Distribution Agreement

In presenting this thesis or dissertation as a partial fulfillment of the requirements for an advanced degree from Emory University, I hereby grant to Emory University and its agents the non-exclusive license to archive, make accessible, and display my thesis or dissertation in whole or in part in all forms of media, now or hereafter known, including display on the world-wide web. I understand that I may select some access restrictions as part of the online submission of this thesis or dissertation. I retain all ownership rights to the copyright of the thesis or dissertation. I also retain the right to use in future works (such as articles or books) all or part of this thesis or dissertation.

Signature

_____ _____

Anna R. Wood Date

Spatiotemporal surveillance of pediatric community-onset MRSA infections in Metro Atlanta using electronic health record data

By

Anna R. Wood
Master of Public Health

Epidemiology

_____

Dr. Scott Fridkin, MD
Committee Chair

_____

Dr. Lilly Immergluck, MD
Committee Member

_____

Dr. Traci Leong, PhD
Committee Member

Spatiotemporal surveillance of pediatric community-onset MRSA infections in Metro Atlanta using electronic health record data

By

Anna R. Wood

B.S., Loyola University Chicago, 2017

Faculty Thesis Advisor: Dr. Scott Fridkin, MD

An abstract of
A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
Master of Public Health
in Epidemiology
2019

Abstract

Spatiotemporal surveillance of pediatric community-onset MRSA infections in Metro Atlanta using electronic health record data

By Anna R. Wood

While hospital-associated *Staphylococcus aureus* infections decreased in the United States in recent years, community-onset methicillin resistant *Staphylococcus aureus* (CO-MRSA) and community-onset methicillin sensitive *Staphylococcus aureus* (CO-MSSA) infection rates have been stagnant. CO-MRSA and CO-MSSA commonly affect children and are a massive economic burden. This study sought to understand how the epidemiology of these infections compared to one another across time and space in the Atlanta Metropolitan Statistical Area (MSA). We assessed socioeconomic risk factors for infection at the individual level using electronic health records (EHR) from two pediatric hospitals in the MSA from 2002 through 2010. We geocoded patients' addresses and linked each to a census tract. Infection counts were aggregated for each census tract in the MSA. Incidence ratios were calculated and mapped for each census tract. Population level data was also collected using the 2000 American Community Survey (ACS) (2002-2004) and the 2010 ACS (2005-2010). Census tract level socioeconomic risk factors were then identified. CO-MRSA incidence was highest in 2008 (63.17 infections per 100,000 children), while CO-MSSA incidence was highest in 2009 (51.62 infections per 100,000). Cumulatively, census tract incidence ratios ranged from 0 infections per 100,000 children to 6,250 infections per 100,000 over the nine-year study. Increased CO-MRSA incidence was associated with increased nursery school and preschool enrollment (IDR: 0.9993, 95% CI: 0.9989-0.9997, $p < 0.0001$) while increased CO-MSSA incidence was associated with increased nursery school and preschool enrollment as well as proportion of the population that was black (aIDR: 1.0008, 95% CI: 1.00-1.00, $p < 0.0001$). Statistically significant hot spots of CO-MRSA moved from the northeast region of the MSA toward the center in 2005 and remained centrally located for the remainder of the study. CO-MSSA statistically significant hot spots appeared more sporadic from year to year, but also became centrally located from 2008 through 2010. Further research is essential to identifying and implementing interventions in individual census tracts at highest risk for CO-MRSA and CO-MSSA. This study shows the importance of integrating population level demographics with EHR to inform diagnoses and treatments for CO-MRSA and CO-MSSA and decrease the burden of these infections in DeKalb and Fulton counties.

Spatiotemporal surveillance of pediatric community-onset MRSA infections in Metro Atlanta using electronic health record data

By

Anna R. Wood

B.S., Loyola University Chicago, 2017

Faculty Thesis Advisor: Dr. Scott Fridkin, MD

An abstract of
A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
in partial fulfillment of the requirements for the degree of
Master of Public Health
in Epidemiology
2019

Acknowledgments

I would like to extend my sincere gratitude to the three mentors of my thesis committee. Their unwavering dedication to students' success should not go unnoticed. Dr. Leong, I cannot thank you enough for your quick mentorship this past semester. Your commitment to academic leadership is particularly admirable. Dr. Immergluck, I wish to thank you your extremely comprehensive guidance and devotion to students like me. Your passion for pediatrics and teaching is evident and laudable. Dr. Fridkin, thank you for your willingness to help and your great guidance.

I would also like to wholeheartedly thank my family, friends, and colleagues, especially Mom and Dad, for their persistent moral support. Every milestone is quite literally thanks to you. Thank you for encouraging me to follow my dreams and for being there to see them come true.

Table of Contents

Background 1

Methods 3

Results 6

Discussion 10

Conclusion 13

References 14

Tables

Table 1. Data sources 17
Table 2. MRSA and MSSA Infections and Rates (2002-2010) 17
Table 3. Patient Level Characteristics 18
Table 4a. Census Tract Level Characteristics Medians – MRSA 19
Table 4b. Census Tract Level Characteristics – MRSA 20
Table 5. Patient Level Characteristics – MSSA 21
Table 6a. Census Tract Level Characteristics Medians – MSSA 22
Table 6b. Census Tract Level Characteristics – MSSA 23
Table 7. Census Tract Level Factors – MRSA 24
Table 8. Census Tract Level Factors – MSSA 24

Figures

Figure 1. Atlanta MSA 25
Figure 2. Study Enrollment Schema 26
Figure 3. CO-MRSA and CO-MSSA Incidence Rates 27
Figure 4. CO-MRSA and CO-MSSA Census Tract Transference 28
Figure 5. CO-MRSA and CO-MSSA Incidence Rates by Year and Census Tract 29

Appendix

Children's Healthcare of Atlanta Institutional Review Board Approval 30
Table 9. Patient Level Characteristics – MRSA v. MSSA (n = 10,642) 32
Figure 6. MRSA Infections Incidence Rates (2002-2010) 33
Figure 7. MSSA Infections Incidence Rates (2002-2010) 34
Figure 8. Cluster Maps for Pediatric MRSA Infections by Year 35
Figure 9. Cluster Maps for Pediatric MRSA Infections by Year 36

Background

Community-onset methicillin resistant *Staphylococcus aureus* (CO-MRSA) and community-onset methicillin sensitive *Staphylococcus aureus* (CO-MSSA) infection rates remain unchanged as rates of other types of *Staphylococcus aureus* infections have declined over the same time period (1, 2). More than 15,000 infections and more than 1,000 deaths associated with CO-MRSA occur annually (3). From 2002 to 2007, hospitalizations associated with CO-MRSA increased from 6.7 cases per 1,000 admissions to 21.2 cases per 1,000 admissions (4). These infections disproportionately affect children ages 5 to 10 years old and community-onset infections are the more common type of MRSA in children (5). The economic burden is also extensive. Direct costs for CO-MRSA total $478 million to $2.2 billion each year in the United States (6).

Further research is needed to better understand the socioeconomic risk factors associated with CO-MRSA and CO-MSSA infections. The inception and growing ubiquity of electronic health records (EHR) allow for implementation of their data in public health research. EHR commonly collect patients' residential addresses. This allows researchers to integrate patients' geocoded addresses with community-level demographics from sources such as the United States Census Bureau's American Community Survey (ACS). A community's socioecological characteristics can serve as a proxy to further understand patients' risks for CO-MRSA and CO-MSSA who reside within that community. Spatial analyses incorporating place-based social determinants of health can better characterize a community's risks for CO-MRSA and CO-MSSA, which might otherwise not be evident using data from EHR.

The use of EHR data can also be more informative than traditional data sources such as registries because information such as patient demographics, test results, diagnoses, and health insurance provider can be extracted from EHR (7). Utilizing EHR data alongside community-level data can potentially have useful implications in delivering more effective treatments if key environmental and social community-level predictors of CO-MRSA and CO-MSSA become included in making diagnoses (8).

In this study, the utilization of multi-year geocoded EHR data and place-specific sociodemographic data allows for the characterization of pediatric CO-MRSA and CO-MSSA burden in the Atlanta Metropolitan Statistical Area (MSA) over space and time (5). This method of enhanced geographic surveillance improves description of the spatial patterns and demographic features of CO-MRSA and CO-MSSA infections across time, which potentially allows for targeted community-level primary and secondary interventions to prevent disease transmission (5). This study assessed annual burden and risk factors for both CO-MRSA and CO-MSSA infections at the census tract level in the Atlanta MSA over the same nine-year timespan during the height of community-associated MRSA infections in the US. This is the first study of its kind to address how the epidemiology of CO-MRSA compares to CO-MSSA over time while also accounting for specific place-based social determinants of health.

