Concentrated Trauma Risk: Social and Environmental Determinants of Injury Mortality

by
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ABSTRACT

Most Americans live within one hour of a Level I or II trauma center, but many rural, low income, and historically underrepresented minority communities lack access to appropriate trauma care services. Underserved populations tend to have higher injury incidence rates and mortality, but little is known about the role of trauma center access and injury scene characteristics as determinants of injury disparities.

Using data from the Maryland Adult Trauma Registry and eMEDS Patient Care Reporting System, the goals of this dissertation were to 1) examine the role of the built and social environment at the injury scene as determinants of injury mortality using multilevel logistic regression, 2) identify patterns of injury scene characteristics associated with increased risk of injury mortality using latent class analysis, and 3) assess the role of environmental, social, and health characteristics as mediators of the effects of race, ethnicity, and sex on injury mortality.

Manuscript one examined characteristics of the built and social environment at injury incident locations, while controlling for patient characteristics. Odds of death increased with increasing distance to the nearest trauma center and when the nearest trauma center was publicly-owned or designated as Level III. Odds of death also increased with increasing median age at the community level, and when per capita income was less than $25,000.

Manuscript two identified eight patterns of injury scene characteristics, including rural, exurban, young middle suburb, aging middle suburb, inner suburb, urban fringe, high income urban core, and low income urban core. Injury mortality was highest at rural and low income urban core locations.

Manuscript three examined potential mediators of the effects of race, ethnicity, and sex on injury mortality. Prehospital time, trauma center distance, injury mechanism, and insurance type fully mediated the effect of race. Trauma center distance, injury mechanism, and insurance type partially mediated the effect of ethnicity. Prehospital time, injury severity, and insurance type partially mediated the effect of sex.

The results of these analyses suggest that features of the built and social environment at injury scenes are associated with injury mortality, and may contribute to disparities in injury outcomes.

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CHAPTER ONE: INTRODUCTION

Rationale for Research

Background

While most Americans live within one hour of a Level I or II trauma center by ground or air ambulance,[1,2] many rural residents,[1-4] low income communities,[3,4] and historically underrepresented minority populations[3-5] lack access to appropriate medical care following traumatic injury. These disparities persist despite nearly 50 years of effort to regionalize trauma care services in the United States and provide higher levels of care following injury events.[6,7]

Injury Incidence and Response

Injuries, both intentional and unintentional, are a leading cause of death in the United States as a whole,[8,9] and specifically in Maryland.[10] Injuries were responsible for nearly 200,000 deaths in the United States in 2014,[8] including approximately 3,500 in Maryland alone.[10] Recent estimates indicate that fatal injuries may cost Maryland more than $3 billion each year due to medical costs and lost work.[10]

The current best practices for injury response include high quality emergency medical services (EMS) care at the injury scene, rapid transport to a hospital that can provide definitive medical care, and treatment of injuries in a specialized trauma center equipped to care for a range of injury types and levels of severity.[11] These recommendations are a central component of trauma care regionalization, which is motivated by the hypothesis that timely delivery of appropriate medical care following injury can reduce risk of death, widely referred to as the "golden hour."[12-16]

Barriers to Trauma Care

While standardization of trauma care has improved injury outcomes throughout the United States,[17] the American College of Emergency Physicians cites continued barriers to accessing emergency medical and trauma care as a substantial limitation of the United States emergency medical care system.[18] Many studies have explored the role of prehospital time and the impact of barriers to trauma care in urban settings, with results demonstrating considerable variation in the relationship between time, access, and outcomes.[19-31] Fewer studies have addressed the impact of barriers to trauma care in rural settings, but existing literature does suggest that most rural residents lack timely access to Level I or II trauma centers,[1,2] along with evidence of increased risk of injury and death in rural settings.[32-34] Disparities in access to trauma care and injury outcomes also persist for low income communities,[3-5,35,36] and historically underrepresented minority populations.[3-5,37-44] Barriers to trauma care in underserved communities are exacerbated by environmental factors that increase injury risk, such as roadway design and land use,[32] as well as community-level factors such as average wealth,[45] but efforts to address geographic disparities in trauma care and outcomes are primarily concerned with reducing prehospital travel time.[46]

Significance and Innovation

To date, research examining the impact of geographic disparities in trauma outcomes on injury mortality is largely limited to exploration of the relationship between the duration of the prehospital interval and trauma outcomes, particularly the time required to transport a patient from the site where the injury incident occurred to the hospital where the patient received definitive medical care; however, evidence of the relationship between time and outcomes is mixed.[12,47] This focus on the prehospital interval as the sole determinant of geographic disparities ignores the potential interplay between geographic barriers, quality of available trauma care, and the social and economic factors that may determine trauma mortality. The scope of prior research is partly limited by the availability of research data sets containing both prehospital and trauma center data, a challenge recently highlighted by the National Academies of Sciences, Engineering, and Medicine (NASEM).[48] While the National Trauma Data Bank (NTDB)[49] and the National Emergency Medical Services Information System (NEMSIS)[50] include measures of pre-hospital time that are readily available for use in research, these data sets either exclude or have high levels of missingness on other key variables of interest for examination of geographic disparities in trauma outcomes, and they are not easily linked with spatial variables associated with injury incident locations. The Maryland Institute for Emergency Medical Services Systems (MIEMSS) collects trauma center data for NTDB submission, and prehospital data for NEMSIS submission. MIEMSS permitted linkage between the two data bases for use in this project, presenting a novel opportunity to link prehospital and trauma center records with geographic features of injury incident locations, using data from a state based trauma system, regardless of treating hospital or payment type.

Determinants of Injury Incidence and Mortality

Individual-Level Determinants

Several individual health and demographic characteristics are known to influence injury outcomes at the individual patient level. Critical health characteristics include injury severity[51] and comorbid health conditions[52,53] at the time of the injury event. Influential demographic characteristics include age,[54-56] race and/or ethnicity,[5,37-44] sex,[57-71] and socioeconomic status.[5,35,36,39,40,59,72-75]

<u>Injury severity</u>

Injury severity is highly correlated with injury mortality.[51] Multiple measures of severity exist, using diagnoses, injury mechanism, injury intent, and procedure data from emergency department records.[51] The Abbreviated Injury Scale (AIS) was the first measure of injury severity specifically developed for use in injury research. AIS scores are based on patient reported complaints and provider assessment of physical status, with scores assigned independently to each body region.[76] While many other injury severity measures have been introduced in the decades since AIS was first used, AIS continues to be a useful tool for predicting trauma mortality as the severity of the single worst injury diagnosis can explain most severity-related variation in mortality.[77] Introduced shortly after the AIS, the Injury Severity Score (ISS) combines AIS scores for individual body systems in order to provide a measure of multi-system severity for patients with multiple injuries. ISS is highly predictive of the probability of death within three months of a traumatic injury.[78]

Comorbidities

Comorbid health conditions are also associated with increased probability of death following injury.[52,53] Specifically, cardiovascular and neurologic conditions are consistently associated with increased mortality.[52,53] The presence of multiple comorbidities further increases risk of death.[53] The Charlson Comorbidity Index (CCI) predicts probability of death based on the number and severity of comorbid conditions, which can improve prediction of probability of death in patients with traumatic injuries.[79] CCI predictive performance improves when models are also adjusted for age, sex, and other characteristics that may confound the relationship between comorbidities and mortality.[79]

