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The Spatial Epidemiology of Pediatric Trauma: A Statewide Assessment

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Abstract

Introduction—Despite significant advances in the prevention and treatment of pediatric trauma, preventable injuries continue to burden the lives of millions of children. In order to target prevention strategies, it is critical to identify areas with high burdens of pediatric trauma. Therefore, this study analyzed statewide data from the Ohio Trauma Registry (OTR) from 2007–2012 to identify geographical patterns in pediatric injury.

Methods—Data from the first hospital of care for 16,330 pediatric trauma patients under 16 years old were analyzed using the disease mapping method adaptive spatial filtering to estimate a series of maps that display age- and sex-adjusted rates of pediatric trauma, severe trauma, and standardized mortality ratios (SMR) while controlling for population size to create stable estimates throughout the study area. The locations of all trauma centers were mapped to highlight access to trauma care.

Results—Areas with significantly higher than expected rates of severe injury were identified in non-urban areas, where children lacked timely access to a Pediatric Trauma Center (PTC) or Level 1 Adult Trauma Center (ATC). Although highest SMRs were in urban areas, non-urban areas experienced elevated mortality with rates over 4 times higher than expected.

Conclusion—Areas with higher than expected age- and sex-adjusted rates of severe injury and mortality should be further explored to identify opportunities for injury prevention and appropriate access to timely care.

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Author Contributions
Dr. Allison Ertl conducted the literature review and was primarily responsible for the spatial analysis and manuscript preparation.
Dr. Sergey Tarima contributed to the study design, the analysis files, providing statistical support and interpretation of analyses.
Dr. Kirsten Beyer is an expert in spatial analysis and contributed to the design of the spatial analysis methods, overseeing Dr. Ertl's analysis and interpretation of results.
Dr. Yuhong Zhou assisted Dr. Ertl with the more complicated aspects of the spatial analysis and interpretations.
Dr. Jonathan Groner contributed to the study design, acquisition of the data, interpretation of results, and manuscript preparations.
Dr. Laura Cassidy is the Principal Investigator of the study and responsible for study design, oversight of the project, interpretation of results, and manuscript preparation.

BACKGROUND

Despite significant advances in trauma prevention and treatment, traumatic injuries continue to impact the lives of millions of children.[1] The United States maintains highly developed public health programs and trauma systems, yet every hour, another child will tragically die as a result of an injury.[1,2] Over the course of a year, more than 12,000 children will die from injuries in the United States.[2] Despite a 30% decline in pediatric injury fatalities over the last decade, injury remains the number one cause of death among children and youth 0–19 years.[1] Untimely fatalities resulting from pediatric injury are deleterious to families and communities, and the overall burden of pediatric injury on the health care system in the United States is inordinate. For every child that dies from a pediatric injury, there are 925 treated in emergency departments, resulting in more than 9 million emergency department visits for pediatric injuries every year.[1–3]

Public health agencies, including the Centers for Disease Control and Prevention and the World Health Organization, have identified systematic and ongoing surveillance as essential to effective injury control and prevention. In order to target and improve prevention strategies, it is critical to identify discrete geographic areas with high burdens of pediatric trauma through surveillance.[4–12] Disease mapping is a surveillance method that depicts the geographic distribution of diseases or injury rates, facilitating the identification of areas with high or low rates.[4–7,9–13] A study of burn injuries in 1996 used this approach to isolate a 24-square-mile area within Oklahoma City with the highest rate of burns from residential fires.[14] After targeting a smoke-alarm-giveaway program to the high-risk area identified through surveillance, fire-injury rates significantly decreased, demonstrating the efficacy of interventions targeted at discrete geographic areas with elevated injury incidence.[14] Similar disease mapping methods have been successfully implemented in studies of pediatric burn injuries and pediatric pedestrian injury,[15,16] supporting the utility of these methods in contributing to reductions in morbidity and mortality from pediatric injuries.

