59 242	(21.6)	59 242	(21.6)	233 179	(84.8)
Michigan	1 574 224	(65.9)	2 161 993	(90.5)	2 007 924	(84.0)	2 246 982	(94.0)
Minnesota	806 178	(64.3)	968 339	(77.2)	965 738	(77.0)	1 047 704	(83.5)
Missouri	825 050	(58.0)	1 024 848	(72.1)	1 019 668	(71.7)	908 192	(63.9)
Mississippi	73 771	(09.6)	300 782	(39.2)	259 432	(33.8)	79 326	(10.3)
Montana	0		98 662	(44.8)	59 088	(26.8)	75 220	(34.1)
North Carolina	646 601	(28.8)	2 002 822	(89.3)	1 980 943	(88.3)	1 804 213	(80.4)
North Dakota	0		60 476	(42.3)	60 476	(42.3)	96 021	(67.1)
Nebraska	259 827	(58.1)	268 046	(60.0)	268 014	(60.0)	328 696	(73.5)
New Hampshire	220 479	(75.2)	213 395	(72.7)	213 395	(72.7)	269 707	(91.9)
New Jersey	1 968 660	(96.1)	1 985 384	(97.0)	1 982 448	(96.8)	2 017 913	(98.6)
New Mexico	0		274 171	(54.6)	274 171	(54.6)	274 145	(54.6)
Nevada	0		608 405	(91.1)	608 405	(91.1)	608 014	(91.0)
New York	2 701 918	(61.3)	3 750 112	(85.1)	3 749 964	(85.1)	4 180 262	(94.8)
Ohio	2 193 837	(80.3)	2 490 999	(91.2)	2 253 459	(82.5)	2 672 456	(97.9)
Oklahoma	0		607 963	(67.1)	607 963	(67.1)	599 677	(66.2)
Oregon	527 462	(60.8)	499 298	(57.6)	498 413	(57.4)	498 562	(57.5)
Pennsylvania	2 237 838	(81.0)	2 329 885	(84.4)	2 327 448	(84.3)	2 699 891	(97.8)
Rhode Island	212 243	(92.9)	189 310	(82.8)	189 304	(82.8)	212 154	(92.8)
South Carolina	391 517	(36.7)	830 479	(77.9)	830 479	(77.9)	1 063 038	(99.7)
South Dakota	0		106 053	(53.5)	106 020	(53.5)	73 131	(36.9)
Tennessee	1 124 976	(76.1)	1 349 320	(91.3)	1 348 866	(91.2)	1 230 167	(83.2)
Texas	4 117 156	(61.2)	5 735 079	(85.3)	5 136 664	(76.4)	5 228 422	(77.7)
Utah	649 976	(76.5)	683 337	(80.4)	542 587	(63.9)	723 002	(85.1)
Virginia	989 992	(54.3)	1 686 979	(92.5)	1 304 355	(71.5)	1 036 696	(56.9)
Vermont	1669	(01.3)	113 595	(88.1)	113 595	(88.1)	117 665	(91.3)
Washington	1 056 738	(68.6)	926 079	(60.1)	239 627	(15.5)	1 071 040	(69.5)
Wisconsin	1 010 094	(76.8)	1 132 214	(86.1)	705 327	(53.7)	1 240 984	(94.4)
West Virginia	26 535	(06.9)	275 862	(71.4)	255 079	(66.1)	253 738	(65.7)
Wyoming	0		303	(00.2)	303	(00.2)	29 471	(22.9)

(continued)

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II trauma and pediatric trauma centers, and general and pediatric burn centers. The term "unit" used in this study is defined as records with quantifiable numbers of "staffed beds" for that subspecialty. According to documentation of the American Hospital Association (AHA) Annual Hospital Survey Database,[12] "staffed beds" are beds that are set up for patient care in a dedicated subspecialty care unit; that provide subspecialty expertise and facilities for the support of vital functions; and that use the skill of medical nursing and other staff experienced in the management of these problems.

TABLE

Number and Percent of Pediatric Population Living Within 50 Miles of Selected Pediatric Critical Care Resources by State (continued)

