The relationship between the location of pediatric intensive care unit facilities and child mortality: A county-level ecologic study

By

Folafoluwa O. Odetola

A Master’s paper submitted to the faculty of

The University of North Carolina at Chapel Hill

In partial fulfillment of the requirements for

The degree of Master of Public Health in

The Public Health Leadership Program

3/22/04

Date
ABSTRACT

Objective: To describe the relationship between the location of Pediatric Intensive Care Unit (PICU) facilities and county-level child mortality in the USA.

Design: Cross-sectional ecologic study.

Setting: 3110 counties in the contiguous USA. Pediatric Care Area (PCA) was specified as counties within a 60-mile radius of the geographic center of a county with PICU facilities.

Interventions: None

Measurements and main results: In 1997, PICU facilities were present in 9% of USA counties and were predominantly urban (98%) in location. Over half (58%) of USA counties were included in PCAs. There were 96,413 deaths of children 0-14 years during the study period from 1996 to 1998. In bivariate analyses, residence within a PCA was related to lower mortality from trauma (incidence rate ratio [IRR] = 0.85, 95% confidence interval [CI] 0.83-0.87) and congenital anomalies (IRR= 0.98, 95% CI: 0.97-0.99). Controlling for residence in rural counties, poverty, and presence of pediatric intensivists, residence in a PCA remained associated with lower mortality from trauma (IRR= 0.87, 95% CI 0.85-0.89) and congenital anomalies (IRR = 0.97, 95% CI 0.96-0.99) compared to residence outside a PCA. Mortality from conditions of perinatal origin, infectious diseases, and benign neoplasms was higher in counties within PCAs compared to those outside PCAs.

Conclusion: Proximity to PICU facilities is associated with significant differences in child mortality particular to specific causes at the county level.
These associations have implications for the establishment of PICU facilities, and warrant further study at the level of the individual patient.
INTRODUCTION

Intensive care units for the care of critically ill and injured children in the USA have expanded both in size and number over time (1). A direct relationship between higher patient volume and lower risk-adjusted mortality has been described in the care of children requiring pediatric surgical, trauma, and critical care (2-5). In addition, many states and communities have developed trauma care systems with improved care of the most critically injured persons at high volume trauma facilities that have in-house surgical staff (6, 7). These relationships have led to regionalization of care for pediatric trauma patients with improved outcomes (8), and the establishment of guidelines for regionalization of care for critically ill and injured children (9,10).

While considerable variation exists in the processes of care among pediatric intensive care units (PICUs) (11, 12), the admission of a critically ill child to a non-PICU has been associated with higher odds of mortality when compared to care in a PICU, adjusted for severity of illness (13). Likewise, studies of critically injured children treated in designated pediatric trauma centers have reported better outcomes than for children treated in general trauma centers (14).

The concept of the golden hour was established in the trauma care literature to emphasize the importance of the rapid stabilization of critically injured patients, failing which reduces the likelihood of a good outcome (15). In this context, proximity to a hospital where definitive care can be given to a critically ill or injured child is critical. This concept has been extended to non-
trauma critical illness. Prior studies have shown that in areas where specialised pediatric emergency and critical care are not available, the outcome of pediatric critical illness and injury is adversely affected (16). Knowledge of the relationship between the location of pediatric intensive care facilities and outcomes in the population being served will help inform health policymakers and hospital management teams regarding the future establishment and distribution of pediatric intensive care facilities.

This study was designed to assess the relationship between the location of PICU facilities and county-level mortality from the leading causes of childhood death in the USA.
MATERIAL AND METHODS

Data were aggregated at the county level and linked using the Federal Information Processing System county codes. Counties were the units of analysis.

Data sources

Hospital facility data: Data from the 1997 American Hospital Association annual survey on hospital facility availability were used to ascertain the presence of PICU facilities at the county level (17). The survey does not contain information regarding pediatric trauma systems or adult trauma systems that also care for children.

We accounted for accessibility to PICU facilities by developing an accessibility measure using the geographic center (centroid) of the county as proxy for PICU location, and adjusted for distance between neighbouring county centroids using a distance decay parameter. County centroids were determined by a Geographic Information System, and the accessibility measures were calculated by a Euclidean distance algorithm written in SAS statistical software package (SAS Institute; Cary, NC, USA). Information on counties outside the contiguous United States (Alaska and Hawaii) was excluded in order to preserve geographic continuity.

The general accessibility measure for each mortality variable was calculated as:

\[ A_i = \sum_j E_j h_{ij} \]
where $A_i$ is the accessibility to the PICU at location $i$, $E_j$ is the value of the PICU variable at county centroid $j$, which is weighted by a distance decay measure ($h_{ij}$), and summed over all county centroid pairs.