Methods

All children admitted to two Children's Healthcare of Atlanta hospitals (Scottish Rite Children's Hospital or Egleston Children's Hospital) in the emergency department, through inpatient care, or a Children's Healthcare of Atlanta outpatient center (urgent care center) from 2002 to 2010 were included. The chosen hospitals serve over 80% of pediatric hospitalizations in the 20 counties that comprise the Atlanta MSA (5, Figure 1). Children with an International Classification of Diseases, Clinical Modification (ICD-9-CM) code for a staphylococcal infection, a positive *S. aureus* culture, and who lived within the 20-county MSA were included (5). Patients with addresses that could not be geocoded were excluded. Children were also excluded for having healthcare-onset MRSA and MSSA infections that were confirmed based on established risk factors for acquisition of infection in a healthcare setting (9). This study was approved by the institutional review board of the Children's Healthcare of Atlanta (Appendix).

Individual data on race, ethnicity, age, sex, type of health insurance, hospital of clinical presentation (Egleston Children's Hospital or Scottish Rite Children's Hospital), and type of infection (CO-MRSA or CO-MSSA) were retrieved from the EHR of the two pediatric hospitals (5, Table 1). Type of infection was dichotomized into CO-MRSA and CO-MSSA and defined as an infection which began 48 hours or less from the time of hospital admission (9). Population data on race, ethnicity, age, K-12 school enrollment, adult educational attainment, employment status (population 16 years old and over in the workforce), household income, household value, and household crowding were retrieved at the census tract level for the state of Georgia (Table 1). For infections occurring in 2002-2004, ACS population level data from 2000 was matched to individual patient EHR

information at the census tract level (10). For infections occurring in 2005-2010, ACS population level data from 2010 was matched to individual patient EHR information at the census tract level (11).

The unit of observation for data analysis was an individual child diagnosed with a *S. aureus* infection. Statistical analyses were performed using SAS 9.4 (SAS Institute, Cary, NC, USA). Case counts were aggregated by study year and by type of infection (MRSA or MSSA). Univariate analyses were then conducted by year and by type of infection at the individual patient level on race, ethnicity, age, sex, health insurance type, and hospital and at the area level, using census tract data, on race, ethnicity, age, K-12 school enrollment, adult educational attainment, employment status (population 16 years and over in the workforce), household income, household value, and household crowding. Chi-square tests and general linear models tested for statistical significance of categorical and continuous variables, respectively. A Wilcoxon Two-Sample Test assessed median single age years between CO-MRSA and CO-MSSA patients. Chi-square Goodness of Fit Tests calculated differences in categorical individual level data between CO-MRSA and CO-MSSA patients. Risk factors for CO-MRSA and CO-MSSA were also assessed at the census tract level, another unit of observation, by year (2002-2010). Crude and adjusted incidence density ratios were calculated using the Generalized Estimating Equations procedure to determine within year scores from aggregated infection counts in individual census tracts. Since aggregated counts of CO-MRSA and CO-MSSA infections per census tract were not normally distributed, negative binomial distribution was determined most appropriate to use.

Spatial analyses were performed using ArcGIS (ESRI, Redlands, CA, USA). Aggregated case counts and total number of children were used to calculate incidence rates per 100,000 children for each census tract included in the study. Total number of children living within each census tract was calculated by aggregating counts of children per single year of age and sex (males: less than 1 year old through 18 years old; females: less than 1 year old through 18 years old) (12, 13). Subsequently, these incidence rates were mapped at the census tract level for the Atlanta MSA. In cases occurring in 2002-2004, census tract boundaries from the 2000 United States Census were used (14). In cases occurring in the 2005-2010, census tract boundaries from the 2010 United States Census were used (14). For reference, county boundaries were incorporated into all of the maps to show the census tracts contained within each county (Figures 1, 5, Appendix). Infection clusters were also plotted at the census tract level within the Atlanta MSA using the ArcGIS Optimized Hot Spot Analysis spatial statistics tool. The Getis-Ord Gi* statistic was mapped at 99%, 95%, 90% confidence for hot spots and cold spots.

Results

Patient Level

After excluding children with healthcare-onset MRSA and MSSA and children with addresses that could not be geocoded, there were 10,642 children in the Atlanta MSA with CO-MRSA and CO-MSSA from 2002-2010 (Figure 2). Of those children, 50.5% had CO-MRSA and 49.5% had CO-MSSA (Figure 2). At the individual level, hospital, race, age, and health insurance all differed significantly between CO-MRSA compared to CO-MSSA over the 2002-2010 time period ($p < 0.0001$, Table 3).

Incidence rates of CO-MRSA and CO-MSSA varied. The lowest incidence rates per 100,000 children across the nine-year study were in 2002 when the incidence of CO-MRSA was 6.37 and CO-MSSA was 24.14 (Table 2). The highest incidence of CO-MRSA was 63.17 per 100,000 children in 2008, while the highest incidence of CO-MSSA was 51.96 per 100,000 children in 2009 (Table 2). By the end of 2010, the CO-MRSA incidence rate was still 7.8 times the 2002 rate and the CO-MSSA rate of infection was nearly double the 2002 rate.

Overall, race, sex, age, and health insurance were significantly different between CO-MRSA and CO-MSSA (Table 9). However, some heterogeneities existed year to year for sex and age. For example, there was no difference in the sex as well as age of CO-MRSA and CO-MSSA patients in 2002. Additionally, there was not a significant difference in CO-MRSA and CO-MSSA patient's ages in 2003. Specific hospital of clinical presentation was also not statistically different between CO-MRSA and CO-MSSA overall, but it was year to year.

Census Tract Level

At the population level, the percentage of census tracts with at least one case varied between CO-MRSA and CO-MSSA. At the beginning of the study in 2002, only about 10% of existing census tracts (2002-2004: $n_{MSA} = 706$, $n_{Georgia} = 1,618$) contained at least one case of CO-MRSA, while 35% contained at least one case of CO-MSSA (Figure 4). By 2005, both CO-MRSA and CO-MSSA existed in 40% of MSA census tracts. From 2005 through 2010, the percentage of census tracts (2005-2010: $n_{MSA} = 967$, $n_{Georgia} = 1,967$) with CO-MRSA infections surpassed that of CO-MSSA infections. By 2010, CO-MRSA existed in nearly 5% more census tracts than CO-MSSA (Figure 4).

Selected census tract level characteristics varied by time period (2002-2004, 2005-2010) and by CO-MRSA and CO-MSSA. Between 2002-2004 and 2005-2010, census tracts with at least one CO-MRSA infection observed a decrease in the percentage of black population (-5.36%) and adult educational attainment (-30.80%) and an increase in the percentage of white population (+3.05%) as well as percentage of the population under 18 years old (+7.82%). Between 2002-2004 and 2005-2010, census tracts with at least one CO-MSSA observed a decrease in percentage of white population (-3.55%) and adult educational attainment (-31.59%) and an increase in percentage of black population (+6.65%) and percentage of the population under 18 years old (+7.38%).

Risk Factors

The incidence rates of CO-MRSA and CO-MSSA changed annually from 2002 through 2010 in Atlanta MSA census tracts (Figure 5). Risk factors for CO-MRSA and CO-MSSA varied. The percentage of nursery school and preschool enrollment in a census tract was associated with CO-MRSA incidence rates ($p < 0.0001$). For every one

percent increase in nursery school and preschool enrollment, CO-MRSA incidence rates increased by 1% (Table 7). CO-MSSA infections were also most associated with the percentage of nursery school and preschool enrollment as well as percentage of the population that was black. The incidence rate of CO-MSSA increased by 1% as the percentage of nursery school and preschool enrollment increased by 1% (Table 8). The percentage of the population that was black had the same effect on CO-MSSA incidence rates (Table 8).

Spatial Analyses

Changes in case clusters for CO-MRSA from 2002 through 2010 showed that statistically significant hot spots shifted gradually from the counties in the northeast region of the MSA inward toward Fulton, DeKalb, and Cobb counties (Figure 8). In 2002, there were not any statistically significant hot spots. In 2003 and 2004, hot spots were located in most of the census tracts in Forsyth and Barrow counties as well as half of the Gwinnett county census tracts. In 2005, a shift in hot spots occurred and remained intact for the duration of the study. Nearly all of the statistically significant hot spots were now in DeKalb and Fulton counties and parts of Cobb, Gwinnett, Clayton, and Henry counties.

CO-MSSA clusters followed a similar pattern but not until 2008 (Figure 9). In 2002, Pickens, Bartow, Forsyth, and part of Cherokee and Fulton counties contained a majority of the statistically significant hot spots. From 2003 through 2005, nearly all of the statistically significant hot spots were in Barrow County. By 2006, part of Forsyth, Gwinnett, Fulton, DeKalb, and Cobb counties contained hot spots. Only Barrow County, Gwinnett County, and part of Barrow County had hot spots. In 2008, hot spots consumed

DeKalb, Forsyth, Gwinnett, and Cobb counties and most of Bartow County. Spatial patterns were similar in 2009 and 2010. Fulton, Gwinnett, Cobb, Forsyth, and Clayton counties contained most of the statistically significant hot spots.