State	Pediatric Trauma Centers, No.	(%)	Burn Centers, No.	(%)	Pediatric Burn Centers, No.	(%)	Total Pediatric Population, No. (%)
United States	**39 256 969**	**(53.4)**	**52 336 748**	**(71.2)**	**19 433 504**	**(26.4)**	**73 476 729**
Alabama	60 742	(05.4)	509 980	(45.5)	333 608	(29.7)	1 121 877
Arkansas	0		280 636	(39.9)	226 747	(32.3)	702 481
Arizona	1 069 452	(62.6)	1 324 542	(77.6)	1 066 740	(62.5)	1 707 221
California	6 478 750	(69.2)	8 086 001	(86.3)	844 900	(09.0)	9 364 530
Colorado	934 308	(77.4)	814 987	(67.5)	735 508	(60.9)	1 207 135
Connecticut	808 773	(99.6)	810 493	(99.8)	1629	(00.2)	812 213
District of Columbia	107 986	(96.4)	107 929	(96.4)	107 816	(96.3)	112 016
Delaware	156 842	(76.1)	145 155	(70.4)	129 073	(62.6)	206 229
Florida	2 264 079	(56.5)	2 670 108	(66.7)	766 125	(19.1)	4 004 271
Georgia	1 965 689	(77.1)	1 668 172	(65.4)	0		2 548 841
Iowa	364 734	(51.2)	474 242	(66.5)	10 650	(01.5)	712 613
Idaho	38 412	(09.3)	38 540	(09.3)	0		412 640
Illinois	129 676	(04.1)	2 616 639	(82.3)	264 907	(08.3)	3 179 260
Indiana	982 411	(62.0)	1 172 477	(74.0)	941 125	(59.4)	1 584 681
Kansas	186 013	(26.6)	426 242	(60.8)	237 846	(34.0)	700 485
Kentucky	386 747	(38.4)	626 949	(62.2)	400 843	(39.8)	1 008 064
Louisiana	0		399 357	(36.0)	0		1 107 973
Massachusetts	1 341 758	(94.0)	1 366 130	(95.7)	1 143 860	(80.2)	1 427 033
Maryland	1 193 524	(89.0)	1 198 460	(89.4)	1 193 420	(89.0)	1 340 583
Maine	0		148 706	(54.1)	0		274 867
Michigan	1 980 696	(82.9)	2 124 274	(88.9)	1 163 607	(48.7)	2 390 198
Minnesota	880 685	(70.2)	846 099	(67.4)	7002	(00.6)	1 254 644
Missouri	0		1 075 618	(75.7)	809 582	(57.0)	1 421 469
Mississippi	0		159 876	(20.9)	0		766 720
Montana	0		39 573	(18.0)	0		220 358
North Carolina	5273	(00.2)	949 695	(42.3)	603 242	(26.9)	2 243 677
North Dakota	0		0		0		143 048
Nebraska	0		304 711	(68.2)	0		446 995
New Hampshire	212 635	(72.5)	183 535	(62.6)	134 147	(45.7)	293 358
New Jersey	1 98 825	(92.7)	1 944 050	(94.9)	720 157	(35.2)	2 047 582
New Mexico	0		223 079	(44.4)	0		502 450
Nevada	479 804	(71.8)	479 842	(71.9)	0		667 801
New York	3 058 580	(69.4)	3 814 773	(86.5)	277 137	(06.3)	4 408 016
Ohio	2 338 196	(85.6)	2 482 698	(90.9)	2 060 442	(75.5)	2 730 377
Oklahoma	329 651	(36.4)	602 734	(66.5)	330 035	(36.4)	906 035
Oregon	0		485 634	(56.0)	0		867 575
Pennsylvania	1 774 569	(64.2)	2 006 770	(72.7)	1 143 040	(41.4)	2 762 004
Rhode Island	189 464	(82.9)	225 385	(98.6)	156 520	(68.5)	228 540
South Carolina	116 755	(11.0)	241 507	(22.7)	0		1 066 227
South Dakota	70 305	(35.5)	72 797	(36.7)	69 923	(35.3)	198 309
Tennessee	398 019	(26.9)	866 307	(58.6)	0		1 478 594
Texas	3 870 878	(57.6)	4 159 147	(61.8)	2 416 695	(35.9)	6 725 771
Utah	649 853	(76.5)	650 201	(76.5)	0		849 635
Virginia	582 441	(31.9)	1 453 532	(79.7)	584 870	(32.1)	1 823 201
Vermont	45 717	(35.5)	76 641	(59.4)	0		128 930
Washington	934 284	(60.6)	1 064 956	(69.1)	0		1 541 175
Wisconsin	874 279	(66.5)	794 725	(60.5)	548 344	(41.7)	1 314 412
West Virginia	96 165	(24.9)	119 465	(30.9)	3964	(01.0)	386 158
Wyoming	0		3380	(02.6)	0		128 457

Abbreviations: PICU, pediatric intensive care unit; PCICU, pediatric cardiac ICU.

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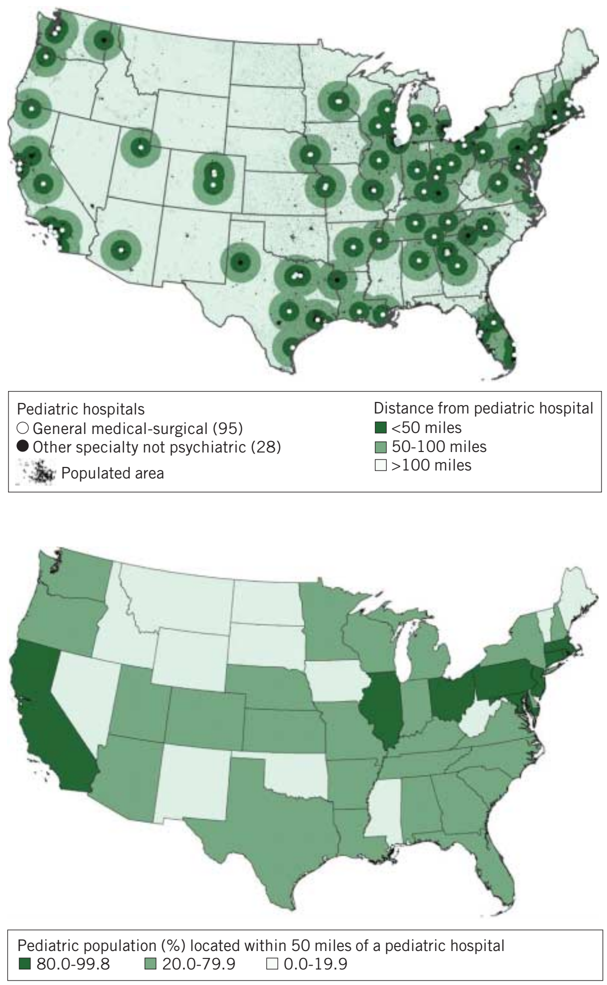
FIGURE 1

Location of Pediatric Hospitals and Proximity of Pediatric Population (%) to Those Hospitals.