The distance decay measure was calculated as:

$$h_{ij} = \frac{(m - d_{ij})}{(m - c\alpha d_{ij})}$$

where $m$ is the maximum allowable distance, $d_{ij}$ is the distance between county centroids $i$ & $j$, and $\alpha$ is a decay parameter.

We chose a maximum distance ($m$) of 60 miles (96.54 kilometers) to account for the golden hour of care for traumatic injuries beyond which the likelihood of survival may be diminished. Also, inter-hospital transfer of critically ill patients to a tertiary intensive care unit beyond a distance of 60 miles has been associated with increased mortality (18). The decay parameter ($\alpha$) determines the decay gradient (Figure), and after iterative testing with expected decay effects we used a value of zero which results in a linear distance decay.

County centroids within a 60-mile distance were weighted based on their actual distance to the centroid of the nearest county with PICU facilities. A county with PICU facilities and its neighboring counties with centroids within a 60-mile radius constituted a pediatric care area (PCA).

Mortality data: We used data from the National Center for Health Statistics compressed mortality file (19). The file summarizes all USA deaths, stratified by age group, race, sex, year, and 4-digit International Classification of Disease (ICD-9) code, aggregated by county of residence. We restricted the data to the leading causes of death in children 0-14 years of age, collapsing across age,
race, and sex categories for the 3-year period 1996-1998. Denominator population data for all children 0-14 years were also included in the file. Death rates were calculated as a ratio of death counts in children 0-14 years in each county per total population of children 0-14 years residing there. The ten leading causes of death and associated ICD-9 codes are shown in the appendix.

**Poverty data:** We selected poverty as a county-level control variable, as lower socioeconomic status has been linked to increased child mortality (20-22). The number of children 0-17 years living below the poverty level was obtained from the 1990 USA census (23).

**Number of pediatric intensivists at the county level:** 1997 data on the number of pediatric intensivists at the county level were obtained from the American Medical Association master file via the Medical Marketing Service (24).

**County of residence:** Delayed transfer of critically ill or injured patients from rural to tertiary care facilities could negatively impact outcome (25-27). The county of residence was dichotomized into rural and urban counties based on the 10-code Rural-Urban Continuum codes provided by the USA Department of Agriculture (28). **Statistical Analysis:** All count data were standardized to the county population of children 0-14 years. We used negative binomial regression to perform bivariate comparisons of mortality rates between counties within the PCAs and those outside, and to subsequently construct multivariate models adjusting for county of residence, poverty, and the presence of pediatric intensivists, adding one variable at a time. Negative binomial regression models
account for distributions with the mode at zero and probability masses that decline as the count increases, as in phenomena with low expected rates such as child mortality (29). Incidence rate ratios with corresponding 95% confidence intervals were calculated to estimate the difference in mortality rates for counties within a PCA versus those outside. Analyses were conducted using Stata 7 for Windows (Stata Corporation; College Station, Texas, USA).
RESULTS

Of 3110 counties in 1997, 271 (9%) had PICU facilities, located predominantly (98%) in urban counties. Over half (58%) of the counties were included in PCAs, while 42% were beyond 60 miles of the geographic center of a county with PICU facilities. There were 210 counties (7%) with pediatric intensivists.

Among children 0-14 years of age, there were 96,413 deaths from the ten leading causes of death between 1996 and 1998 (Table 1). Of these, 18,337 (19.0%) deaths were from trauma. Among non-trauma deaths, a large proportion (78%) was attributed to conditions of perinatal origin and congenital anomalies. Overall, medical conditions including conditions of perinatal origin and congenital anomalies exceeded trauma /accidents as the leading cause of death.

In regression analyses (Table 2), residence in a county within a PCA was associated with lower mortality due to trauma and congenital anomalies, but higher mortality from conditions of perinatal origin, infectious disease, and benign neoplasms. After adjustment for residence in rural counties and poverty, as well as the presence of pediatric intensivists, these associations remained significant. Child mortality from malignancies, heart disease, pneumonia, and cerebrovascular disease was not significantly related to the location of PICU facilities.
DISCUSSION

As PICU facilities expand in size and number, it is essential to understand how their location may impact patterns of care and mortality for children. Findings in this study suggest that the influence of proximity to PICU facilities in the USA may differ substantially by cause of death. Mortality from trauma and congenital anomalies, which accounted for almost half of all pediatric deaths in the USA, is lower in counties proximate to PICU facilities in the 3-year sample studied.

Rapid stabilization and definitive care of trauma victims has been associated with improved outcomes (15, 25, 26). Proximity to a hospital where such care can be provided is critical, and rapid transport to definitive care may result in major mortality reduction in trauma patients (30-32). These tenets of trauma care are corroborated by our study, which accounted for distance to the geographic center of a county with PICU facilities. The choice of 60 miles as cut-off distance for accessibility to pediatric intensive care was further modified by the distance decay parameter, a novel approach that assigns greater weight to areas proximate to PICU facilities.