Geographically detailed surveillance of injury burdens is needed; however, mapping health information for small geographic areas, such as ZIP codes, presents significant challenges due to small numbers of injuries that can result in unstable rates. This is particularly problematic in less densely populated areas, especially rural areas. Therefore, spatial and statistical methods need to be utilized to stabilize the rates and minimize the possibility of erroneous conclusions. Adaptive spatial filtering (ASF) is a disease mapping method that mitigates this problem.[17–19] ASF displays quantities of interest as a smooth rate surface to identify finely detailed geographical patterns, while ensuring statistically stable rates and data confidentiality protections.[13,17–19] In ASF, a grid is laid over the study area, and for each grid point, a rate is calculated by using a circular filter that expands to obtain data from multiple locations until it obtains enough observations to calculate a stable rate. The user defines a threshold value to guide the filter bandwidth size, such as an expected number of injuries or a population size that will result in a stable rate calculation. The area in between the grid points is interpolated to create a continuous surface representation of a disease or injury burden. The geographic scale of the measured rates varies across the map as the density of the population at risk varies.

Although basic mapping strategies have been utilized to study injury, to our knowledge, only one study has attempted to apply disease mapping methods such as ASF as a surveillance tool for pediatric injury prevention and improved trauma care, and that study lacked population-based, representative trauma data.[15] Currently, no national trauma system exists that captures clinical data on large samples of pediatric trauma patients with pre-hospital and inpatient data from both trauma and non-verified/non-designated trauma centers (NTC). Existing pediatric trauma maps do not capture a representative sample of data from NTCs, thereby limiting their public health utility in targeting childhood injury prevention efforts. Furthermore, major trauma centers are typically located in urban settings, placing children injured in rural areas at increased risk for poor outcomes from severe trauma and with inadequate surveillance to target and improve prevention strategies.

This study takes a critical step toward addressing two gaps in pediatric trauma surveillance research. This is the first study to apply ASF methodology to a statewide pediatric trauma dataset to provide stable, detailed, geographical estimates of injury rates that can be used to inform targeted prevention efforts. To date this is the most comprehensive spatial analysis of pediatric trauma because it uses a comprehensive statewide trauma registry includes 87% of the state's hospitals including both trauma centers and community hospitals in rural areas.

METHODS

The Ohio trauma registry has uniform statewide coverage of pediatric trauma admissions, including non-verified trauma centers, making the registry a unique and comprehensive source for statewide trauma surveillance and analysis of spatial patterns. To ensure patients were not double counted and that data reflects the geographic region where the child was injured, data were analyzed from the first hospital of care for 16,330 unique pediatric trauma patients under 16 years of age admitted to Ohio hospitals in 2007–2012 and residing in Zip codes within the state of Ohio. Pediatric traumatic injuries occurred in 1,009 out of 1,197 unique Ohio zip codes. Severe pediatric trauma, defined as an Injury Severity Score (ISS) greater than 15, was identified in 2,648 unique patients and resulted in 383 fatalities.

Significant differences in pediatric trauma rates per 100,000 population were identified by age and sex for the state of Ohio. Therefore, rates were estimated using indirect age-sex adjustment procedures. Indirect adjustment is preferred in many geographical analyses, as direct adjustment would rely on rates calculated for small geographies that are very likely to be unstable.[20] For indirect adjustment, a standard set of age-sex specific injury rates are applied to local population counts to estimate the local injury experience for the observed population.[21] This method relates the observed number of injuries to the "expected" number of injuries in the local area, by assuming that the age-sex specific injury rates apply to the observed population.[21] Indirect age-sex adjustments were presented as the ratio of observed injuries to expected injuries.[21] When applied to deaths, this ratio is called the standardized mortality ratio (SMR) and is given, for a local area, by

$$\mathrm{SMR}=\frac{\mathrm{Observed}}{\mathrm{Expected}}=\frac{D}{R_{\mathrm{si}}\times P_i}$$