Discussion

Place- and time-specific staphylococcal disease burden and the associated risk factors were identified, using spatial statistical information obtained from ACS and hospital EHR. This potentially shows spatially where a primary intervention might best provide guidance in appropriate measures to reduce incidence of this community-based pediatric infectious disease. During the study period, populations affected by CO-MRSA and CO-MSSA shifted at both the patient and census tract level. Statistically significant hot spots became more centrally located in the MSA by the end of the study. By 2010, both affected census tracts with younger, less educated populations.

Only percentage of nursery school and preschool enrollment was significantly associated with CO-MRSA incidence. The proportion of population that was black as well as the percentage of nursery school and preschool enrollment was associated with CO-MSSA incidence in the MSA. These findings could guide the development of primary and secondary interventions for both CO-MRSA and CO-MSSA. Spatiotemporal patterns differed by infection type. CO-MRSA was influenced most by black race, age, and income, while CO-MSSA was most influenced by white race, Hispanic ethnicity, age, and income. Traditionally, risk factors are identified using individual level data (15). However, census tract level estimates were desired in order to determine any population level patterns in these infections.

One limitation of the study is current generalizability. Although this study contains nearly complete EHR and socioecological data for nine years (2002-2010), it may not be completely applicable to the current Atlanta MSA population. Atlanta is a growing population with a changing socio-demographic profile (16). The epidemiology

of CO-MRSA and CO-MSSA are changing too based on this study. Developing primary and secondary interventions from these findings may not be the most efficacious as the wrong populations may be targeted. Another limitation is the compatibility of ACS 2000 and ACS 2010. A majority of variables remained unchanged in the survey from 2000 to 2010. However, there were some changes to the ACS questionnaire and response options for variables collected in this study (17). Data collection also became more granular in ACS 2010 for some variables such as educational enrollment and household crowding (17). These changes made comparisons between 2000 and 2010 could have introduced error due to unreliable exchangeability (17). An additional limitation of this study is ability to account for spatial changes. Census tract boundaries shifted and new census tracts were created from 2000 (2002-2004) to 2010 (2005-2010) as the Atlanta MSA population grew overall (18). The same census tract could not be reliably compared in 2000 and 2010 because the boundaries may have shifted. Thus, these changes could not be accounted for during analyses.

This study had many strengths. The EHR data contained nearly complete (85%) demographical and clinical information important to the study. Additionally, data was extracted from the EHR of two hospitals within Children's Healthcare of Atlanta. Similar protocols for electronic data entry within Children's Healthcare of Atlanta limited systematic error in the study. Another strength was the selection of hospitals. Since 80% of all MSA pediatric hospitalizations are in these two hospitals, the findings of this study to provide generalizable to the Atlanta MSA catchment area for this time period. An additional strength was the utilization of data from the ACS because the United States Census Bureau's data collection methodology is highly standardized (19).

Future research includes integrating MRSA and MSSA strain data and accessing additional multi-year data after 2010 to continue surveying CO-MRSA and CO-MSSA in the changing Atlanta MSA over a longer period of time. Additionally, interventions should consider the change in incidence rates. These analyses should focus on specific census tracts with consistently high incidence rates over time. at the individual census tract. Developing appropriate community-targeted primary and secondary interventions based on these findings and evaluating the effectiveness over time could reduce the burden of CO-MRSA and CO-MSSA in Atlanta MSA communities.

Conclusion

The utilization of multi-year EHR data from pediatric patients with CO-MRSA and CO-MSSA alongside census tract level data allowed for identification of place-based determinants of health over time. It also supports the relevance of community level-specific interventions in the Atlanta MSA. Additionally, it shows the robustness and importance of using EHR data and population level data in research-based decision-making generally.

References

1. Centers for Disease Control and Prevention. Data Summary of HAIs in the US: Assessing Progress 2006-2016. https://www.cdc.gov/hai/data/archive/data-summary-assessing-progress.html. Published December 5, 2017. Updated September 24, 2018. Accessed April 15, 2019.
2. Centers for Disease Control and Prevention. Morbidity and Mortality Weekly Report (MMWR). "Vital Signs: Epidemiology and Recent Trends in Methicillin-Resistant and in Methicillin-Susceptible Staphylococcus aureus Bloodstream Infections – United States. https://www.cdc.gov/mmwr/volumes/68/wr/mm6809e1.htm. Published March 8, 2019. Accessed April 15, 2019.
3. See I, Wesson P, Gualandi N, Dumyati G, Harrison LH, Lesher L, Nadle J, Petit S, Reisenauer C, Schaffner W, Tunali A, Mu Y, Ahern J, Socioeconomic Factors Explain Racial Disparities in Invasive Community-Associated Methicillin-Resistant *Staphylococcus aureus* Disease Rates, *Clin Infect Dis*. 2017;64(5):597–604.
4. Sandora T. Prevention of healthcare associated infections in children: new strategies and success stories. *Curr Opin Infect Dis*. 2010;23:300-5.
5. Immergluck LC, Leong T, Matthews K, Malhotra K, Parker TC, Ali F, Jerris RC, Rust GS. Geographic surveillance of community associated MRSA infections in children using electronic health record data. BMC Infect Dis. 2019;19:170.
6. Lee BY, Singh A, David MZ, et al. The economic burden of community-associated methicillin-resistant Staphylococcus aureus (CA-MRSA). *Clin Microbiol Infect*. 2012;19(6):528–536.

7. Birkhead GS, Klompas M, Shah NR. Uses of electronic health records for public health surveillance to advance public health. *Annu Rev Public Health*. 2015;36:345-59.
8. Casey JA, Schwartz BS, Stewart WF, Adler, NE. Using Electronic Health Records for Population Health Research: A Review of Methods and Applications. Annual Review of Public Health 2016 37:1,61-81.
9. Naimi TS, LeDell KH, Como-Sabetti K, et al. Comparison of Community- and Health Care–Associated Methicillin-Resistant *Staphylococcus aureus* Infection. *JAMA.* 2003;290(22):2976–2984.
10. United States Census Bureau. Census 2000 Gateway. https://www.census.gov/main/www/cen2000.html. Accessed March 19, 2019.
11. United States Census Bureau. Decennial Census of Population and Housing. https://www.census.gov/programs-surveys/decennial-census/data/datasets.2010.html. Accessed March 19, 2019.
12. United States Census Bureau. Single Years of Age and Sex: 2000. https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=bkmk. Accessed March 24, 2019.
13. United States Census Bureau. Single Years of Age and Sex: 2010. https://www.census.gov/programs-surveys/decennial-census/data/datasets.2010.html. Accessed March 24, 2019.
14. United States Census Bureau. 2010 TIGER/Line® Shapefiles: Census Tracts. https://www.census.gov/cgi-

bin/geo/shapefiles/index.php?year=2010&layergroup=Census+Tracts. Accessed March 20, 2019.

15. Perez, G, Martiren, S, et al. Community-acquired Staphylococcus aureus bacteremia in children: a cohort study for 2010-2014. *Arch Argen Pediatr*. 2016; 114(6):508-513.
16. Pandley L, Sjoquist D. Changing Face of Atlanta Maps (1970-2015: Age, Race/Ethnicity, Income, Poverty and Education). The Center for State and Local Finance, Andrew Young School, Georgia State University. April 10, 2017. https://cslf.gsu.edu/changing-face-atlanta/#1522901338677-2c1db827-6a5c.
17. United States Census Bureau. American Community Survey (ACS): Comparing ACS Data. https://www.census.gov/programs-surveys/acs/guidance/comparing-acs-data.html. Accessed April 9, 2019.
18. United States Census Bureau. Geographies: Relationship Files. https://www.census.gov/geographies/reference-files/time-series/geo/relationship-files.html. Accessed April 2, 2019.
19. United States Census Bureau. American Community Survey (ACS): Methodology. https://www.census.gov/programs-surveys/acs/methodology.html. Accessed April 13, 2019.