The presence of pediatric trauma and critical care specialists with high levels of expertise and technical skills may contribute to the finding of lower trauma mortality in areas with PICU facilities, although adjustment for the presence of pediatric intensivists in our models did not alter the findings substantially. We could not control for the availability of trauma surgeons, nor were we able to control for the availability of pediatric trauma facilities or
designated adult trauma facilities that treat children within these counties. Another possible explanation for our findings regarding trauma could be that the organization of Emergency Medical Services for Children, the emergency transport system, is better coordinated in counties within a PCA.

Mortality from congenital anomalies ranked second to conditions of perinatal origin in frequency. We found lower mortality in counties within a PCA, a finding likely related to the provision of highly specialized multidisciplinary care to children with these anomalies in these counties. For instance, congenital heart disease is the most common group of congenital malformations requiring surgical intervention during infancy and childhood, and outcomes are clearly affected by surgical volume which is concentrated in children's hospitals (33). Proximity to PICU facilities might also make early palliation or correction of the anomalies easier to achieve.

Counties within PCAs had higher mortality from conditions of perinatal origin which include birth trauma, respiratory distress syndrome, birth asphyxia, and prematurity. These conditions often have chronic sequelae and the care of such children is often highly dependent on the availability of specialist care. Feudtner et al. reported a higher likelihood, and longer duration, of mechanical ventilation in children with complex chronic conditions at the end of life (34). Facilities with the capacity to provide care to children at risk of mortality from chronic conditions are likely concentrated within a PCA. We could not adjust for confounding of the relationship between PICU facilities and mortality from
conditions of perinatal origin by the presence of neonatal ICUs, where initial care for infants with perinatal conditions is often conducted.

The factors that underlie the findings of higher mortality from infectious disease and benign neoplasms in counties within PCAs are less clear, and cannot be ascertained from this study. Mortality from malignancies, pneumonia, acquired heart disease, and cerebrovascular disease was not significantly related to the location of PICU facilities.

Our analyses have certain limitations common to ecologic studies. One is that the validity of the inferences made will depend on the ability to control for differences among counties in the joint distribution of confounders, including individual variables (35). To address this concern, we controlled for certain county-level variables related to child mortality, including poverty and rural status of the county, while recognizing our inability to control for other potential confounders. An additional limitation is that the causes of death were ascertained from death certificates, and are susceptible to inaccuracies of detection and attribution that may have biased our findings.

We describe differences in the association between various causes of child mortality and the location of PICU facilities. One must be cautious not to draw causal inferences. While such patterns may help us understand the implications of the location of scarce PICU resources in the USA, reasons for these differences in PCA-mortality relationships warrant further investigation with studies that include patient physiologic data and adjustment for severity of illness, as well as facility and provider information. There also should be further study regarding transfer of
pediatric trauma patients and children with congenital anomalies to facilities with higher pediatric capacity.
CONCLUSION

Proximity to PICU facilities is associated with significant differences in mortality at the county level. Lower mortality rates for children with congenital anomalies and trauma may reflect the concentration of pediatric subspecialty care in counties with PICUs, while higher mortality due to conditions of perinatal origin might be related to the care of children with complex chronic conditions. These associations warrant further examination at the individual patient level, as they have implications for policies that affect the establishment and distribution of PICU facilities in the USA.
REFERENCES


room resuscitation on outcome of traumatic injuries. *Arch Surg* 1989; 124: 906-910


13. Pollack MM, Alexander SR, Clarke N, Ruttimann UE, Tesslera HM, Bachulis AC. Improved outcomes from tertiary center


24. Medical Marketing Service Inc. Wood Dale IL.


28. US Department of Agriculture. Rural urban continuum codes 1993. Available at:
http://www.ers.usda.gov/data/ruralurbancontinuumcodes/


### Table 1. Mortality attributed to the ten leading causes of child death in the United States 1996-1998

<table>
<thead>
<tr>
<th>Causes of child death</th>
<th>Number of deaths</th>
<th>% of deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conditions of perinatal origin</td>
<td>39,284</td>
<td>41.0</td>
</tr>
<tr>
<td>Congenital anomalies</td>
<td>21,729</td>
<td>22.5</td>
</tr>
<tr>
<td>Trauma/Accidents</td>
<td>18,337</td>
<td>19.0</td>
</tr>
<tr>
<td>Homicide</td>
<td>3,573</td>
<td>4.0</td>
</tr>
<tr>
<td>Heart disease</td>
<td>3,447</td>
<td>3.5</td>
</tr>
<tr>
<td>Infectious disease</td>
<td>3,223</td>
<td>3.0</td>
</tr>
<tr>
<td>Malignancies</td>
<td>2,780</td>
<td>3.0</td>
</tr>
<tr>
<td>Pneumonia/Influenza</td>
<td>2,236</td>
<td>2.0</td>
</tr>
<tr>
<td>Cerebrovascular disease</td>
<td>1,193</td>
<td>1.0</td>
</tr>
<tr>
<td>Benign neoplasms</td>
<td>611</td>
<td>0.5</td>
</tr>
<tr>
<td>Total</td>
<td>96,413</td>
<td>100.0</td>
</tr>
</tbody>
</table>