where D is the total number of deaths in the observed population, R_{si} is the age-sex specific death rate in age-sex interval i in the standard population, and P_i is the population of age-sex interval i in the observed population.[21] ASF was used to estimate a series of maps to display age- and sex-adjusted rates of pediatric trauma, severe pediatric trauma, and standardized mortality ratios (SMR) while controlling for population size to create stable estimates throughout the study area. R software was used to implement ASF.[22] A grid of census block group centroids was created for the state of Ohio with rates calculated using a circular filter to expand and obtain aggregated counts of pediatric trauma, severe pediatric trauma, and pediatric trauma mortality from multiple locations until enough observations were obtained to calculate stable rates. Thresholds of 20, 50, and 100 pediatric trauma observations with 95% confidence intervals were explored to ensure the selection resulted in stable rate calculations and to explore the influence of threshold on resultant spatial patterns. Ultimately, a threshold value of 50 pediatric trauma observations was selected to guide the filter bandwidth size for the indirect trauma rates and severe indirect trauma rates, because it maximized statistical stability and spatial resolution. This method was repeated for pediatric trauma fatalities using threshold values of 5, 10, and 20 pediatric trauma fatalities. Ultimately, a threshold value of 10 pediatric trauma fatalities was selected, because it produced the most stable estimates without masking spatial variation

Using Esri ArcGIS 10.4 software,[23] inverse distance weighting (IDW) was applied to interpolate a surface based on the rates estimated for each grid point to produce continuously defined surfaces representing the indirectly age-sex adjusted pediatric trauma incidence rate, the indirectly age-sex adjusted severe pediatric trauma incidence rate, and the indirectly age-sex adjusted mortality rate (SMR). The locations of all trauma centers were mapped to highlight access to verified trauma care, with level one adult trauma centers (ATC 1) shown in green, adult trauma centers with pediatric capabilities (ATC PC) shown in light blue, levels two and three adult trauma centers (ATC 2 or 3) shown in dark blue, and level one and two pediatric trauma centers (PTC 1 or 2) shown in black. Red circles indicate major cities throughout the state of Ohio that have populations over 100,000, including Toledo, Cleveland, Dayton, Columbus, Akron, and Cincinnati. Interstate highways were also mapped to enhance interpretation.

RESULTS

Pediatric Trauma Indirect Rate

Figure 1 depicts the age- and sex-adjusted rates for pediatric trauma across the state of Ohio. The continuous indirect rates are shown with the lightest pink areas indicating lower than expected rates of pediatric trauma and the darkest pink areas indicating higher than expected rates of pediatric trauma. The highest rate was nearly 3.5 times the expected rate. Although the major urban areas in Ohio demonstrated higher than expected rates of pediatric trauma, rural areas suffered from the highest observed to expected rates of pediatric trauma. Specifically, non-metropolitan areas in the Central and Southeast or Appalachian regions of the state experienced significantly higher than expected rates of pediatric trauma. Among urban areas, the Cleveland Metropolitan Area demonstrated the highest indirect rates of pediatric trauma.

Pediatric Trauma Severe Indirect Rate

Figure 2 illustrates age- and sex-adjusted rates for severe pediatric trauma across the state of Ohio (ISS>15). The continuous spatial distribution of severe pediatric trauma indirect rates are shown with the lightest pink areas indicating lower than expected rates of severe pediatric trauma and the darkest pink areas indicating higher than expected rates of severe pediatric trauma. The Cleveland, Toledo, Columbus, Cincinnati, and Dayton metropolitan areas, the five largest metropolitan areas in the state, all demonstrated the highest age- and sex-adjusted indirect rates of severe pediatric trauma. The highest rate of 2.9 times the expected rate was identified in Cleveland. Importantly, higher than expected adjusted rates of severe pediatric trauma were identified in the rural Appalachian region of Ohio.