Age

Patient age determines both a patient's course of treatment following injury, and their probability of death. Older patients are less likely to be treated at trauma centers,[54] and more likely to die from injuries,[55] compared to otherwise similar patients who are younger. Trauma mortality among older patients is strongly associated with pre-morbid functional status, and patients with limitations to activities of daily living, barriers to completing physical tasks, or poor self-rated health prior to their injury are the most likely to die.[56]

Race/ethnicity

African Americans consistently have higher mortality from injuries and worse long-term outcomes than White injury patients.[5,37-43] Injury outcomes for Hispanic[38,43,44] and Asian patients[37-39] demonstrate similar disparity patterns. The relationship between injury severity and death appears to be modified by race and ethnicity, with the effect of severity on mortality increasing for African American and Hispanic patients, compared to White patients.[42] Disparities in injury mortality are most pronounced among African American patients with mild to moderate injuries, and among Asian patients with severe injuries.[37] Insurance status may also modify the association between race and injury mortality, with lack of insurance further increasing the odds of death attributed to African American race.[39,40]

The causes of racial and ethnic disparities in trauma outcomes are not clear. Among patients who receive treatment in trauma centers, there are no racial or ethnic differences in initial management of injury,[80] but patients from historically underrepresented minority groups may be less likely to reach trauma centers following injury due to limited access to trauma centers and emergency rooms.[4,75] There is evidence of disparities in injury care after the initial assessment and treatment in the emergency department. Patients from historically underrepresented race and ethnic groups tend to have shorter hospital stays,[44] are more likely to be transferred to nursing homes upon hospital discharge,[44] and are less likely to receive rehabilitation care following traumatic injury.[38,81] In addition to individual disparities in care, there is evidence that racial and ethnic disparities may stem from hospital-level differences.[82,83] Hospital-level mortality rates are higher for hospitals with a large proportion of African American patients, compared to hospitals with mostly White trauma patients.[82,83] When results are stratified by the distribution of race at each hospital, individual race does not predict outcomes.[82,83] Regardless of individual race and/or ethnicity, patients treated at trauma centers with a high proportion of historically underrepresented racial and ethnic minorities are more likely to die than patients treated at trauma centers with fewer minority patients.[84]

<u>Sex/Gender</u>

Males are more likely to experience traumatic injury[57] and die from injuries[58,59] than females, but there is evidence that injury incidents involving females are underreported.[57] There is also evidence that the experience of injury and recovery is different for male and female patients. While a handful of studies failed to find an association between sex and mortality,[60,61] many more studies demonstrate associations between sex and mortality that vary by age and type of injury.[59,62-68] Among patients with traumatic brain injuries (TBI), females are more likely to die than males,[62] though most additional TBI deaths among females occur after hospital discharge.[62] The difference in mortality from TBI may be isolated to older adults, with mortality among women greatly increasing after age 55.[64] Females with TBI are also more likely to experience disability,[62] persistent vegetative state,[62] and loss of functional status.[63] Among patients with blunt injuries, men are more likely to die than women,[66] with a pattern of age-related mortality similar to TBI.[66] Among patients with burn injuries, women younger than 60 years of age are more likely to die than men of the same age. After age 60, there is no difference in mortality.[69] There is no apparent disparity in mortality between men and women with penetrating injuries.[66] Differences in body composition and hormones may be protective against infections and support faster healing among women, compared to men.[70,71] There is also evidence that differences in the incidence of pneumonia infection may explain much of the mortality disparity between men and women.[65] Men are more likely to experience complications following trauma, but it is not clear if differences in complications explain differences in mortality.[65]

Socioeconomic Status

Socioeconomic status, as indicated by income and insurance status, determines injury mortality both by influencing risk of injury incidence[5,35,36] and by determining the level of care patients receive following injury.[39,59,73,74] Low income is associated with increased risk of injury and mortality overall,[5] and specifically death from unintentional injuries and homicide.[35] Higher income is associated with increased risk of suicide and self-inflicted injury.[35] Patients with lower household income are more likely to die from injuries than wealthier patients with similar injuries regardless of race, ethnicity, insurance status, or comorbidities.[36]

Trauma patients without insurance are less likely to experience complications, compared to patients with Medicaid, Medicare, or private insurance, but uninsured patients who do experience complications are more likely to die than insured patients with complications.[72] Patients with Medicare or Medicaid are more likely to experience complications than privately insured patients, but there is no difference in the probability of death following complications.[72] Health insurance status also predicts mortality following injuries with uninsured patients having greater odds of death than similar patients with insurance,[39,59,73,74] despite being younger and less severely injured than patients with insurance.[73]

Community-level Social and Economic Determinants

In addition to the individual-level impact of age, race, sex, and socioeconomic status, there is evidence that community-level distribution of some social and economic factors also determines injury incidence and mortality. Treatment at a trauma center with a high proportion of patients identified as historically underrepresented racial or ethnic minorities is associated with increased injury mortality for all patients, regardless of individual race and/or ethnicity,[84] suggesting that the distribution of race and ethnicity in a community impacts injury outcomes for all residents. While higher individual income does appear to improve injury outcomes, relatively wealthy people living in relatively poor neighborhoods tend to face increased risk of injury and death, compared to similarly wealthy people living in wealthy neighborhoods.[45] Likewise, the proportion of residents with health insurance may influence outcomes for all residents by determining financial resources available for EMS services, especially in rural communities.[85] Socioeconomic disparities are further exacerbated by changes in the trauma care system as emergency department and hospital closures are more likely to impact low income communities.[40,75]

Environmental Determinants

In addition to prehospital time, several environmental factors appear to increase risk of injury incidence and mortality in rural settings. Rural roadways tend to have higher speed limits,[86] and fewer crash prevention features, such as medians between travel lanes and controlled access entry/exit.[32] These differences in roadway design increase both the incidence and severity of motor vehicle crashes.[32] Beyond roadway design as a determinant of traumatic injury, land use is also a critical factor predicting injury incidence and outcomes. Mining and agriculture are among the highest risk industries when it comes to injury incidence, and they are primarily located in rural areas due to the availability of open space and low population densities.[32] While this increased risk of occupational injury due to mining and agriculture is intuitive, these industries are also associated with increased risk of injury for children and other residents who are not directly employed in high risk industries. For example, the presence of farm equipment on public roads increases the risk of crashes for all motorists.[32] Other features of rural land use are also associated with injury risk, such as the use or all-terrain vehicles for recreation on undeveloped land.[32]

Hospital Characteristics

Hospital organization and designation as a trauma center are directly associated with injury outcomes. In general, trauma centers are larger than non-trauma centers, and are more likely to be teaching hospitals.[87] Trauma centers accredited by the American College of Surgeons tend to have shorter intervals between patient arrival and assessment by a trauma surgeon.[88] Trauma center patient volume is also associated with shorter wait times to surgical assessment,[88] shorter hospital stays, and reduced injury mortality.[89] Severely injured patients treated at Level I trauma centers are more likely to survive, compared to similar patients treated at Level II centers,[14,16,25] and treatment at a Level II center increases probability of survival compared to Level III and non-trauma centers.[13] Trauma patients receiving care at public hospitals tend to have worse health status and more severe injuries than patients treated at private hospitals.[90]