### Table 2. Negative binomial regression models of mortality attributed to the ten leading causes of child death

<table>
<thead>
<tr>
<th>Cause of Death</th>
<th>PCA</th>
<th>+ rural-urban county</th>
<th>+ child poverty</th>
<th>+ Intensivists</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Incidence rate ratio (95% CI)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trauma/Accidents</td>
<td>0.85(0.83-0.87)</td>
<td>0.86(0.84-0.88)</td>
<td>0.86(0.84-0.88)</td>
<td>0.87(0.85-0.89)</td>
</tr>
<tr>
<td>Congenital Anomalies</td>
<td>0.98(0.97-0.99)</td>
<td>0.98(0.97-0.99)</td>
<td>0.97(0.96-0.99)</td>
<td>0.97(0.96-0.99)</td>
</tr>
<tr>
<td>Conditions of perinatal origin</td>
<td>1.08(1.06-1.11)</td>
<td>1.08(1.05-1.10)</td>
<td>1.06(1.03-1.08)</td>
<td>1.05(1.03-1.08)</td>
</tr>
<tr>
<td>Infectious disease</td>
<td>1.09(1.06-1.13)</td>
<td>1.09(1.06-1.12)</td>
<td>1.08(1.04-1.11)</td>
<td>1.08(1.04-1.11)</td>
</tr>
<tr>
<td>Benign Neoplasms</td>
<td>1.05(1.01-1.09)</td>
<td>1.05(1.01-1.09)</td>
<td>1.06(1.02-1.10)</td>
<td>1.06(1.02-1.10)</td>
</tr>
<tr>
<td>Homicide</td>
<td>1.03(0.99-1.06)</td>
<td>1.03(0.99-1.07)</td>
<td>0.99(0.95-1.02)</td>
<td>0.98(0.95-1.02)</td>
</tr>
<tr>
<td>Heart Disease</td>
<td>0.99(0.97-1.02)</td>
<td>0.99(0.97-1.02)</td>
<td>0.99(0.96-1.02)</td>
<td>0.99(0.96-1.02)</td>
</tr>
<tr>
<td>Malignancies</td>
<td>1.00(0.98-1.02)</td>
<td>1.00(0.98-1.02)</td>
<td>1.00(0.98-1.02)</td>
<td>1.00(0.98-1.02)</td>
</tr>
<tr>
<td>Pneumonia/Influenza</td>
<td>1.02(0.98-1.05)</td>
<td>1.01(0.98-1.05)</td>
<td>1.00(0.98-1.04)</td>
<td>1.00(0.96-1.04)</td>
</tr>
<tr>
<td>Cerebrovascular Disease</td>
<td>1.01(0.98-1.05)</td>
<td>1.01(0.98-1.05)</td>
<td>1.01(0.97-1.05)</td>
<td>1.01(0.97-1.05)</td>
</tr>
</tbody>
</table>
Figure. Weighting on inter-centroid distance from the center of county with pediatric intensive care unit facilities
### APPENDIX

**Leading causes of death in children 0-14 years in 1997 in the United States**

<table>
<thead>
<tr>
<th>Cause of Death</th>
<th>ICD-9 codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accidents/Trauma and adverse effects</td>
<td>E800-E949</td>
</tr>
<tr>
<td>Congenital anomalies</td>
<td>740-759</td>
</tr>
<tr>
<td>Malignant neoplasms</td>
<td>140-208</td>
</tr>
<tr>
<td>Homicide and legal intervention</td>
<td>960-978</td>
</tr>
<tr>
<td>Acquired heart disease</td>
<td>390-398, 402,404-429</td>
</tr>
<tr>
<td>Pneumonia and Influenza</td>
<td>480-487</td>
</tr>
<tr>
<td>Certain conditions originating in the perinatal period</td>
<td>760-779</td>
</tr>
<tr>
<td>Septicemia</td>
<td>038</td>
</tr>
<tr>
<td>Benign neoplasms, carcinoma in situ, and neoplasms of uncertain behavior and of unspecified nature</td>
<td>210-239</td>
</tr>
<tr>
<td>Cerebrovascular diseases</td>
<td>430-438</td>
</tr>
</tbody>
</table>