Pediatric Trauma Standardized Mortality Ratio

The continuous spatial distribution of SMRs are depicted with the lightest pink areas indicating lower than expected pediatric trauma mortality rates and the darkest pink areas indicating higher than expected pediatric trauma mortality rates (Figure 3). The observed pediatric mortality rates were approximately 11 times higher than the expected rate. Consistent with the spatial pattern of severe pediatric trauma, the major metropolitan areas of Cleveland, Toledo, Columbus, Cincinnati, and Dayton experienced the highest mortality rates from pediatric trauma. Although some non-metropolitan areas across the state demonstrated higher than expected mortality, the highest mortality rates were not identified in any rural areas.

DISCUSSION

The statewide spatial analysis identified two non-metropolitan regions with the highest observed to expected rates of pediatric trauma. Identifying these areas is particularly important, because major trauma centers, including pediatric trauma centers, are generally located in large metropolitan areas. Therefore, children in rural settings are at increased risk for poor outcomes from trauma due to travel distances and potential delays in care. The elevated observed to expected rates of pediatric injury, especially severe injury, in the rural Appalachian region of Southeast Ohio are particularly concerning, as many of these children do not reside within an hour of a trauma center. Appropriate trauma-specific medical treatment at a trauma center within the hour following a traumatic injury is thought to provide the highest likelihood of survival.[24,25] The primary cause of injury for the children residing in these rural areas with elevated adjusted pediatric trauma rates was motor vehicle collisions, suggesting an opportunity for motor vehicle-related injury prevention. A limitation to this study was the ability to link detailed patient information with the mapping results due to confidentiality issues. Therefore, future research into the demographic information and injury characteristics of children residing in high risk rural areas will aid in targeting and improving pediatric injury prevention strategies.

Children living in the largest Metropolitan Areas of the state were at greatest risk for severe injuries. These results may guide prevention strategies in large urban areas, because children in urban areas were more likely to experience severe trauma resulting from penetrating injuries including gunshot and stab wounds. The major metropolitan areas across the state experienced both the highest observed to expected rates of severe pediatric trauma and mortality. This is not unexpected; however these children have access to prompt, high level care. This study was the first to identify a health disparity for pediatric trauma patients by using sophisticated age and sex adjusted spatial analyses to confirm the higher than expected rates of severe injury in children in rural settings. Most studies report pediatric mortality rates using trauma registry data from trauma centers and do not report by patient zip code. Therefore, this study provides a unique insight into the distribution of injury and mortality rates based on patient residence and their access to timely care.

Using a comprehensive state-wide pediatric trauma dataset in conjunction with a sophisticated spatial analysis approach provides stable, population-based estimates of age- and sex-adjusted pediatric trauma. The calculation of these rates and uncovering of spatial patterns can support future research to explore relationships more deeply, including a consideration of demographic and social factors, to help identify high risk populations and places with elevated pediatric trauma rates. Prevention strategies can then be more effectively targeted to the specific geographic areas or populations at risk. Thus, spatial analysis is a vital public health surveillance tool for studying and monitoring pediatric trauma. These approaches can be effectively utilized in future studies to identify determinants associated with the risk of trauma to guide injury prevention efforts and to evaluate the spatial organization and accessibility of acute trauma care systems.

A limitation to this study is that the injury location may differ from the patient's home address. In trauma registries, only the patient's residential address is typically obtained. Therefore, maps depicting the spatial distribution of trauma are often based on patient's residence rather than injury location, leading to the potential for inappropriate conclusions if the residential location is not representative of the injury location. However, the majority of children in this study were injured within their own homes or neighborhoods, suggesting that this limitation may minimally impact the findings. A further limitation of this study is the retrospective study design. Trends and spatial patterns of pediatric trauma may change over time, calling for the access to timely data to advance the management of the prevention of childhood injury. As surveillance methods develop and real time data becomes available, a dashboard could be developed to monitor pediatric trauma, improve trauma systems and inform timely prevention efforts.