Tables

Table 1. Data sources				
Data type	**Source**	**Years applied to study**	**Variables collected**	
Individual Level	Hospital electronic health records from 2002-2004	2002-2004	Race/ethnicity	Health insurance
	Hospital electronic health records from 2005-2010	2005-2010	Age	Hospital
			Sex	Type of infection
Population Level	American Community Survey 2000	2002-2004	Race/ethnicity	Employment status
	American Community Survey 2010	2005-2010	Age	Household income
			K-12 school enrollment	Household value
			Adult educational attainment	Household crowding

Table 2. MRSA and MSSA Infections and Rates (2002-2010)				
	MRSA		**MSSA**	
Year	**No. of Infections (n = 5,379)**	**Rate per 100,000**	**No. of Infections (n = 5,263)**	**Rate per 100,000**
2002	76	6.37	288	24.14
2003	171	14.33	526	44.09
2004	341	28.58	468	39.23
2005	564	39.02	531	36.74
2006	767	53.07	672	46.50
2007	847	58.61	598	41.38
2008	913	63.17	746	51.62
2009	890	61.58	751	51.96
2010	810	56.05	683	47.26

Table 3. Patient Level Characteristics – MRSA (n = 5,379)										
Variable	**Overall**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Hospital, n (%)**										
Egleston	2331 (43.34)	23 (30.26)	55 (32.16)	93 (27.27)	213 (37.77)	299 (38.98)	390 (46.04)	451 (49.40)	408 (45.79)	399 (49.32)
Scottish Rite	3048 (56.66)	53 (69.74)	116 (67.84)	248 (72.73)	351 (62.23)	468 (61.02)	457 (53.96)	462 (50.60)	483 (54.21)	410 (50.68)
Race/ethnicity, n (%)**										
White	2502 (46.82)	47 (62.67)	105 (62.87)	195 (58.21)	272 (49.45)	354 (46.70)	371 (43.85)	402 (44.08)	398 (44.67)	357 (44.18)
Black	2224 (41.63)	25 (33.33)	52 (31.14)	109 (32.54)	217 (39.45)	320 (42.22)	391 (46.22)	393 (43.09)	371 (41.64)	346 (42.82)
Other	377 (7.06)	3 (4.00)	10 (5.99)	31 (9.25)	61 (11.09)	84 (11.08)	40 (4.73)	47 (5.15)	51 (5.72)	50 (6.19)
Unknown	28 (0.52)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	4 (0.47)	9 (0.99)	7 (0.79)	8 (0.99)
Hispanic	212 (3.97)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	40 (4.73)	61 (6.69)	64 (7.18)	47 (5.82)
Sex, n (%)										
Female	2731 (50.77)	35 (46.05)	82 (47.95)	175 (51.32)	278 (49.29)	381 (49.67)	419 (49.47)	462 (50.60)	481 (53.98)	418 (51.67)
Male	2648 (49.23)	41 (53.95)	89 (52.05)	166 (48.68)	286 (50.71)	386 (50.33)	428 (50.53)	451 (49.40)	410 (46.02)	391 (48.33)
Age group, n (%)**										
0-4 years	3110 (57.82)	25 (32.89)	83 (48.54)	183 (53.67)	273 (48.40)	430 (56.06)	499 (58.91)	574 (62.87)	566 (63.52)	477 (58.96)
5-14 years	1703 (31.66)	37 (48.68)	64 (37.43)	115 (33.72)	213 (37.77)	259 (33.77)	250 (29.52)	256 (28.04)	251 (28.17)	258 (31.89)
15-18 years	566 (10.52)	14 (18.42)	24 (14.04)	43 (12.61)	78 (13.83)	78 (10.17)	98 (11.57)	83 (9.09)	74 (8.31)	74 (9.15)
Age, mean (SD)**	5.47 (5.54)	8.46 (5.65)	6.85 (5.74)	6.17 (5.65)	6.52 (5.83)	5.57 (5.50)	5.42 (5.65)	4.78 (5.28)	4.87 (5.31)	5.27 (5.41)
Health Insurance, n (%)**										
Multiple types	10 (0.19)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	2 (0.22)	8 (0.99)
Private	2101 (36.06)	43 (56.58)	90 (52.63)	152 (44.57)	213 (37.77)	284 (37.03)	330 (38.96)	354 (38.77)	340 (38.16)	295 (36.46)
Public	3002 (55.81)	31 (40.79)	77 (45.03)	177 (51.91)	331 (58.69)	431 (56.19)	462 (54.55)	498 (54.55)	506 (56.79)	489 (60.44)
Self-Pay	266 (4.95)	2 (2.63)	4 (2.34)	12 (3.52)	20 (3.55)	52 (6.78)	55 (6.49)	61 (6.68)	43 (4.83)	17 (2.10)

* denotes a p-value < 0.05

** denotes a p-value < 0.001

Table 4a. Census Tract Level Characteristics Medians – MRSA		
Variable	**2002-2004**	**2005-2010**
Black population	16.20	28.42
White population	72.30	55.11
Hispanic population	2.90	5.23
Under 18 years old	27.70	30.20
Employment status	69.35	70.40
Poverty	8.30	9.80
Education		
Less than high school	10.68	8.20
Bachelor's degree	15.50	17.20
Household crowding		
1.01 – 1.50 occupants per room	96.40	1.48
Greater than 1.50 occupants per room	2.20	0.96*

*Denotes 1.50-2.00 occupants per room

Table 4b. Census Tract Level Characteristics – MRSA		
Variable	**2002-2004**	**2005-2010**
Black population, n (%)		
< Median	288 (48.98)	2,395 (49.99)
≥ Median	300 (51.02)	2,396 (50.01)
White population, n (%)		
< Median	***364 (61.90)***	***2,703 (56.42)***
≥ Median	***244 (38.10)***	***2,088 (43.58)***
Hispanic population, n (%)		
< Median	287 (48.81)	2,390 (49.89)
≥ Median	301 (51.19)	2,401 (50.11)
Under 18 years old, n (%)		
< Median	288 (48.98)	2,365 (49.36)
≥ Median	300 (51.02)	2,426 (50.64)
K-12 school enrollment, mean (SD)		
Nursery school, preschool	8.00 (3.17)	7.00 (4.03)
Kindergarten	5.70 (2.41)	5.34 (3.29)
Grades 1-8	47.55 (7.90)	43.49 (9.82)
Grades 9-12	21.70 (4.96)	21.23 (7.73)
Adult educational attainment, n (%)		
Less than high school: < Median	294 (50.00)	2,381 (49.70)
≥ Median	294 (50.00)	2,410 (50.30)
Bachelor's degree: < Median	294 (50.00)	2,376 (49.59)
≥ Median	294 (50.00)	2,415 (50.41)
Employment status, n (%)		
< Median	294 (50.00)	2,373 (49.53)
≥ Median	294 (50.00)	2,418 (50.47)
Poverty, n (%)		
< Median	293 (49.83)	2,386 (49.80)
≥ Median	295 (50.17)	2,405 (50.20)
Household crowding, n (%)		
1.01-1.50 occupants/room < Median	293 (49.83)	***3,593 (74.99)***
≥ Median	295 (50.17)	***1,198 (25.01)***
Greater than 1.50 occupants per room < Median	291 (49.49)	***4,551 (94.99)***
≥ Median	297 (50.51)	***240 (5.01)***

*Denotes 1.50-2.00 occupants per room

Denotes a p-value < 0.05

Denotes a p-value < 0.001

Table 5. Patient Level Characteristics – MSSA (n = 5,263)										
Variable	**Overall**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Hospital, n (%)**										
Egleston	2206 (41.92)	136 (47.22)	224 (42.59)	185 (39.53)	208 (39.17)	254 (37.80)	244 (40.80)	305 (40.88)	322 (42.88)	328 (48.02)
Scottish Rite	3057 (58.08)	152 (52.78)	302 (57.41)	283 (60.47)	323 (60.83)	418 (62.20)	354 (59.20)	441 (59.12)	429 (57.12)	355 (51.98)
Race/ethnicity, n (%)**										
White	3148 (60.38)	198 (69.72)	381 (73.84)	315 (68.63)	339 (65.07)	390 (59.27)	337 (56.35)	414 (55.50)	412 (54.93)	362 (53.08)
Black	1329 (25.49)	57 (20.07)	85 (16.47)	99 (21.57)	112 (21.50)	162 (24.62)	168 (28.09)	210 (28.15)	227 (30.27)	209 (30.65)
Hispanic	215 (4.12)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	49 (8.19)	63 (8.45)	58 (7.73)	45 (6.60)
Other	480 (9.21)	29 (10.21)	50 (9.69)	45 (9.80)	70 (13.44)	106 (16.11)	37 (6.19)	52 (6.97)	41 (5.47)	50 (7.33)
Unknown	42 (0.81)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	7 (1.17)	7 (0.94)	12 (1.6)	16 (2.35)
Hispanic	215 (4.12)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	49 (8.19)	63 (8.45)	58 (7.73)	45 (6.60)
Sex, n (%)*										
Female	2371 (45.05)	113 (39.24)	215 (40.87)	204 (43.59)	241 (45.39)	283 (42.11)	269 (44.98)	350 (46.92)	360 (47.94)	336 (49.19)
Male	2892 (54.95)	175 (60.76)	311 (59.13)	264 (56.41)	290 (54.61)	389 (57.89)	329 (55.02)	396 (53.08)	391 (52.06)	347 (50.81)
Age group, n (%)**										
0-4 years	2155 (40.95)	98 (34.03)	196 (37.26)	162 (34.62)	172 (32.39)	267 (39.73)	255 (42.64)	341 (45.71)	355 (47.27)	309 (45.24)
5-14 years	2417 (45.92)	153 (53.13)	261 (49.62)	235 (50.21)	281 (52.92)	306 (45.54)	269 (44.98)	321 (43.03)	309 (41.15)	282 (41.29)
15-18 years	691 (13.13)	37 (12.85)	69 (13.12)	71 (15.17)	78 (14.69)	99 (14.73)	74 (12.37)	811.26)	87 (11.58)	92 (13.47)
Age, mean (SD)**	6.98 (5.64)	7.59 (5.48)	7.28 (5.53)	7.65 (5.58)	7.75 (5.50)	7.13 (5.61)	6.69 (5.70)	6.52 (5.75)	6.43 (5.59)	6.68 (5.72)
Health Insurance, n (%)**										
Multiple types	10 (0.19)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	3 (0.40)	7 (1.02)
Private	2775 (52.73)	190 (65.97)	338 (64.26)	291 (62.18)	286 (53.86)	350 (52.08)	302 (50.50)	375 (50.27)	338 (45.01)	305 (44.66)
Public	2280 (43.32)	96 (33.33)	180 (34.22)	158 (33.76)	224 (42.18)	289 (43.01)	253 (42.31)	342 (45.84)	371 (49.40)	367 (53.73)
Self-Pay	196 (3.72)	2 (0.69)	8 (1.52)	19 (4.06)	21 (3.95)	33 (4.91)	43 (7.19)	29 (3.89)	37 (4.93)	4 (0.59)
Unknown	2 (0.04)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	2 (0.27)	0 (0.00)