Conceptual Model

The conceptual framework for this dissertation is adapted from the Aday model for evaluating healthcare system effectiveness, efficiency, and equity,[91] which combines features of the Donabedien structure-process-outcome framework[92] and the Andersen-Aday framework for access to medical care.[93] According to the Aday model, policies at the federal, state and local levels determine the features of the environment (physical, social and economic), the healthcare delivery system, and the population at risk of injury and illness. These features collectively comprise the structural determinants of health outcomes. The structural determinants are directly related to process determinants including environmental and behavioral health risks, health care utilization, and patient satisfaction, which also predict health outcomes. Intermediate outcomes include health care effectiveness at the individual and population levels, efficiency in terms of healthcare production and allocation, and equity in terms of the distribution of health outcomes across the population. The ultimate outcome of the Aday model is individual and population level health.[91]

When the Aday model is applied to trauma outcomes for vulnerable populations (Figure 1.1), health policies determine features of the health care delivery system including medical direction,[94-101] EMS and hospital staffing,[88,102-104] treatment and transport protocols, and hospital characteristics.[13,14,16,25,87-90] Policies also determine environmental factors such as trauma center locations and distance between injury scenes and trauma centers.[1-4,105,106] Together, delivery system and environmental characteristics determine features of realized access to care, including prehospital treatment,[25,107-113] transportation decisions,[106,112,114-120] receiving hospitals,[121-125] and transfer decisions,[15,55,126-130] which then determine health and wellbeing, including individual injury mortality. At the population level, health and wellbeing determine healthcare effectiveness as a function of mortality and case fatality rates. Healthcare effectiveness determines efficiency, indicated by cost of care and poor outcomes. Effectiveness also determines equity in terms of the distribution of the burden of injury incidence and mortality across the population. Collectively, the structure-process-outcome continuum is determined by individual characteristics, individual health risks, and injury characteristics. Key individual characteristics include age, [54-56] race,[4,5,37-44,75,80-83] sex/gender, [57-71] income,[5,35,36] and insurance status.[39,40,59,72-75] Individual health risks include comorbidities,[52,53,79] and the primary injury characteristic of interest is injury severity.[51]

Study Aims

In order to address the limitations in our understanding of social and environmental determinants of injury mortality in the context of the known determinants of injury mortality and the conceptual model described above, this dissertation aims to:

1) Examine the role of environmental and community-level variables at the injury incident scene as determinants of injury mortality in Maryland using multilevel logistic models, while controlling for patient and hospital characteristics.

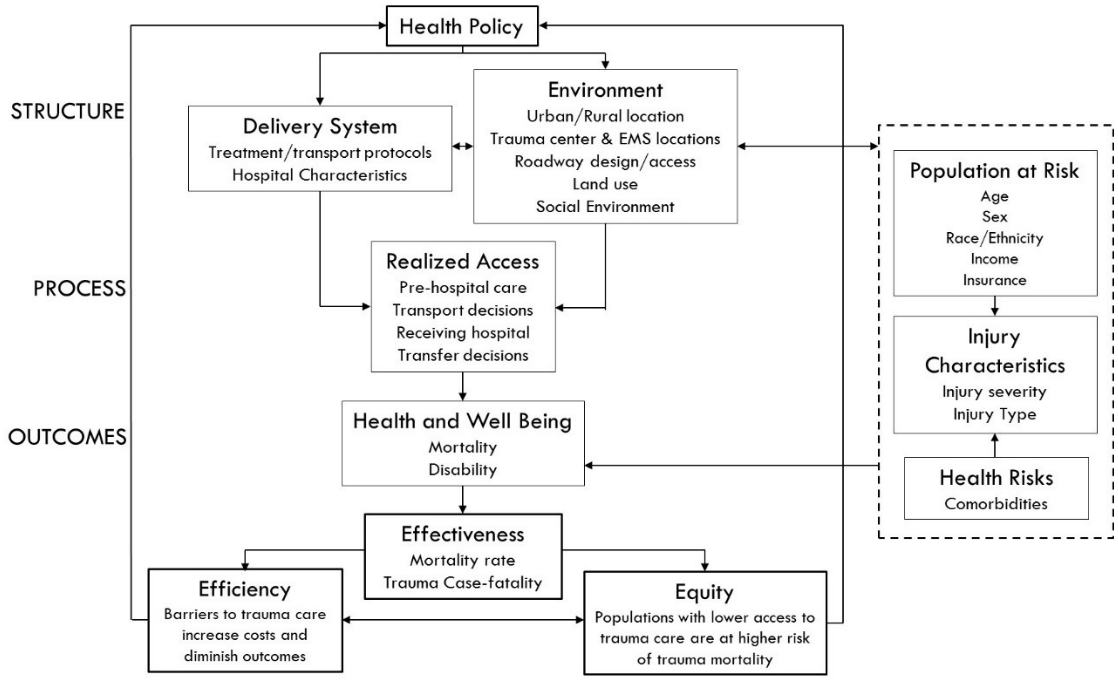
2) Develop a profile of injury scene characteristics associated with concentrated risk of mortality from traumatic injury, and identify regions in Maryland with concentrated risk of injury mortality.
3) Examine incident scene and individual characteristics mediating the effects of race, ethnicity, sex on injury mortality.

Dissertation Organization

Chapters 2-5 of this dissertation include three manuscripts and a concluding chapter. Manuscript one uses data from the Maryland Adult Trauma Registry (MTR), the MIEMSS eMEDS Patient Care Reporting System (PCRS), the Maryland Geographic Information Office, and the United States Census Bureau to examine the role of environmental and community characteristics in determining injury mortality. Manuscript two uses the same data sets to identify latent classes among injury incident locations based on characteristics of the injury scene, and to examine patterns of individual characteristics and injury outcomes across location classes. Manuscript three uses the MTR and eMEDS data in a set of a mediation analyses examining factors in the causal pathway between individual demographic characteristics (race, ethnicity, sex) and injury mortality. Finally, in chapter five, I summarize my dissertation findings and discuss policy implications and priorities for future research.

TABLES AND FIGURES

Figure 1.1: Conceptual Model



CHAPTER TWO: MANUSCRIPT ONE

Community and environmental determinants of injury mortality

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ABSTRACT

Background: Disparities in access to trauma care and injury mortality persist for rural, low income, and historically underrepresented minority populations despite efforts to improve care through regionalization and standardization of trauma and EMS systems. Little is known about the contribution of injury incident location to these disparities. This study sought to examine characteristics of injury scene locations, including trauma center proximity, features of the nearest trauma center, land use at the incident scene, and community level socioeconomic and demographic measures, as predictors of injury mortality and potential determinants of disparities.

Methods: Injury incidents (n = 16,082) in the 2015 MTR were geocoded using associated address information from the Maryland eMEDS PCRS, then linked with structural, environmental, and social factors present at each injury scene using data from the Maryland Department of Planning and the United States Census Bureau. Missing data were treated as missing at random, and addressed using multiple imputation with predictive mean matching. Multilevel logistic regression models with random intercepts for zip code tabulation area (ZCTA) were used to estimate odds of death associated with structural, environmental, and social factors present at the scene of the injury incident, while controlling for total prehospital time, injury severity, injury mechanism, comorbidities, insurance status, age, sex, race, and ethnicity.