The lack of standardized information regarding the capabilities of the staff and available technology in any one PICU precluded our ability to evaluate the PICU level of care. Therefore, all PICUs were treated as critical care units in this study, even though some may be very small and offer as little additional care as increased observation for moderately ill children.[13]

The project was conducted in three main steps: preparation of the geospatial layer of the pediatric population (children aged 0-17 years) using dasymetric mapping methods; preparation of the geospatial layer for each resource zone including the identification, verification, and location of hospital facilities with the target resources; and the proximity analysis of the pediatric population within these zones.

It should be noted that pediatric populations may vary in these scenarios due to the expertise available in any one unit. For example, some PCICUs may serve an older population—beyond the ages defined in this study—if they have a performance record for specific congenital cardiac lesions and have followed up the same patient for years. With the improved life expectancy of some rare childhood conditions, it is possible that a small percentage of adults with these conditions may still use pediatric resources. This may or may not change with health reform and family insurance until age 26 years.[14]

The traditional methodological approach to a proximity analysis is to use a geographic information system (GIS) overlay function, in which spatial buffers of a defined radius are placed around a point and then superimposed on a distribution map of the pediatric population to determine the number of persons living within these radii. In addition, populations of children not living within these radii can be determined, thus representing unserved populations. By comparing the population living within the radii to the total population, it is possible to estimate the proportion of persons with access to each type of specialized unit.

The limitation of this traditional approach is that population distribution maps have an inherent lack of spatial precision. Annual population estimates obtained from most agencies including the US Census[15] are not available in administrative units small enough to overcome this lack of spatial precision. Population numbers assigned to administrative units such as states and counties are assumed to be homogeneously distributed throughout the entire area. This assumption is not valid for nonresidential areas; this is especially problematic for rural counties, which tend to have large unpopulated areas. Furthermore, because large areas of the United States west of the Mississippi River are rural,[16] this lack of precision in population distribution can introduce a regional bias in GIS-derived estimates of unserved/served populations. Therefore, in this analysis the underlying population distribution map was refined to remove as much of this potential source of bias as possible. Dasymetric distributions—defined as the redistribution of regionally aggregated population statistics into smaller area units to reveal a more realistic spatial population distribution—are preferable for proximity studies because of this ability to realistically place population over geography.

The GIS software used to accomplish the dasymetric redistribution, create the hospital proximity zones, and the proximity analysis for this project was ArcGIS version 9.3 from ESRI®.

To refine the location of the pediatric population, a dasymetric map of the pediatric population was created. Dasymetric mapping is the process of transforming data from one spatial aggregation—usually mapped as a choropleth map, in which the entire land area is shaded according to one overall value for the area—into a map that is a more accurate depiction of the magnitude and spatial extent of the data.[17] In this study, county-level populations were redistributed and restricted to residential areas within each county. This process involves the use of additional information about each county—information that allows differentiation between residential and nonresidential areas—to make the resulting redistribution more meaningful. Although the field of public health still relies heavily on choropleth (thematic) maps, dasymetric maps are becoming more prevalent in the developing fields of public health preparedness and sustainable development.

Lists of hospitals with the target pediatric specialty in the continental United States were acquired from national and international accrediting agencies. Each list was either geocoded using Centrus Desktop, where actual addresses were available, or were linked with the 2010 Homeland Security Infrastructure Program (HISP) Gold data set[18] to create an accurately located spatial layer of hospitals for each of the five specialties.

A zonal radius of 50 miles was chosen because it is an approximation for the "golden" hour. The golden hour is referred to by most trauma specialists as the need to get severely injured persons from the accident scene to a trauma center within an hour to achieve an optimal recovery outcome.[19-21] One hundred miles is twice that distance, and appears to be the farthest distance most people are willing to travel to get any type of specialized medical care.[22-24] Most medical providers agree that 100 miles is too far to travel for any type of critical medical care.

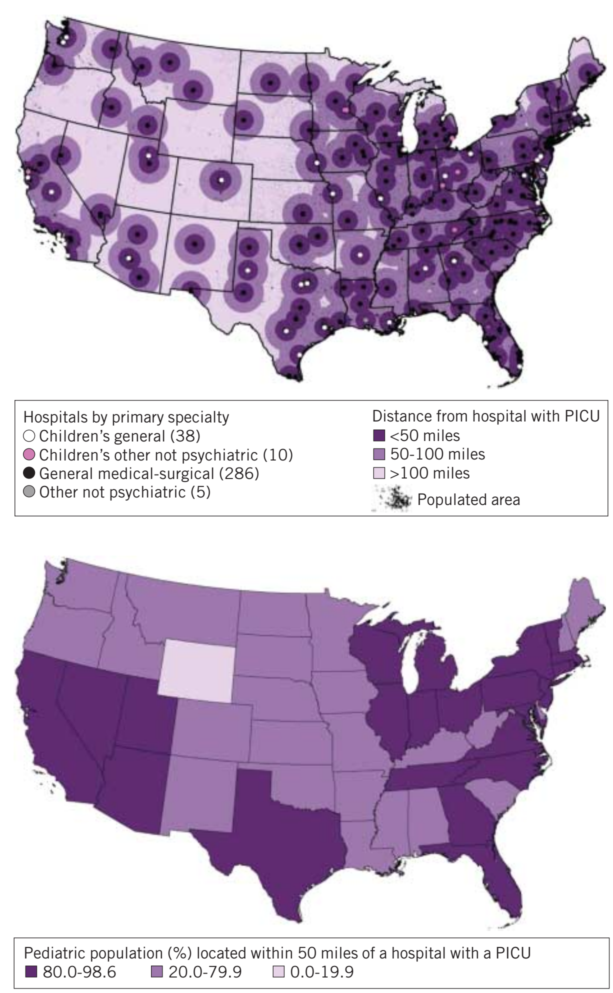
The hospital proximity zones were then split by the state boundaries, so the populations within the zones could be summarized by state.