* denotes a p-value < 0.05

** denotes a p-value < 0.001

Table 6a. Census Tract Level Characteristics Medians – MSSA		
Variable	**2002-2004**	**2005-2010**
Black population	12.20	18.63
White population	80.00	66.85
Hispanic population	3.00	5.28
Under 18 years old	27.35	30.10
Employment status	70.80	70.20
Poverty	7.10	8.40
Education		
Less than high school	10.58	7.20
Bachelor's degree	17.72	18.60
Household crowding		
1.01 – 1.50 occupants per room	96.80	1.48
Greater than 1.50 occupants per room	2.00	1.06*

*Denotes 1.50-2.00 occupants per room

Table 6b. Census Tract Level Characteristics – MSSA		
Variable	**2002-2004**	**2005-2010**
Black population, n (%)		
< Median	636 (49.61)	1,991 (50.01)
≥ Median	646 (50.39)	1,990 (49.99)
White population, n (%)		
< Median	631 (49.22)	***2,252 (56.57)***
≥ Median	651 (50.78)	***1,729 (43.43)***
Hispanic population, n (%)		
< Median	621 (48.44)	1,999 (50.21)
≥ Median	661 (51.56)	1,982 (49.79)
Under 18 years old, n (%)		
< Median	641 (50.00)	1,967 (49.41)
≥ Median	641 (50.00)	2,014 (50.59)
K-12 school enrollment, mean (SD)		
Nursery school, preschool	7.80 (2.85)	7.17 (4.30)
Kindergarten	6.00 (2.17)	5.44 (3.27)
Grades 1-8	48.10 (7.98)	43.59 (10.45)
Grades 9-12	21.00 (4.65)	21.23 (7.64)
Adult educational attainment, n (%)		
Less than high school: < Median	647 (50.47)	1,979 (49.71)
≥ Median	635 (49.53)	2,002 (50.29)
Bachelor's degree: < Median	**584 (45.55)**	1,975 (49.61)
≥ Median	**698 (54.45)**	2,006 (50.39)
Employment status, n (%)		
< Median	**577 (45.01)**	1,989 (49.96)
≥ Median	**705 (54.99)**	1,992 (50.04)
Poverty, n (%)		
< Median	***557 (43.45)***	1,980 (49.74)
≥ Median	***725 (56.55)***	2,001 (50.26)
Household crowding, n (%)		
1.01-1.50 occupants/room < Median	**575 (44.85)**	***3,033 (76.19)***
≥ Median	**707 (55.15)**	***948 (23.81)***
Greater than 1.50 occupants per room < Median	668 (52.11)	***3,881 (97.49)***
≥ Median	614 (47.89)	***100 (2.51)***

*Denotes 1.50-2.00 occupants per room

Denotes a p-value < 0.05

Denotes a p-value < 0.001

Table 7. Census Tract Level Factors – MRSA				
Variable	**Crude IDR (95% CI)**	**p-value**	**Adjusted IDR (95% CI)**	**p-value**
K-12 school enrollment				
% Nursery school, preschool	1.00 (1.00, 1.00)	0.0001	-	-

Table 8. Census Tract Level Factors – MSSA				
Variable	**Crude IDR (95% CI)**	**p-value**	**Adjusted IDR (95% CI)**	**p-value**
Race/ethnicity				
% Black	1.00 (1.00, 1.01)	0.005	1.00 (1.00, 1.00)	0.2911
K-12 school enrollment				
% Nursery school, preschool	1.00 (1.00, 1.01)	0.0368	1.00 (1.00, 1.00)	<0.0001

Figures

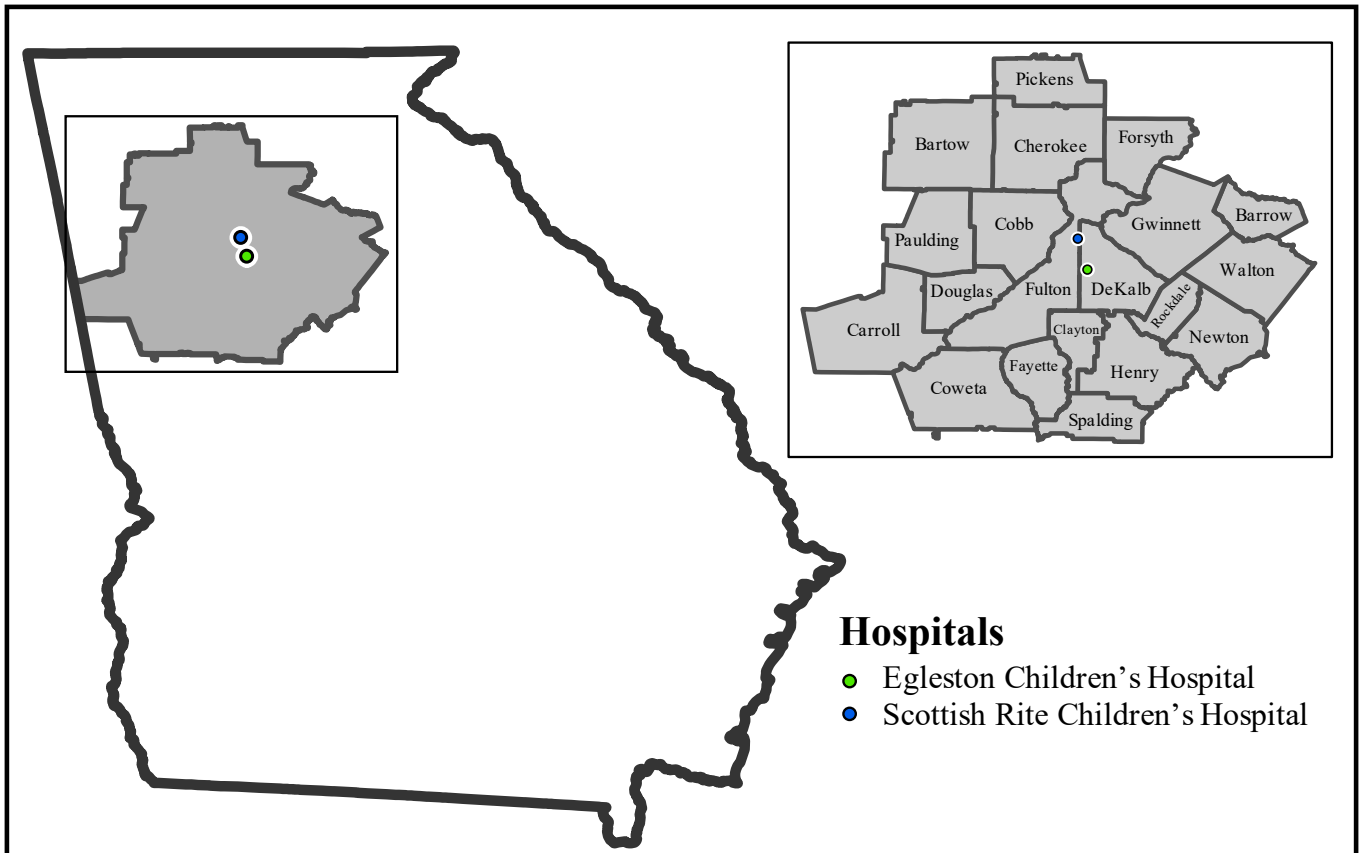


Figure 1 – Atlanta MSA. The Atlanta Metropolitan Statistical Area (MSA) contains 20 counties in northwest Georgia. Egleston Children's Hospital and Scottish Rite Children's Hospital hospitalizations comprise 80% of pediatric hospitalizations in the Atlanta MSA.