Results: Distance from the injury scene to the nearest trauma center was associated with mortality, independent of prehopsital time, with a 1.52% increase in odds of death for every 1-mile increase in distance (p = 0.026). Characteristics of the nearest trauma center were also independent determinants of mortality, with a 49.89% increase in odds of death when the nearest trauma center was designated Level III (*p* = 0.021) and a 80.58% decrease in odds of death when the nearest trauma center was privately-owned (p < 0.001). Characteristics of the incident scene predicted mortality, with a 32.58% decrease in odds of death for incidents occuring in commercial spaces (p = 0.014) and 69.99% increase in odds of death for incidents occuring on roadways and in other transportation land use spaces (p = 0.001). Characteristics of the

community surrounding the incident scene also predicted mortality, with a 1.51% increase in odds of death for every one year increase in median age at the ZCTA level ($p = 0.015$), and a 26.59% decrease in odds of death for ZCTAs with per capita income greater than \$25,000 ($p = 0.010$).

Conclusions: This study suggests that environmental and community features of the injury scene contribute to injury mortality independent of individual characteristics, and may explain disparities in injury outcomes. Proximity to a trauma center is directly associated with mortality, independent of the duration of the prehospital interval, with odds of death increasing with distance. The characteristics of the nearest trauma center also contribute to mortality, with higher odds of death associated with Level III designation and public hospital ownership. Several other features of the injury scene appear to determine injury mortality, independent of trauma system features and individual demographic and health characteristics. Odds of death were highest for incidents occurring on roadways and other areas associated with transportation land use, and lowest in commercial spaces. At the community level, odds of death appear to increase with increasing median age, and decrease with increasing per capita income.

INTRODUCTION

Injuries are a leading cause of death in the United States,[8] contributing to an estimated 3.5 million years of life lost and $190 billion in health care spending and lost productivity in 2010.[10] The current body of literature includes substantial evidence for the relationship between injury outcomes and individual characteristics, including age,[54,55] sex,[57-59] race and ethnicity,[5,37-44,59,62-68] socioeconomic status,[35,39,59,73,74] injury severity,[51,76-78] and comorbidities.[52,53] There is also evidence of population-level disparities in injury incidence and outcomes for rural,[1-4] low income,[3,4] and historically underrepresented minority communities, suggesting that features of the healthcare system, physical environment, and social environment associated with injury incidents may contribute to mortality independent of known individual-level determinates. Unfortunately, little is known about the role of environmental and community-level social variables as determinants of injury mortality.

Trauma System Features

The primary system-level determinant addressed in the literature is time to treatment, which is a major consideration in the design of trauma systems and allocation of trauma care resources.[131,132] Evidence of the role of prehospital time and injury outcomes is mixed and largely limited to studies in urban populations.[19-31,133,134] While several studies show no association between time and mortality,[19-22] most indicate some survival benefits from shorter prehospital times.[23-31,133] Time intervals associated with improved survival range from EMS response within four minutes of the injury event[23] to trauma center treatment within two hours.[27] Changes in injury mortality following recent changes in military EMS policies also indicate a benefit from shorter prehospital times and use of advanced life support (ALS) during the prehospital interval.[134] There is some evidence of a relationship between rural location, prehospital interval, and injury mortality, with longer prehospital intervals observed for incidents occurring in rural areas,[105,106] and increases in mortality among rural patients with extended EMS response times.[34,105,135] There is also evidence that communities with longer predicted prehospital intervals tend to have disproportionately large populations of racial and/or ethnic minorities and low-income residents.[3,4]

In addition to the duration of the prehospital interval, hospital organization and designation as a trauma center are independently associated with injury outcomes. Trauma centers accredited by the American College of Surgeons tend to have shorter intervals between patient arrival and assessment by a trauma surgeon, and trauma center patient volume is associated with shorter wait times to surgical assessment,[88] shorter hospital stays, and reduced injury mortality.[89] Severely injured patients treated at Level I trauma centers are more likely to survive, compared to similar patients treated at Level II centers,[14,16,25] and treatment at a Level II center increases probability of survival compared to Level III and non-trauma centers.[13] Trauma patients receiving care at public hospitals tend to have worse health status and more severe injuries than patients treated at private hospitals.[90] Despite evidence of differences in timing and sequence of prehospital care in rural settings,[53] and disparities in access to Level I and II trauma centers,[3,4] prehospital time alone is the primary focus of trauma system design. Prior studies have examined distance as a proxy for prehospital time, but no studies have examined proximity to trauma centers as an independent determinant of injury mortality. This is a critical gap in the literature as evidence of geographic variation in mortality due to trauma center proximity and characteristics, independent of prehospital time, would suggest a need for EMS and trauma system approaches that extend beyond efforts to minimize travel time.

Built and Social Environment

There is limited evidence regarding the role of environmental and community level factors as determinants of injury outcomes. There is potential for increased injury incidence and severity in rural and underserved settings due to differences in the built environment, such as roadways with fewer crash prevention design features and land use categories associated with occupational and recreational injuries,[32] but no studies have specifically examined land use at the injury scene as a determinant of injury outcomes. There is also evidence that elements of the social environment in the patient population, such as the distribution of income,[45] race and/or ethnicity,[84] and insurance status,[35,45] are independent determinants of outcomes at the hospital level, but it is not clear if the social environment at the injury scene has a similar impact on outcomes. The lack of evidence concerning the potential relationship between injury mortality and the physical and social characteristics of the injury scene limits the ability of policymakers and health providers to respond to the needs of vulnerable populations.

Using individual injury incident data linked with measures of the built and social environment at the scene of the injury incident, this study examined features of the injury scene as determinants of mortality, independent of individual demographics, health characteristics, and the duration of the prehospital interval. Based on the literature, I hypothesized that distance to the nearest trauma center would contribute to mortality after adjustment for prehospital time, that the characteristics of the nearest trauma center would contribute to mortality after adjustment for prehospital time and distance, and that characteristics of the built and social environment at the injury scene would contribute to injury mortality after adjustment for prehospital time, distance, and hospital characteristics.

METHODS

Data Sources

Injury incident records from the 2015 MIEMSS MTR were the primary data set for this study. MTR records were linked with EMS treatment and transport records from the Maryland eMEDS PCRS. Data were limited to 2015 based on the availability of electronic EMS records. Maryland began implementing the eMEDS PCRS on a county by county basis in 2014, with all counties adopting the system by January 2015. MTR and eMEDS data for 2016 were not available at the time of data analysis. Additional measures were collected from public data sets provided by the Maryland Geographic Information Office[136] and the United States Census Bureau.[137]

MIEMSS administers the MTR to support research and quality improvement efforts using data from designated trauma centers in Maryland. Trained trauma registrars review emergency department (ED) and in-patient hospital records for injury patients treated at designated trauma centers, and identify patient records meeting the MIEMSS definition of traumatic injury based on injury severity, mechanism, demographics, and outcomes.[138] Registrars enter data into electronic collection systems, and import select prehospital measures collected and entered by EMS providers based on field observations and procedures.[139] MTR data are provided at the individual patient/incident level, including demographics, injury characteristics, diagnoses, outcomes, prehospital care, treatments at referring/transfer facilities, trauma center treatments, in-patient treatments, provider characteristics, and healthcare quality measures.[138] The MTR also includes zip code and geographic coordinates for a subset of incidents. The eMEDS system includes the physical address of each injury incident, in addition to more detailed measures of prehospital care. The Maryland Geographic Information Office maintains public data sets and geographic information systems (GIS) shapefiles, including the land use data set used in this study. Finally, the United States Census Bureau maintains GIS shapefiles with community-level information based on the American Community Survey.[137]

Population and Setting

The analytic sample for this study was based on the 2015 MTR and included adults (age ≥ 18) injured in Maryland in 2015, transported by a Maryland-based EMS company (by ground ambulance or helicopter), and treated at a designated trauma center in Maryland. The sample also included adults who died from injuries at the incident scene or while in transit in an EMS vehicle. Records for patients treated in the MTR were linked with eMEDS prehospital records using unique patient care report numbers. For MTR records with unknown or invalid patient care report numbers, likely matches were identified using probabilistic algorithms based on last name, date of birth, residential zip code, date of injury incident, and incident zip code. Successful probabilistic matches were identified through clerical review of match results. MTR records that were not successfully linked with eMEDS records were retained for analysis if the incident coordinates or zip code were included in the MTR record, to support linkage with limited community level measures. A flow chart of the inclusion criteria and matching process is presented in Figure 2.1.