The national coverage by zone for each type of specialty was mapped to visualize the extent of confluence (or lack of confluence) of the zones over the population both at the 50-mile radius and 100-mile radius. The population proportions were also mapped by state to evaluate variability in access from state to state.

The Appendix contains a detailed description of the processes used for this study including the dasymetric redistribution of the pediatric population; acquisition, verification, and linkage of each critical care resource list and the calculations used.[25-30]

FIGURE 2

Location of Hospitals with Pediatric Intensive Care Units (PICU) and Proximity of Pediatric Population (%) to Those Hospitals.



RESULTS

Pediatric Hospitals

Nationally, 64.1% of the pediatric population living in the continental United States (73.5 million children in 2008) lives within 50 miles of a pediatric hospital (Table, Figure 1). In 10 states (District of Columbia, California, Illinois, Ohio, Pennsylvania, Maryland, New Jersey, Massachusetts, Connecticut, and Rhode Island), 80% or more of the pediatric population lives within 50 miles of a pediatric hospital; and in 13 states, less than 20% of the pediatric population lives within 50 miles of a pediatric hospital. The percent of the pediatric population living within 50 miles of a pediatric hospital ranges, by state, from less than 1% to greater than 99% (Table). In 7 of the 13 states with less than 20% of the pediatric population living within 50 miles of a pediatric hospital, none of the pediatric population lives within 50 miles of a pediatric hospital (Table).

Hospitals with a PICU

Nationally, 82.0% of the pediatric population lives within 50 miles of a hospital that has a PICU (Table, Figure 2). In 24 states, 80% or more of the pediatric population lives within 50 miles of a hospital with a PICU; and in only 1 state (Wyoming) does less than 20% of the pediatric population live within 50 miles of a hospital with a PICU. The range by state is from less than 1% to 98.6% (Table).

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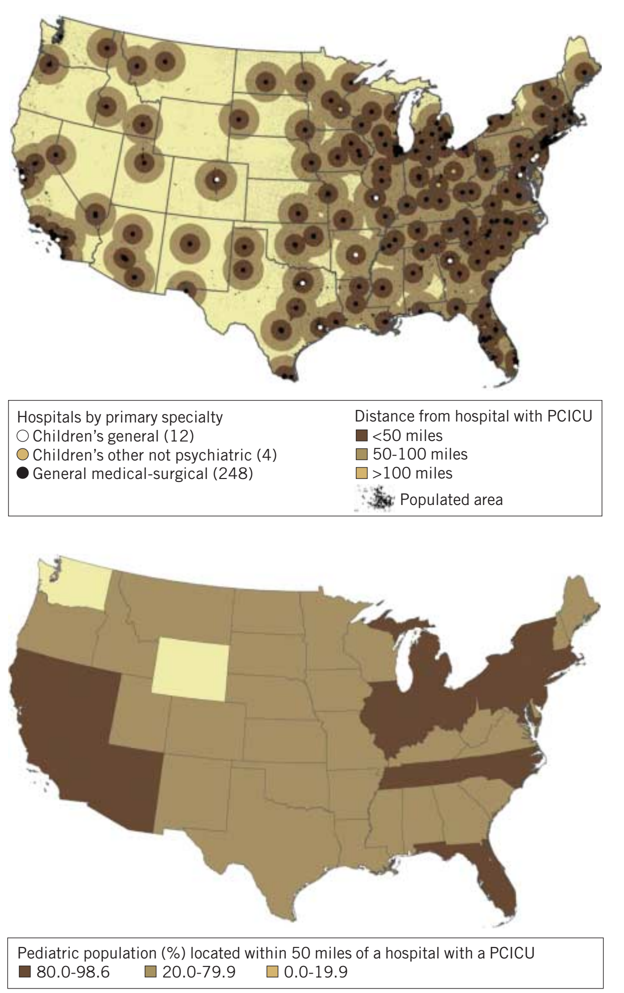
FIGURE 3

Location of Hospitals with Pediatric Cardiac Intensive Care Units (PCICU) and Proximity of Pediatric Population (%) to Those Hospitals.



Hospitals with a PCICU

Nationally, 76.6% of the pediatric population lives within 50 miles of a hospital that has a PCICU (Table, Figure 3). In 19 states, 80% or more of the pediatric population lives within 50 miles of a hospital with a PCICU; in only 2 states (Washington and Wyoming), does less than 20% of the pediatric population live within 50 miles of a hospital with a PCICU. The range by state is from less than 1% to 98.6% for hospitals with PCICUs (Table).