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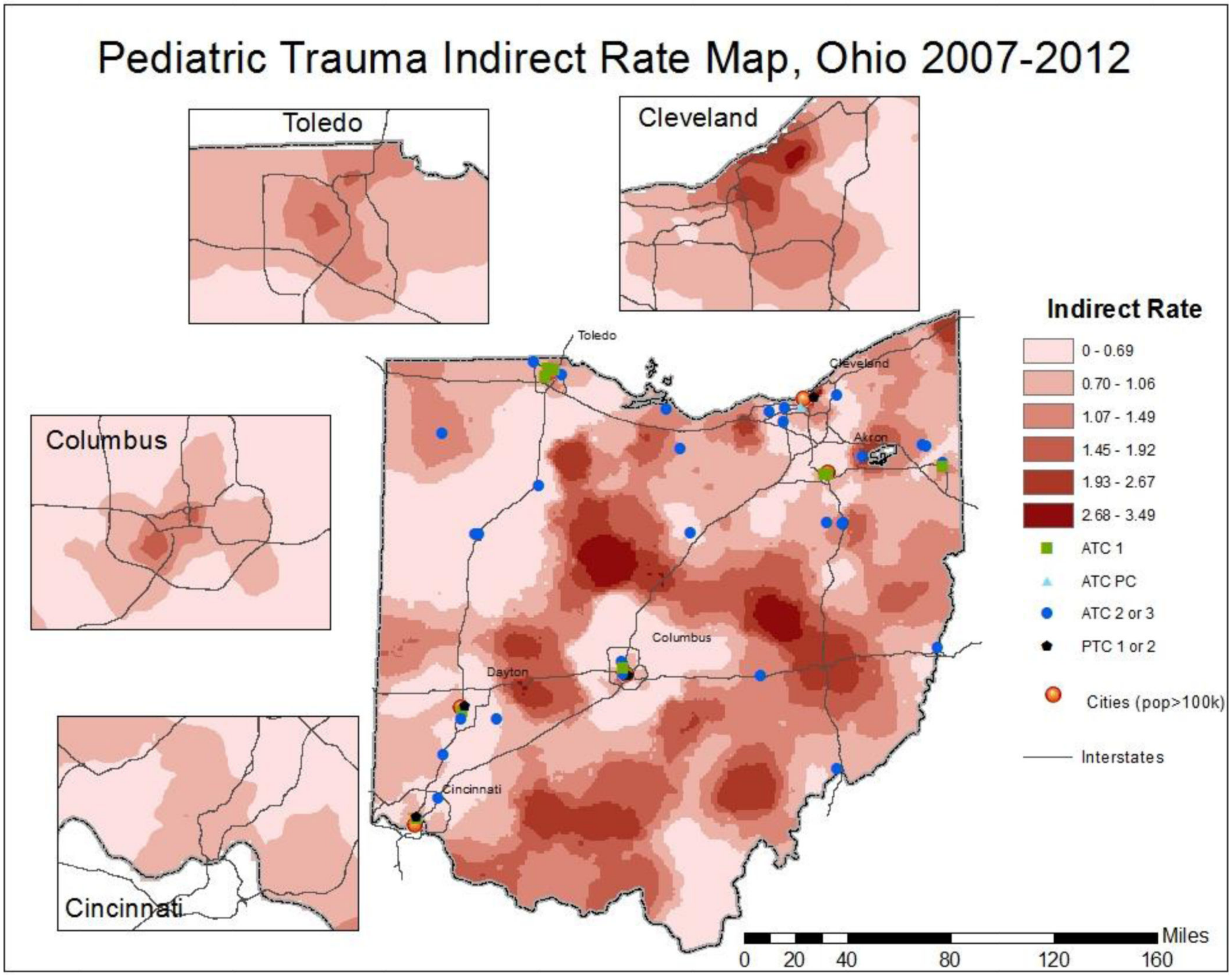

Figure 1.