Variables and Measures

The primary dependent variable for this aim was trauma mortality, measured as a binary variable with patients coded as “died” if they died from traumatic injuries at the injury scene, in transit to the hospital, in the ED/trauma center, or in the hospital prior to discharge. Patients who were alive at the time of discharge from the ED/trauma center or hospital were coded as “did not die.”

Independent variables at the individual, location, and ZCTA levels were included in this analysis. Individual measures included age, sex, race and/or ethnicity, injury severity, injury mechanism, CCI, insurance status, and prehospital time. Age was calculated based on date of birth and date of the injury incident, and was categorized in ten year increments. Sex, race, and ethnicity were based on medical records, self-report and/or provider observation. Sex was measured as male or female. Race and ethnicity were combined in a single variable, measured as White, African American, Hispanic, or Other (i.e. Asian, Native Hawaiian or Pacific Islander, American Indian or Alaska Native, and people with other races). Injury severity was measured based on a combination of ISS and revised trauma score (RTS). ISS was calculated based on *ICD-9-CM* codes reported in the MTR, using the ICDPIC Stata module,[140] and categorized as mild (≤ 9), moderate (10-15), severe (16-24), or critical (≥ 25). RTS was used in lieu of ISS for records without detailed diagnosis codes, including patients who died in the field or in transit and patients with injuries that are not classified with ISS (i.e. poisoning, drug overdose, drowning, burns).[78] Based on criteria used for RTS-based triage decisions,[141] RTS was also categorized as mild (12), moderate (11), severe (4-10), and critical (≤ 3). ISS and RTS categories were combined into a single categorical measure of injury severity, with RTS used only when ISS was unavailable (n = 319, 1.99%). Injury mechanism was measured as blunt, penetrating, both blunt and penetrating, or other mechanism, based on external cause of injury codes reported in the MTR and eMEDS. CCI, categorized as 0, 1-5, and ≥ 5, was calculated using comorbidity codes included in the MTR and the weights proposed by Charlson, et al.[142] Insurance status was coded as private, public/government, or no insurance based on hospital payment records. Prehospital time was calculated as the number of minutes elapsed from the initial call for emergency services to the time of arrival at the trauma center delivering definitive care.

Built environment measures based on the injury event location included distance to the nearest trauma center, designation and ownership status of the nearest trauma center, and land use. Distance to the nearest trauma center was measured based on the Euclidian distance between the scene of the injury incident and the nearest MIEMSS designated trauma center. Trauma center designation level (I/II or III) and ownership (private/public) were measured based on public records searches for hospital characteristics, and assigned to each record based on the nearest trauma center to the incident scene. Designation and ownership were combined into a single variable for hospital type, coded as privately-owned Level I/II, publicly-owned Level I/II, and privately-owned Level III. There were no publicly-owned Level III centers in Maryland at the time of the study. Land use was categorized as residential, commercial, industrial/agricultural, transport (e.g. roadways, parking lots, public transportation facilities) institutional, or undeveloped based on Maryland Department of Planning land use records. Speed limit and roadway design/designation, distance to the nearest EMS base, and teaching status of the nearest trauma center were also examined, but were not included in the final regression models, based on assessment of model fit statistics.

ZCTA measures from the 2010-2014 American Community Survey included median age and per capita income. The United States Census Bureau conducts the American Community Survey on an ongoing basis and provides public use aggregate data sets at regular intervals. ZCTAs are constructed from Census Blocks to approximate postal zip codes when presenting aggregate data, and to support linkage between the American Community Survey and other data sets of interest.[137] Of the 468 ZCTAs in the 2010-2014 Maryland American Community Survey data set, 423 had at least one injury incident in the 2015 MTR. ZCTA measures were assigned to records based on the coordinates of the injury incident scene, or the centroid of the incident zip code when exact coordinates were not available. Median age was measured in years and per capita income was categorized as greater than or less than $25,000 per person. Additional ZCTA measures including aggregate income, poverty rate, income inequality, insurance coverage rate, distribution of sex and race, high school and college education rates, median house age, housing vacancy rate, use of combustible heat sources, private vehicle ownership, commuter transportation patterns, and employment rate were considered but excluded from the final regression models based examination of model fit statistics.

Analytic Approach

All geocoding and measurement of spatial variables was conducted using ArcGIS version 10.2.2.[143] Records were mapped using longitude and latitude coordinates of the injury scene when available in the MTR, or geocoded coordinates based on the injury incident scene address reported in the EMS record. Records without coordinates or address information were mapped using the centroid of the incident zip code. Records with exact scene location were linked with trauma centers using spatial joins based on the nearest feature, and with land use based on the features of the polygon each point fell within. Records were linked with ZCTA measures based on the ZCTA polygon within which the scene location or zip code centroid fell.

All other statistical analyses were conducted using Stata 13.[144] Exploratory data analyses did not indicate any patterns in missing data by county, zip code, or calendar month. Missing data were treated as missing at random, and multiple imputation (MI) with predictive mean matching was used to estimate variance for measures with missing data. A total of ten imputations were used, with a burn in period of twenty iterations per imputation, and the ten nearest neighbors included in the random selection for each iteration. Imputed variables included trauma center distance, hospital ownership status, trauma center designation, land use, insurance status, age, race and/or ethnicity, severity, CCI, and ZCTA measures. Auxiliary variables in the imputation model included injury mechanism, sex, race and/or ethnicity, patient origin (scene/transfer), distance from the zip code centroid to the nearest trauma center, and mortality outcome. Distribution of categorical measures and the mean of continuous measures were assessed for observed and MI estimates.

Bivariate and multivariate analysis were conducted using a randomly selected sample of 10,000 records. Measures were categorized as individual or location-based, and simple logistic regression models were used to assess the relationship between each measure and mortality outcomes. Regression models were developed for each set of measures using a forward stepwise process, and model fit was assessed by comparing log likelihood, Akaike's information criterion, and Bayesian information criterion. Spline and interaction terms were tested based on visual examination of scatterplots and relationships suggested in the literature, and evaluated based on model fit statistics.