Hospitals with a Level I or Level II Trauma Unit or Pediatric Trauma Unit

Nationally, 80.7% of the pediatric population lives within 50 miles of any level I or II trauma center; but only 53.4% live within 50 miles of a pediatric trauma center (Table, Figure 4). In 26 states more than 80% of the pediatric population lives within 50 miles of any trauma center; but in 2 states (Arkansas and Mississippi), less than 20% of the pediatric population lives within 50 miles of any trauma center. The range by state is from 5.7% to greater than 99% for all trauma centers.

For pediatric trauma centers, there are 8 states (District of Columbia, Michigan, Ohio, Massachusetts, Connecticut, Rhode Island, New Jersey, and Maryland) where more than 80% of the pediatric population lives within 50 miles of a pediatric trauma center; and in 16 states, 20% or less of the pediatric population lives within 50 miles of a pediatric trauma center. The range is from less than 1% to greater than 99% (Table). In 11 of the 16 states with less than 20% of the pediatric population living within 50 miles of a pediatric trauma center, none of the pediatric population lives within 50 miles of a pediatric trauma center (Table).

Hospitals with a Burn Center

Nationally, 71.2% of the pediatric population lives within 50 miles of any burn center; but only 26.4% lives within 50 miles of a pediatric burn center (Table, Figure 5). Only 11 states (District of Columbia, California, Illinois, Michigan, Ohio, New York, Massachusetts, Connecticut, Rhode Island, New Jersey, and Maryland) have 80% or more of the pediatric population living within 50 miles of any burn center, and in 4 states (Idaho, Montana, Wyoming and North Dakota) less than 20% of the pediatric population lives within 50 miles of any burn center. The range by state is from less than 1% to 99.8%.

In only 3 states (District of Columbia, Massachusetts, and Maryland) does more than 80% of the pediatric population live within 50 miles of a pediatric burn center; in 25 states, 20% or less of the pediatric population lives within 50 miles of a pediatric burn center. The range by state is from less than 1% to 96.3% (Table). In 17 of the 25 states with less than 20% of the pediatric population living within 50 miles of a pediatric burn center, none of the pediatric population lives within 50 miles of a pediatric burn center (Table).

COMMENT

Although many US states provide adequate geographic coverage for most of their pediatric population—based on location of the population—for general pediatric, PICU, and PCICU care, coverage for pediatric trauma and burn care is less equally distributed. In particular, western mountain states represent the geographic region with the least coverage for each of the five pediatric critical care services.

Historically, as many as 30% of hospitalized victims of all ages in public health emergencies have required intensive care.[31-33] Critical care needs projected by the Department of Homeland Security National Planning Scenarios could exceed the entire national ICU capacity.[34]

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Disaster planning and response to a mass casualty incident involving the pediatric population pose unique demands on medical and public health communities. Children, as a recognized vulnerable population, are often overrepresented as victims in public health emergencies compared to other residential populations. Paired with the fact that children have innate physiologic and social vulnerabilities, this compromised distribution of care contributes to their morbidity and mortality.[35] Pediatric needs may predominate in emergencies involving a pathogen targeting infants, children, or pregnant women.[36] An accident involving schools or other pediatric-specific activities, or terrorism specifically targeting children would result in surges of children disproportionate to the overall population.[1,37] Although exact disease-specific data are often lacking, planners should anticipate a disproportionate number of children needing intensive care is likely, including children with chronic health conditions and special health care needs.

As it can be difficult to visualize the difference among regions using independent small-scale maps (state and local), this study uses dasymetric mapping to illustrate potential gaps and challenges in pediatric critical care resources across the nation. These facts demonstrate the potential utility of our dasymetric methodology and usefulness of having a more realistic understanding of the pediatric population distribution and accessibility to critical care. This method serves many purposes such as refining and expanding the methodology of preparedness and response in disaster planning.

It is clear from the maps that most pediatric critical care resources are located in highly urbanized environments, often with large distances between them. This geographic and economic reality can challenge pediatric regionalized systems in a disaster in which transport may not be possible or inappropriate.[38] To accomplish critical care for mass casualty disasters or pandemics, coordination is needed from the community to tertiary care. Current research in pediatric disasters preparedness and rural medicine has focused on strengthening the capabilities of communities without local pediatric resources by keeping patients in local hospitals and applying pediatric medicine via telemedicine or robotics.[39-41] However, depending on the disaster, the communication resources needed for telemedicine and robotics may not be available; therefore, reliance on this option needs to be tempered with adequate alternate resources on site. In any case, close cooperation, agreements, and unique delivery systems will be needed to provide appropriate pediatric emergency mass critical care. Each state and region must review current emergency operations and devise a plan that is most appropriate to address the population-based needs of children in large-scale disasters. This planning includes not only thinking beyond the need to share resources across state lines but also the consideration of sharing resources across borders.[42]

FIGURE 4

Location of Level I and II General and Pediatric Trauma Centers and Proximity of Pediatric Population (%) to Those Centers.