Continuous spatial distribution of pediatric trauma indirect rate, Ohio

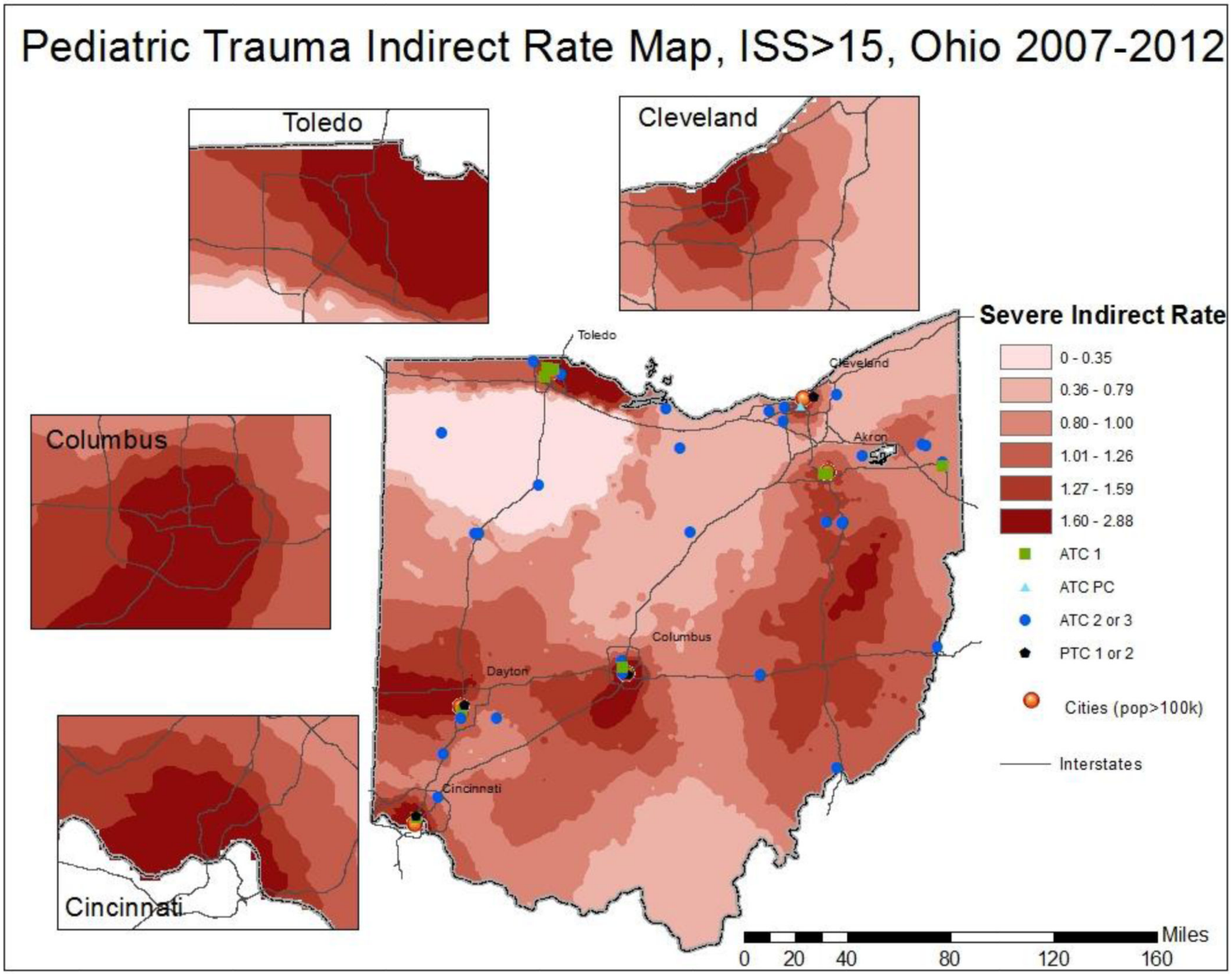

Figure 2.
Continuous spatial distribution of severe pediatric trauma indirect rate, Ohio