Once the parameters for each model were selected, simple logistic regression was used for bivariate analysis of all measures by mortality outcome. Multivariate analyses included multilevel logistic models with random intercepts for incident ZCTA. The effects of individual characteristics (Model 1) and location-level measures (Model 2) were modeled separately before combining all measures into a fully adjusted model (Model 3). Spatial dependence of the residuals was assessed using visual examination of semivariograms of the standardized residuals at the individual level and, and calculation of Moran's I at the ZCTA level. The semivariogram and Moran's I are tools used in spatial statistics to assess spatial dependence at the individual point level (semivariogram) and aggregated level data (Moran's I).[145] To assess sensitivity of the Model 3 to missing location information, the analysis was repeated without records that lacked exact location coordinates or address. The regression models were validated and predictive performance assessed using the remaining 6,082 records.

Predicted probability of death was estimated for each record based on each of the three regression models. Predicted probabilities of death were categorized by increments of 10%. Sensitivity, specificity, and receiver operating characteristic (ROC) curves were used to assess the overall predictive ability of the models.

RESULTS

Population Characteristics

The final analytic sample included 16,082 unique patient-injury records (Figure 2.1), with 15,388 MTR records for patients treated at trauma centers, and 727 eMEDS records for patients who died in the field. Matching eMEDS records were identified for 85.68% of eligible MTR records (n = 13,157). An additional 13.92% of eligible MTR records did not match with an eMEDS record, but did include the zip code of the incident scene (n = 2,198). Thirty-three records (0.20%) lacked any location information and were excluded from the study. Sample characteristics are presented in Table 2.1 and Figure 2.2 illustrates the spatial distribution of injury incidence per 1,000 adults at the ZCTA level. Age ranged from 18 to 100 years old, with 15.56% of subjects age 18-24, 20.49% age 25-34, 13.24% age 35-44, 14.39% age 45-54, 13.34% age 55-64, 8.57% age 65-74, and 14.41% age 75 or older. Most subjects (65.79%) were male, while 51.42% were White, 35.54% African American, and 5.87% Hispanic. Injury severity for most patients was mild (91.84%), with a smaller percentage classified as moderate (3.22%), severe (3.03%), and critical (1.91%). Most patients had blunt injuries (81.94%), while 12.82% had penetrating injuries, 2.43% had both blunt and penetrating injuries, and 2.82% had other injury mechanisms. Most patients had no reported comorbidities (94.56%), while 5.02% had CCI scores between one and four, and 0.42% had CCI scores of five or more. The proportions of patients with public and private insurance coverage were similar (40.28% and 40.59%, respectively), while 19.13% had no insurance coverage. The average total prehospital time was 51.17 minutes. The nearest trauma center was a privately-owned Level I or II center for 43.97% of cases, a publicly-owned Level I or II center for 41.51% of cases, and a privately-owned Level

III center for 14.52% of cases. The average distance to the nearest trauma center was 9.12 miles. Transportation land use was most common (44.15%), followed by residential land use (33.43%), commercial (9.12%), institutional (6.25%), undeveloped land (3.78%), and agriculture/industrial (3.28%). The average ZCTA median age was 38.15 years, and 75.28% of injury incidents occurred in a ZCTA with per capita income greater than $25,000.

Missingness and MI Estimates

Measures of missingness are presented in Table 2.1, along with observed and MI estimated distribution of categorical measures and means of continuous measures included in this analysis. The MI estimated proportion of scenes with transport land use (30.81%) was lower than the observed proportion (44.15%), while the MI estimates proportion of other land use categories were higher than observed. Mean prehospital time including MI estimates (64.55-minutes) was greater than the mean of observed prehospital times (51.17 minutes). There were slight, though statistically significant, differences in MI estimated and observed distribution of injury severity and insurance status. The estimated distributions of age, sex, race and/or ethnicity, injury mechanism, comorbidities, hospital ownership, ZCTA median age, and per capita income did not differ from observed distributions.

Bivariate Analyses

Coefficients (log odds) and confidence intervals from the bivariate regression models are presented in Table 2.2. Female patients were 51.71% less likely to die than male patients ($p < 0.001$). African American patients were 21.53% more likely to die than White patient ($p = 0.007$). Hispanic patients were 42.66% less likely to die than White patients ($p = 0.002$), while patients from Other racial categories were 37.62% less likely to die that White patients ($p = 0.028$). Patients with moderate injuries were 47.78% less likely to die that those with mild injuries ($p = 0.011$) while severe and critical injuries increased odds of death by 2.83 and 57.26 times, respectively ($p < 0.001$). Compared to patients with only blunt injuries, odds of death were more than six times greater for patients with penetrating injuries (OR = 6.32, $p < 0.001$), more than twice as high for patients with both blunt and penetrating injury (OR = 2.01, $p < 0.001$), and more than nine times greater for patients with other types of injury (OR = 9.32, $p < 0.001$). Compared to private insurance coverage, public insurance coverage and uninsured status increased odds of death by 2.31 times ($p < 0.001$) and 4.45 times ($p < 0.001$), respectively. Compared to incidents closest to privately-owned Level I/II trauma centers, odds of death increased by 25.48% ($p = 0.001$) when the nearest trauma center was a publicly-owned Level I/II center, and by 21.89% ($p = 0.040$) when the nearest trauma center was a privately-owned Level III center. Compared to residential land use, odds of death decreased by 38.56% for commercial land use ($p < 0.001$), 47.62% for industrial/agricultural land use ($p = 0.004$), 39.10% for transport land use ($p <0.001$), and 37.91% for institutional land use ($p = 0.001$). Odds of death were 28.63% lower for injury events that occurred in a ZCTA with per capita income greater than $25,000 ($p < 0.001$). Odds of death increased by 5.13% for every 5-mile increase in distance from the incident scene to the nearest trauma center ($p < 0.001$), and by 1.71% for every five-minute increase in prehospital time ($p = 0.002$).

Multivariate Analyses

Coefficients (log odds) and confidence intervals for all multivariate regression models are presented in Table 2.3. In Model 1, the regression of individual demographic and physiologic measures on mortality provides a baseline model for injury mortality using common determinants established in the literature. When adjusting only for individual-level characteristics, patients age 55 to 64 were nearly twice as likely to die than those ages 18 to 24 (OR = 1.86, $p = 0.001$), while patients age 65 to 74 saw a nearly three-fold increase in odds of death (OR = 2.84, $p < 0.001$) and patients are 75 and older saw an almost four-fold increase is odds of death (OR = 3.72, $p < 0.001$). Female patients were 39.78% less likely to die than male patients ($p < 0.001$). Compared to White patients, Hispanic patients were 50.78% less likely to die ($p = 0.007$), and patients from Other racial categories were 53.37% less likely to die than White patients ($p = 0.017$). Compared to patients with mild injuries, those with severe injury were 3.64 times more likely to die ($p <$

0.001) and those with critical injuries were 63.15 times more likely to die ($p < 0.001$). Patients with penetrating injuries were 3.88 times more likely to die that those with blunt injuries ($p < 0.001$), while patients with injury mechanisms other than penetrating and blunt were 7.35 times more likely to die (p < 0.001). Insurance status was associated with morality, with odds of death increased by 63.95% for publicly insured patients ($p < 0.001$), compared to those with private insurance. Patients without insurance were 3.91 times more likely to die than those with private insurance ($p < 0.001$). For patients with penetrating injury, odds of death increased by 6.01% for every five-minute increase in prehospital time ($p < 0.001$), while odds of death increased by 17.29% per five-minute interval for patients with both blunt and penetrating injury ($p = 0.002$), and by 4.81% per five-minute interval for other injury mechanisms. Prehospital time was not associated with mortality for patients with blunt injuries.