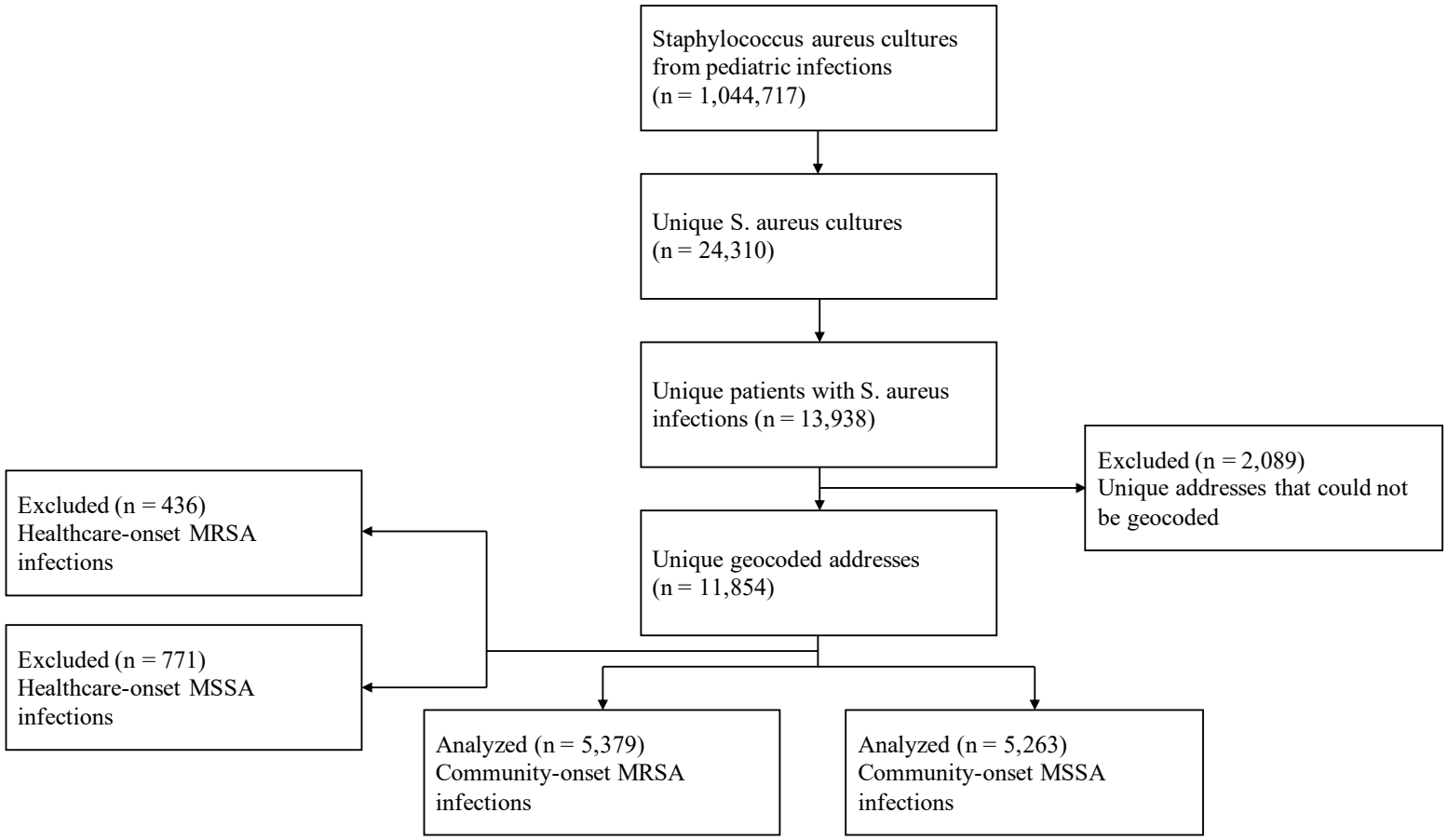


Figure 2 – Study Enrollment Schema. Adapted from Figure 1 of Immergluck et al. (2019).

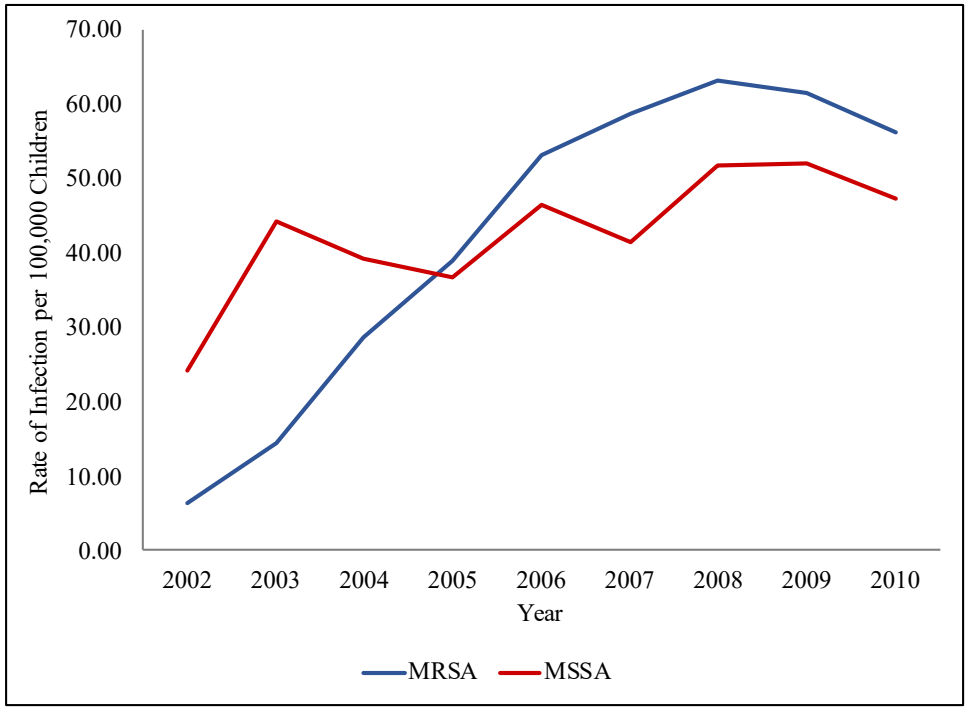


Figure 3 – CO-MRSA and CO-MSSA Incidence Rates. MRSA and MSSA pediatric rates of infections increased as much as 892% and 115%, respectively. In 2010, the MRSA rate of infection was still 7.8 times the 2002 rate and the MSSA rate of infection was nearly double the 2002 rate.

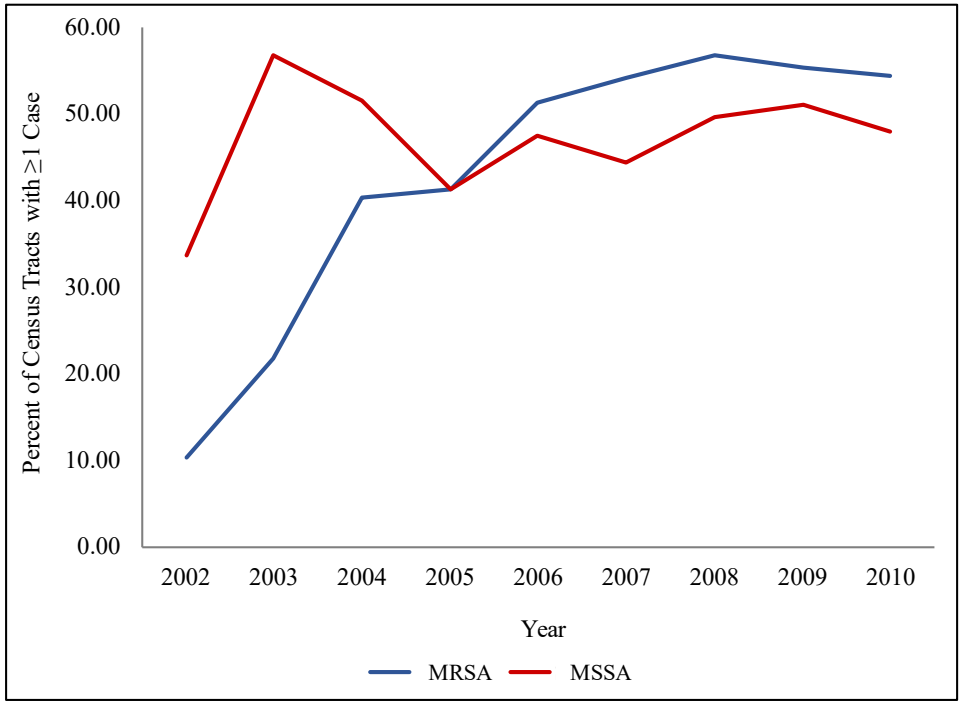


Figure 4 – CO-MRSA and CO-MSSA Census Tract Transference. The percentage of census tracts with at least one case per year differed by type of infection.