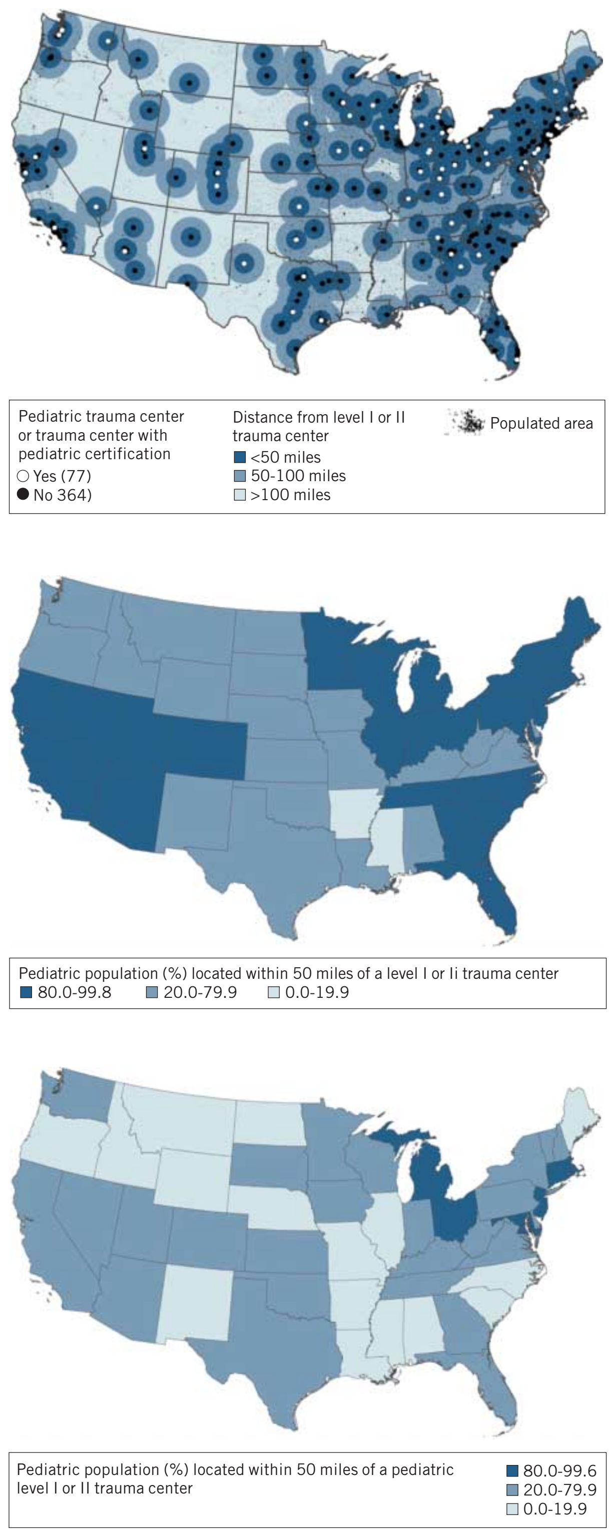

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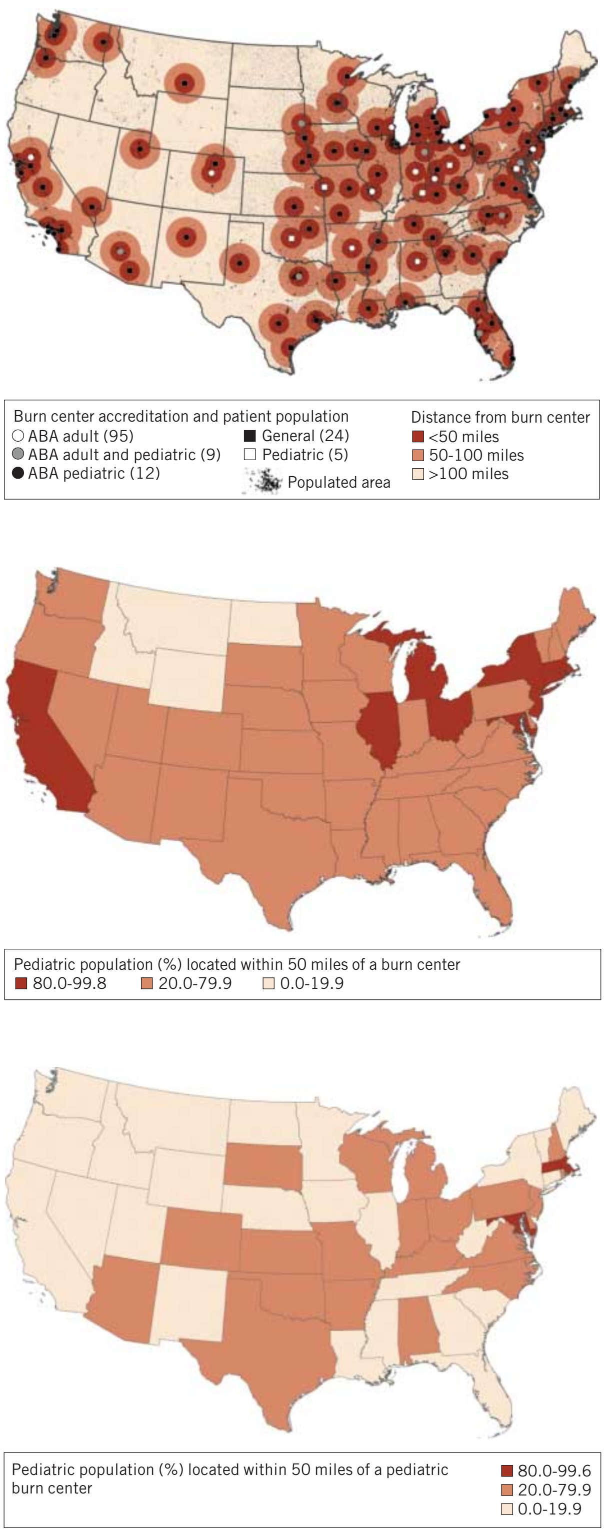
FIGURE 5

Location of General and Pediatric Burn Centers and Proximity of Pediatric Population (%) to Those Centers. ABA Indicates American Burn Association.