Model 2 included measures of the structural and social environment associated with the specific location of the injury incident, to assess the effects of location-specific characteristics without adjustment for individual characteristics, and to support examination of changes in both individual-level and location-level effects in the fully adjusted model. Odds of death decreased by 55.74% when the nearest trauma center was publicly-owned and designated Level I or II ($p < 0.001$), compared to privately-owned Level I/II centers. Compared to residential land use, commercial land use was associated with a 35.81% decrease in odds of death ($p = 0.001$), while industrial/agricultural land use reduced odds of death by 52.23% ($p = 0.002$), transportation land use reduced odds of death by 42.34% ($p < 0.001$), and institutional land use reduced odds of death by 47.27% ($p = 0.001$). Odds of death were 39.34% lower in ZCTAs with per capita income greater than $25,000, compared to ZCTAs with lower per capita income ($p < 0.001$). Odds of death increased by 2.10% for every 1-mile increase in distance from the injury scene to the hospital ($p < 0.001$).

Model 3 combines individual, structural, and social measures, to assess the effects of location-specific measures while controlling for individual characteristics. In the combined model, patients age 55-64 were 97.94% more likely to die than patients age 18-24 ($p < 0.001$), while odds of death were 3.02 times higher for patients are 65 to 74 ($p < 0.001$) and 4.30 times higher for patients age 75 and older ($p < 0.001$). Female patients were 39.61% less likely to die than male patients ($p < 0.001$). Compared to White patients, Hispanic patients were 52.61% less likely to die ($p = 0.004$), and patients with Other race and/or ethnicities were 54.85% less likely to die ($p < 0.012$). Odds of death for African American patients were not different than for White patients. Patients with severe injuries were 3.78 times more likely to die, compared to those with mild injury ($p < 0.001$), while critical injuries were associated with a sixty-fold increase in mortality (OR = 60.70, $p < 0.001$). Compared to patients with blunt injuries, patients with penetrating injuries were 5.27 times more likely to die ($p < 0.001$), while patients with other types of injury were 8.26 times more likely to die ($p < 0.001$). Public insurance was associated with a 72.82% increase in odds of death relative to private insurance ($p = 0.001$), while lack of insurance was associated with a four-fold increase in odds of death (OR = 4.05, $p < 0.001$). Total prehospital time was not associated with changes in mortality for patients with blunt injuries, but odds of death did increase by 5.72% for every 5-minute increase in prehospital time for patients with penetrating injuries ($p < 0.001$), by 15.43% per 5-minute increment for patients with both blunt and penetrating injury ($p = 0.011$), and by 4.76% per 5-minute increment for patients with other injury mechanisms ($p = 0.012$). Distance from the injury scene to the nearest trauma center was associated with a 1.52% increase in odds of death for every 1-mile increase in distance ($p = 0.026$). Compared to privately-owned Level I/II centers, odds of death increased by 80.65% when the nearest trauma center was publicly-owned and designated Level III ($p < 0.001$), and odds of death increased by 49.89% when the closest trauma center was a privately-owned Level III center ($p = 0.021$). Commercial land use was associated with a 32.58% decrease in odds of death, relative to residential land use ($p = 0.014$), while transportation land use was associated with a 69.99% increase in odds of death ($p < 0.001$). ZCTA median age was associated with a 3.00% increase in odds of death for every additional year in age ($p = 0.015$), and ZCTA per capita income greater than $25,000 was associated with a 26.56% decrease in odds of death ($p = 0.050$), relative to lower ZCTA incomes.

Assessment of Spatial Dependence

Visual examination of the semivariance of the standardized residuals for the null model (Figure 2.3) and Model 1 (Figure 2.4) indicated some residual spatial dependence at the individual level. Moran's I indicated residual spatial dependence at the ZCTA level for both the null model (I = 1.00, $p < 0.001$) and for Model 1 (I = 0.014, $p < 0.001$). While Moran's I indicated residual spatial dependence at the ZCTA level for Model 2 (I = 0.149, $p < 0.001$) the semivariogram did not indicate residual spatial dependence at the individual point level (Figure 2.5). Neither Moran's I (0.001, $p = 0.272$), nor the semivariogram (Figure 2.6) indicated spatial dependence for Model 3.

Sensitivity Analysis

When records without exact location of the injury scene were excluded from Model 3, the effect of moderate injury was associated with a 60.72% decrease in mortality, relative to mild injury ($p = 0.015$). While the effect size observed in the sensitivity analysis is comparable to the effect observed in the primary analysis (OR = 0.39, $p = 0.236$), the effect of moderate injury was statistically significant in the sensitivity analysis. The effect of ZCTA per capita income did not change in magnitude or direction, but was not statistically significant in the sensitivity analysis. There were modest changes in the effect size for other covariates, but no other changes in direction or significance were observed.

Assessment of Predictive Ability

Based on predicted probability of death for records excluded during the model development process, the sensitivity of Model 1 was 68.55% when 10% probability of death is used to identify fatal cases, and 56.84% when the threshold for identifying fatalities was 20% probability of death. The specificity for Model 1 at each point was 85.58% and 92.93%, respectively. For social and environmental measures alone (Model 2), sensitivity was 45.90% and

1.76% at respective cut points, while specificity was 72.26% and 99.05%. Finally, for Model 3, sensitivity was 70.90% at the first cut point and 57.62% at the second cut point, while specificity was 84.65% and 93.30% at the respective points. Predicted probabilities from Models 2 and 3 did not exceed 30% probability of death; therefore, model performance measures are not available for predicted probabilities greater than 30%. The area under the ROC curve (Figure 2.6) was 78.01% (95% CI: 75.70, 80.31), 59.36% (95% CI: 57.11, 61.61), and 78.45% (95% CI: 76.17, 8.73) for Models 1 through 3, respectively.

DISCUSSION

This study is the first of its kind to combine data from the MTR with prehospital records from the Maryland EMS system, including incident location information. By linking data from these sources, I was able to associate individual characteristics and outcomes with characteristics of the incident scene and community where the injury occurred. While prior studies have examined distance from the nearest trauma center and trauma center designation as measures of trauma center access,[1,2,46] distance is generally considered as a proxy for prehospital time, and not as an independent predictor of mortality. To my knowledge, this is the first study to examine a broad range of spatially-defined characteristics present at the injury scene as determinants of injury mortality, while also controlling for individual patient characteristics.

Men, African Americans, and older adults were overrepresented in the study sample relative to the overall population in Maryland,[146] which is consistent with known patterns in injury incidence in the United States.[10] The effects of age, sex, injury severity, and insurance status identified in this analysis were comparable to the findings of prior studies addressing the role of these factors in determining injury outcomes.[39,51,54,55,57-59,73,74] The apparent relationship between injury mechanism and mortality observed in this study mirrors prior studies of mechanism as a determinant of injury outcomes, with penetrating injury leading to increased odds of death compared to blunt injury.[26,30,102] The observed differences in the effect of prehospital time by mechanism reinforce the role of mechanism in determining mortality.