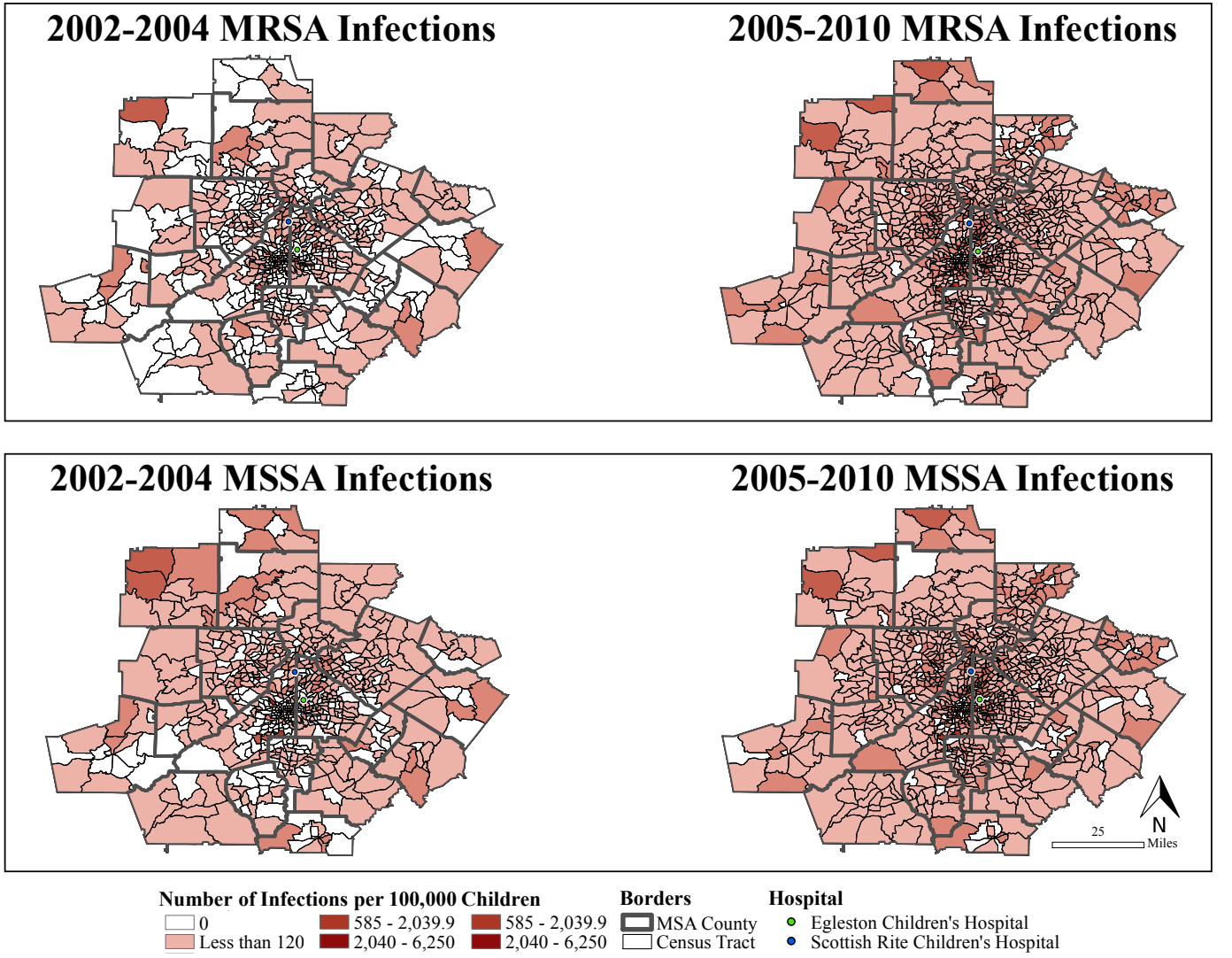
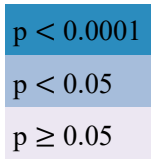


Figure 5 – CO-MRSA and CO-MSSA Incidence Rates by Year and Census Tract. Annual pediatric MRSA and MSSA infection rates differed throughout the Atlanta MSA at the census tract level. Some had as little as 0 infections per 100,000 children while others had as many as 6,250 infections per 100,000 children.

Appendix

Table 9. Patient Level Characteristics – MRSA v. MSSA (n = 10,642)										
Variable	**Overall**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Hospital										
Race/ethnicity										
Sex										
Age group										
Age										
Health insurance										



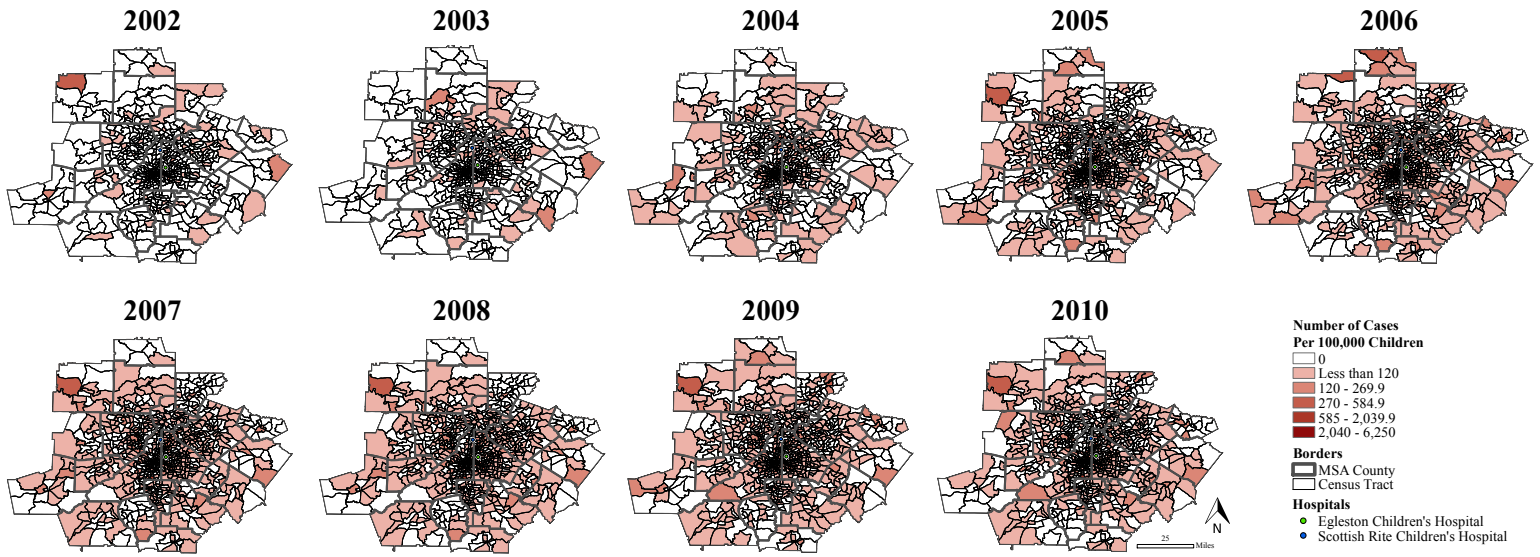


Figure 6. Incidence rates for pediatric MRSA infections by year from 2002 through 2010.