This study supports the steady streams of reports and articles that highlight the increasing concern of health care policy makers, planners, administrators, and medical consumers regarding the need to improve access to pediatric intensive capabilities supporting the care of critically ill and injured children. Our study focuses on the pediatric population's proximity to care as an indicator for measuring accessibility to critical care resources. However, this research does not provide information on the number of functional beds with sufficient staff, space, and other regional inventories of equipment and supplies, or transportation needs to and from resources. In addition, because PICUs are not evaluated on a scale based on technology and staff capabilities as are NICUs and trauma centers, it is impossible to separate out the subspecialty PICUs from nonsubspecialty PICUs. Nor does it provide information regarding regions that are currently engaged in collaboration for regionalization of pediatric critical care resources such as those building on or creating pediatric telemedicine forums that bring together individuals with expertise in pediatric and neonatal medicine, pediatric emergency and critical care medicine, pediatric surgery, and emergency management that consider planning issues and serve as a medical resource once a disaster incident begins. Likewise no information is provided regarding those areas in which jurisdictional rules may not permit ease in facilitating the use of regional resources.

Finally, this study focuses on pediatric resources. Recent experience with the H1N1 influenza pandemic indicates that conditions involving pregnant women may also result in a surge of severely ill newborns needing critical care.[3] Less attention has been given to planning for perinatal critical care in public health emergencies. Data are available regarding perinatal issues of the mother and her newborn infant; however, the authors have elected to address neonatal resources and maternal obstetrics capacity separately.

CONCLUSIONS

This geospatial analysis describes the current state of pediatric critical care resources and supplies a set of data for regionalization of these resources. It provides a visual and analytic overview of existing gaps in local pediatric hospital resources. It also highlights the use of dasymetric mapping as a tool for public health preparedness planning. Dasymetric mapping for population density studies is preferable over other methods because of its ability to place the population data in a more precise geographic location.