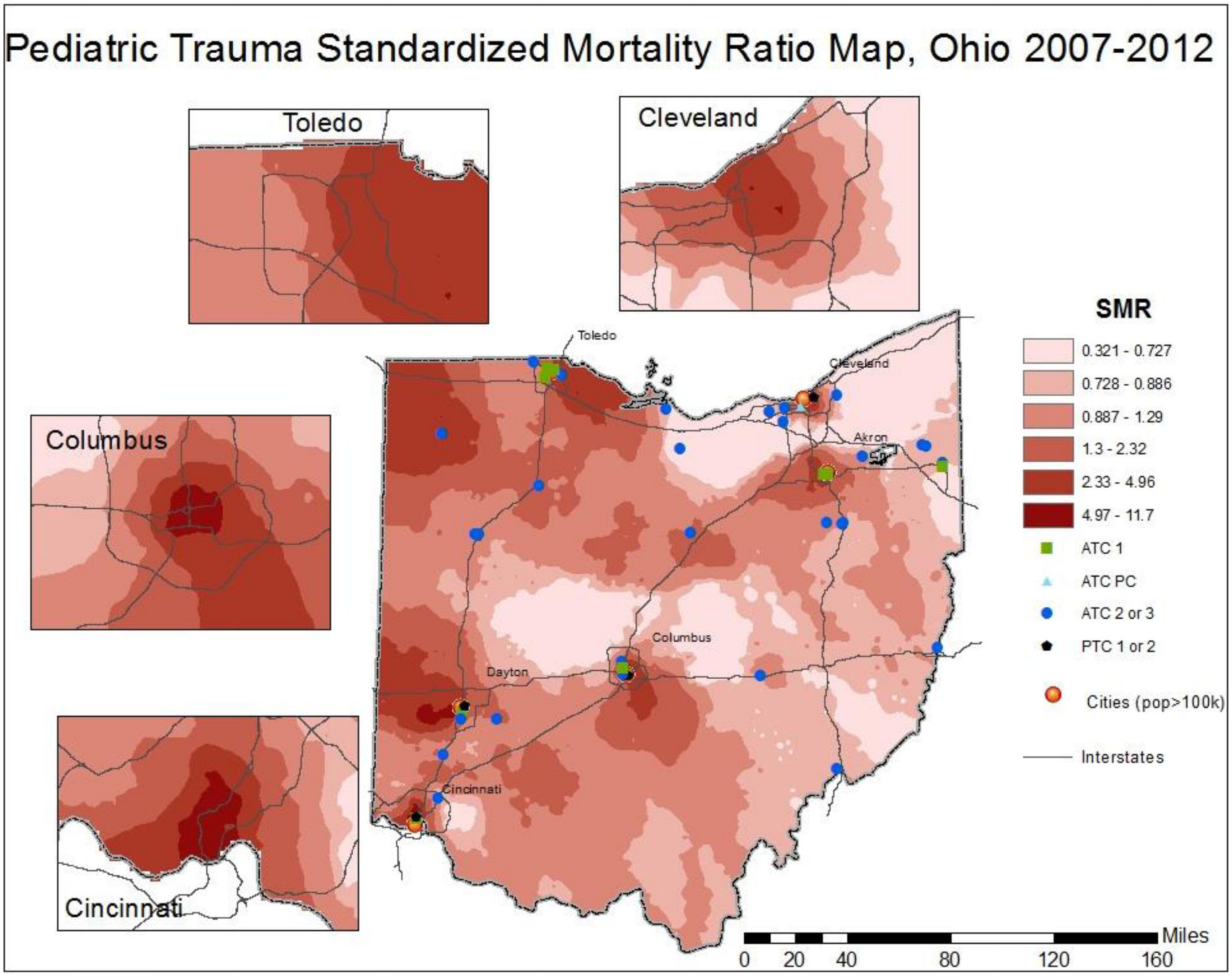

Figure 3.

Continuous spatial distribution of pediatric trauma SMR, Ohio