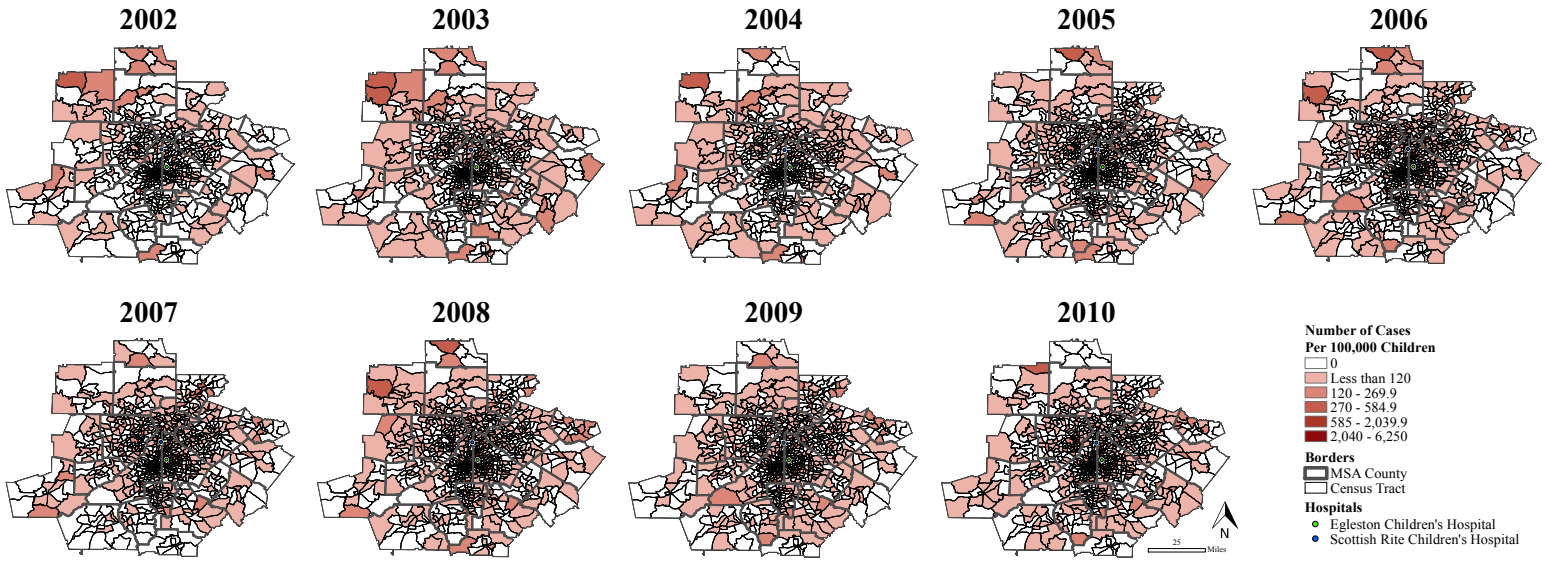


Figure 7. Incidence rates for pediatric MSSA infections by year from 2002 through 2010.

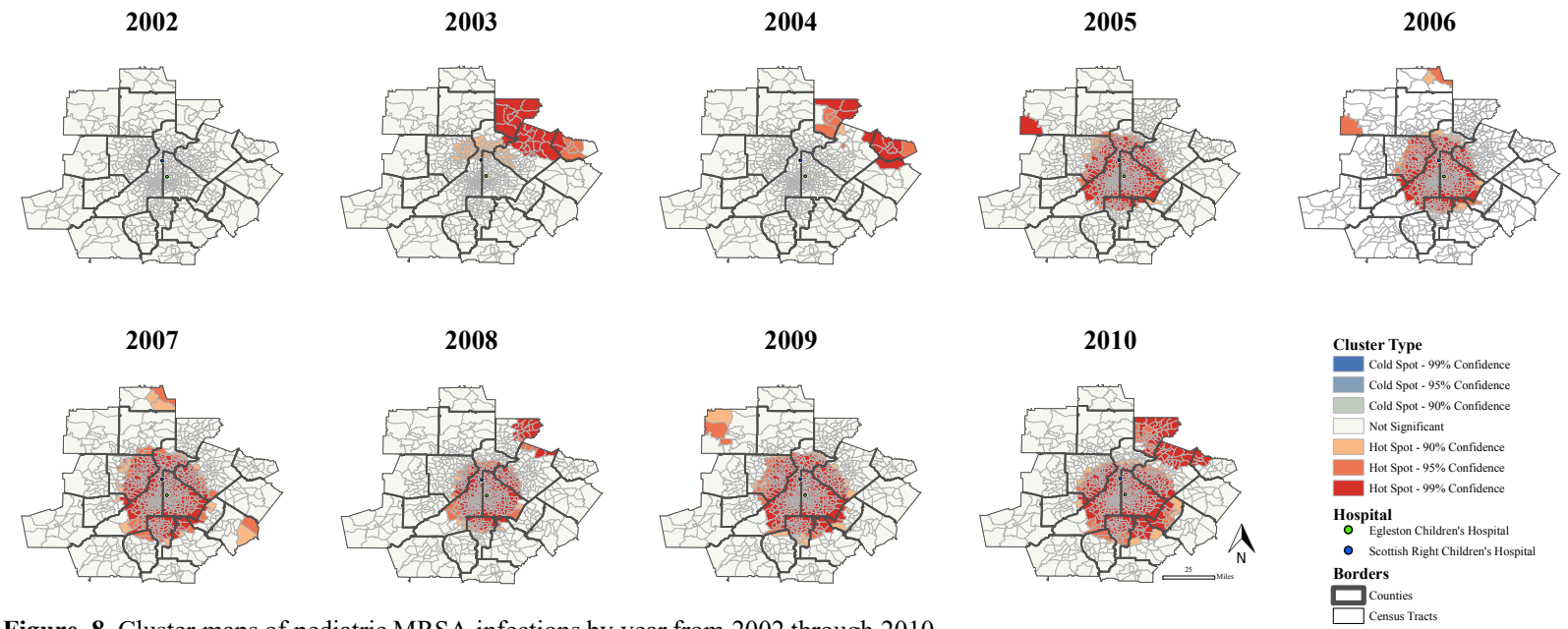


Figure 8. Cluster maps of pediatric MRSA infections by year from 2002 through 2010.

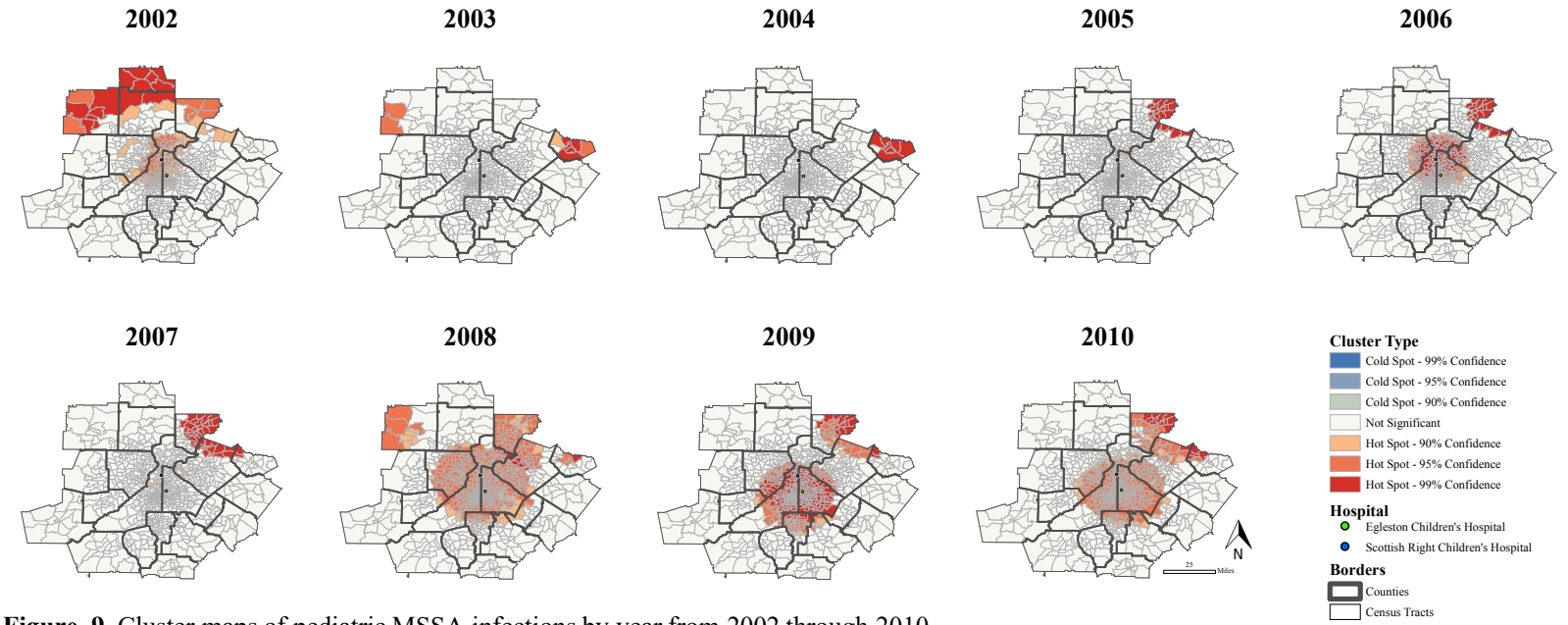


Figure 9. Cluster maps of pediatric MSSA infections by year from 2002 through 2010.