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REFERENCES

1. Bravata DM, McDonald KM, Owens DK, et al. *Regionalization of Bioterrorism Preparedness and Response*. Rockville, Maryland: Agency for Healthcare, Research and Quality. 2004. No. 04-E016-2.
2. Graham J, Shirm S, Liggin R, Aitken ME, Dick R. Mass-casualty events at schools: a national preparedness survey. *Pediatrics*. 2006;117(1):e8-e15.
3. Louie JK, Acosta M, Jamieson DJ, Honein MA; California Pandemic (H1N1) Working Group. Severe 2009 H1N1 influenza in pregnant and postpartum women in California. *N Engl J Med*. 2010;362(1):27-35.
4. Lasswell SM, Barfield WD, Rochat RW, Blackmon L. Perinatal regionalization for very low-birth-weight and very preterm infants: a meta-analysis. *JAMA*. 2010;304(9):992-1000.
5. Pollack MM, Alexander SR, Clarke N, Ruttimann UE, Tesselaar HM, Bachulis AC. Improved outcomes from tertiary center pediatric intensive care: a statewide comparison of tertiary and nontertiary care facilities. *Crit Care Med*. 1991;19(2):150-159.
6. Tilford JM, Simpson PM, Green JW, Lensing S, Fiser DH. Volume-outcome relationships in pediatric intensive care units. *Pediatrics*. 2000; 106(2, pt 1):289-294.
7. Osler TM, Vane DW, Tepas JJ, Rogers FB, Shackford SR, Badger GJ. Do pediatric trauma centers have better survival rates than adult trauma centers? an examination of the National Pediatric Trauma Registry. *J Trauma*. 2001;50(1):96-101.
8. Densmore JC, Lim HJ, Oldham KT, Guice KS. Outcomes and delivery of care in pediatric injury. *J Pediatr Surg*. 2006;41(1):92-98, discussion 92-98.
9. Petrosyan M, Guner YS, Emami CN, Ford HR. Disparities in the delivery of pediatric trauma care. *J Trauma*. 2009;67(2)(suppl):S114-S119.
10. Hartman M, Watson RS, Linde-Zwirble W, et al. Pediatric traumatic brain injury is inconsistently regionalized in the United States. *Pediatrics*. 2008; 122(1):e172-e180.
11. Kanter RK. Regional variation in child mortality at hospitals lacking a pediatric intensive care unit. *Crit Care Med*. 2002;30(1):94-99.
12. American Hospital Association. Annual Survey of Hospitals Database. 2009. http://www.ahadata.com/ahadata/files/2011/as2009lay.pdf. Accessed March 28, 2012.
13. Lorch SA, Myers S, Carr B. The regionalization of pediatric health care. *Pediatrics*. 2010;126(6):1182-1190.
14. Committee On Child Health Financing. Scope of health care benefits for children from birth through age 26. *Pediatrics*. 2012;129(1):185-189.
15. US Census Bureau. United States—States and Puerto Rico GCT-PH1. Population, Housing Units, Area, and Density: 2000; Dataset: Census 2000 Summary File 1 (SF 1) 100-Percent Data. http://factfinder2.census.gov/faces/nav/jsf/pages/index.xhtml.
16. US Census Bureau. Census 2000 Urban and Rural Classification; Source: Final Federal Register Notice for Urban Area Criteria. March 15, 2002;l67 (No.51):11663-11670. http://www.census.gov/geo/www/ua/ua_2k.html.
17. Mennis J. Dasymetric mapping for estimating population in small areas. *Geography Compass*. 2009;3(2):727-745.
18. National Geospatial Intelligence Agency. Homeland Security Infrastructure Program (HSIP) Gold 2010 database. http://www1.nga.mil/Partners/ResearchandGrants/SmallBusinessInnovationResearch/Pages/RDPriorities.aspx.
19. Stroud MH, Prodhan P, Moss MM, Anand KJS. Redefining the golden hour in pediatric transport. *Pediatr Crit Care Med*. 2008;9(4):435-437. doi: 10.1097/PCC.0b013e318172da62.
20. Lerner EB, Moscati RM. The golden hour: scientific fact or medical "urban legend"? *Acad Emerg Med*. 2001;8(7):758-760.
21. Original data supporting the "Golden Hour" concept produced from French World War I data. Trauma Resuscitation at Trauma.com. http://www.trauma.org/archive/history/resuscitation.html. Accessed June 1, 2010.
22. Burn Centers in the United States and Canada. Washington, DC: International Association of Fire Fighters' Burn Foundation; 2006. http://burn.iaff.org/burncenters.shtml.
23. Yantzi N, Rosenberg MW, Burke SO, Harrison MB. The impacts of distance to hospital on families with a child with a chronic condition. *Soc Sci Med*. 2001;52(12):1777-1791.
24. Mobley LR, Frech T. *Managed Care, Distance Traveled, and Hospital Market Definition*. Dep of Economics, University of California at Santa Barbara (USCB); 1998. Economics Working Paper Series 13-98.
25. National Center for Health Statistics. U.S. Census Populations With Bridged Race Categories. January 21, 2010. www.cdc.gov/nchs/nvss/bridged_race.htm.
26. Multi-Resolution Land Characteristics Consortium (MRLC). About the MRLC Program. http://www.mrlc.gov/about.php. Accessed October 28, 2009.
27. Verified Trauma Centers. American College of Surgeons Committee on Trauma, American College of Surgeons, Chicago, Illinois; 2010. http://www.facs.org/trauma/verified.html.
28. Moritz R. Consultant says trauma system taking shape. *Arkansas News*. April 23, 2010. http://arkansasnews.com/2010/04/23/consultant-says-trauma-system-taking-shape/.
29. Access to Trauma Centers in the U.S. American Trauma Society-CDC Online, Centers for Disease Control and Prevention, National Center for Injury Prevention and Control (NCIPC), Atlanta, Georgia. 2010. http://www.cdc.gov/traumacare/.
30. Burn Care Facilities. United States. American Burn Association, Chicago, Illinois; 2010. http://www.ameriburn.org/BCRD_20100521.pdf.
31. Chang R-KR, Klitzner TS. Can regionalization decrease the number of deaths for children who undergo cardiac surgery? a theoretical analysis. *Pediatrics*. 2002;109(2):173-181.
32. Aharonson-Daniel L, Waisman Y, Dannon YL, Peleg K; Members of the Israel Trauma Group. Epidemiology of terror-related versus non-terror-related traumatic injury in children. *Pediatrics*. 2003;112(4):e280.
33. Centers for Disease Control and Prevention. Predicting casualty severity and hospital capacity. 2003. http://www.bt.cdc.gov/masscasualties/capacity.asp. Accessed January 6, 2010.
34. Peleg K, Aharonson-Daniel L, Stein M, et al; Israeli Trauma Group (ITG). Gunshot and explosion injuries: characteristics, outcomes, and implications for care of terror-related injuries in Israel. *Ann Surg*. 2004;239(3):311-318.
35. Burkle FM Jr, Williams A, Kissoon N; Task Force for Pediatric Emergency Mass Critical Care. Pediatric emergency mass critical care: the role of community preparedness in conserving critical care resources. *Pediatr Crit Care Med*. 2011;12(6)(suppl):S141-S151.
36. Task Force for Mass Critical Care. Definitive care for the critically ill during a disaster. *Chest*. 2008;133(suppl 5):1S-66S.
37. Markenson D, Reynolds S; American Academy of Pediatrics Committee on Pediatric Emergency Medicine; Task Force on Terrorism. The pediatrician and disaster preparedness. *Pediatrics*. 2006;117(2):e340-e362.
38. Kanter RK, Dexter F. Criteria for identification of comprehensive pediatric hospitals and referral regions. *J Pediatr*. 2005;146(1):26-29.
39. Marcin JP, Ellis J, Mawis R, Nagrampa E, Nesbitt TS, Dimand RJ. Using telemedicine to provide pediatric subspecialty care to children with special health care needs in an underserved rural community. *Pediatrics*. 2004;113(1, pt 1):1-6.
40. Spooner SA, Gotlieb EM; Committee on Clinical Information Technology; Committee on Medical Liability. Telemedicine: pediatric applications. *Pediatrics*. 2004;113(6):e639-e643.
41. Marcin JP, Schepps DE, Page KA, Struve SN, Nagrampa E, Dimand RJ. The use of telemedicine to provide pediatric critical care consultations to pediatric trauma patients admitted to a remote trauma intensive care unit: a preliminary report. *Pediatr Crit Care Med*. 2004;5(3):251-256.
42. Barfield WD, Krug SE, Kanter RK, et al; Task Force for Pediatric Emergency Mass Critical Care. Neonatal and pediatric regionalized systems in pediatric emergency mass critical care. *Pediatr Crit Care Med*. 2011;12 (6)(suppl):S128-S134.