Findings regarding the relationship between African American race and injury mortality were inconsistent with prior studies of race as a determinant of injury outcomes,[5,37-44] possibly due to the geographic distribution of African American residents in Maryland, relative to the physical location of trauma centers. Prior studies of race as a determinate of injury mortality have not controlled for prehospital time or proximity to trauma centers.[5,37-44] There is evidence that average travel time to the nearest trauma center is greater for African Americans than for White patients in the United States;[3] however, observed travel times for African Americans in this study were significantly shorter than for White patients. Shorter travel times for African Americans may contribute to better outcomes than expected based prior studies, while longer prehospital intervals in other states drive disparities in mortality at the national level. Given the role of prehospital time in determining mortality, especially for penetrating injury, it is potentially a critical mediator of the relationship between race and mortality.

Increases in distance from the injury scene to the nearest trauma center were associated with increased mortality, even when controlling for prehospital time, indicating that the role of distance in determining outcomes extends beyond distance as a determinant of prehospital time. One factor contributing to the role of distance may be the level of EMS care available in locations further from trauma centers, with more remote locations served by EMS providers with lower service levels than those available in urban centers. It is also possible that the sequence and duration of prehospital events differs for incidents in remote locations, compared to urban and suburban locations. For example, incidents in urban and suburban areas may have short EMS arrival times and still have longer prehospital intervals due to extrication efforts or on scene treatment, while longer intervals in rural areas may stem from extended periods of time prior to EMS arrival on scene.

Level I or II designation of the trauma center closest to the injury scene was found to reduce mortality, which is consistent with prior evidence of the protective benefit of treatment at Level I or II centers.[13] Similarly, private ownership of the trauma center closest to the injury scene was associated with improved outcomes. Prior research on the relationship between hospital ownership and mortality is limited, with only one study specifically examining ownership as a determinant of injury mortality; however, these studies do suggest a protective effect of private ownership, possibly due to higher resource levels and earlier adoption of emerging technologies.[90,147]

The results of this study suggest that injury incidents in commercial land use spaces have the lowest probability of mortality while odds of death are highest in spaces with transportation land use. While no studies to date have examined land use as a determinant of injury mortality, my findings conflict with prior hypotheses that agricultural and industrial land use spaces carry greater risk of mortality, based on presumed differences in injury mechanism and severity due to land use features.[32] It is possible that the public nature of these spaces confers some benefit following an injury incident, as the presence of witnesses increases the likelihood of bystander first aid and may reduce prehospital time with immediate calls for EMS response. In contrast, incidents in transportation land use spaces (e.g. motor vehicle crashes) may be associated with prolonged prehospital times due to EMS travel delays caused by the incident and time spent extricating patients from vehicles. The relationship between transportation land use and mortality changed drastically when individual characteristics were included in the model, suggesting that the population injured in transport-related spaces are at low risk of mortality compared to the total sample of injury patients included in the study, potentially due to the low incidence of penetrating injury in motor vehicle crashes.

ZCTA level median age and per capita income were both associated with mortality. The risk associated with ZCTA median age and mortality is in addition to the risk associated with individual age, and potentially results from the demands an older population places on an EMS system. Injury incidence is higher among older adults than other age groups,[148] and EMS care for older adult populations may require more personnel, time, and resources than response to injuries for younger adults.[149] Higher median age at the ZCTA level suggests a disproportionately large number of older adults living in the community, which may strain the resources available for prehospital care. Per capita income below $25,000 per year was also associated with increased odds of mortality. This may reflect the impact of individual socioeconomic indicators that were not measured in the MTR, but may also reflect differences in the level of prehospital care available in low income communities, or differences in care delivered by trauma centers serving predominantly poor populations, compared to those serving wealthier or economically mixed communities. Based on prior studies, there is evidence that population level socioeconomic measures are related to individual health outcomes, independent of individual socioeconomic status.[83,84]

The overall predictive ability of location-based measures, without adjustment for individual patient characteristics, was limited. Specificity for the location-only model was high, suggesting that location characteristics alone may be useful for identifying very low risk regions with limited need for additional EMS and trauma center services. Sensitivity of the location-only model was low, and the addition of spatial variables to established determinants of injury mortality did not significantly improve predictive performance, compared to individual characteristics alone. This indicates that location alone is not sufficient to identify individual patients at the highest risk for injury mortality, but features of the built environment and community-level social environment may provide critical guidance for injury prevention and response efforts.

Limitations

The sample used for this study was limited to patients treated at designated trauma centers in Maryland, including those who were initially treated at a non-trauma center and subsequently transferred to a designated trauma center, as well as patients who died in EMS care at the injury scene or while in transit. Patients treated at non-trauma centers without transfer to a designated trauma center were not included in the study, nor were individuals who died prior to EMS arrival at the injury scene. These patients represent a small, but potentially meaningful, subset of the injury cases who potentially faced greater barriers to medical care than the general population, introducing some concerns regarding selection bias. This is a well-documented limitation of trauma systems research, and NASEM have identified integration of data from community hospitals and death certificate data as a critical step for expanded trauma outcomes research and quality improvement efforts.[48] These concerns are largely mitigated by the comprehensive protocols for patient triage and transport in place for Maryland EMS providers, an extensive network of public air ambulance services, and the relatively small geographic area of the state, which in combination greatly reduce the number of high risk injury patients who are initially treated at non-trauma centers.

A large number of records in the sample lacked information regarding the exact location of the injury incident, and therefore could not be linked with measures of the built environment. Patterns of missingness were examined by county, mortality outcome, demographic characteristics, and month of incident to rule out likely causes of nonignorable nonresponse. The data appeared to be missing at random, and were imputed using predicted mean matching. Differences in observed and MI imputed measures were significant for transportation land use and prehospital time. A sensitivity analysis excluding records without exact location suggests that the missingness and imputation generally had minimal impact on the study results, but it is possible that an unknown or unmeasured covariate was causally associated with missing location information.

The MTR includes a limited set of codes for comorbid conditions which may underrepresent select conditions or the overall severity of comorbidities, contributing to the lack of association between comorbidities and mortality that is inconsistent with prior literature.[52,53] Comorbidity codes in the MTR are collected based on the best available information at the time of trauma center treatment, which further limits the ability to accurately measure mortality risk related to comorbidities from patients who are unable to respond to health history questions due to the extent of their injuries.

Finally, generalizability of this study to communities outside of Maryland is limited by the unique organization of EMS and trauma care systems in Maryland, and by the relatively small size of the state. In many ways, the Maryland system represents a best-case scenario for the delivery of trauma care, with clear triage and treatment protocols that are implemented using a standardized approach throughout the state. It is likely that states with more variation in EMS and trauma care would see greater effects from features of the built environment and social factors that act as barriers to care. The analyses conducted in this study should be replicated with data from other states, ideally representing a range of approaches to EMS and trauma system organization.

CONCLUSION

This study confirms the role of several individual variables in determining injury mortality, while suggesting that structural, environmental, and social measures also contribute to individual health outcomes. Distance from the injury scene to the nearest trauma center is a particularly strong determinant of injury mortality, independent of prehospital time. In addition to determining prehospital time, distance to the nearest trauma center may be associated with differences in timing, sequence, and/or quality of prehospital care. Future studies should examine the sequence and duration of events during the prehospital interval, paying attention to changes in the prehospital experience as distance from the injury scene to the trauma center increases. Findings from such studies may be especially helpful in the development of recommendations for use of ALS and other prehospital interventions. As researchers identify communities impacted by geographic variation in prehospital care, policymakers, including county and state level EMS directors in Maryland, should consider novel approaches to address the limitations of EMS care in underserved communities, including full time employment of physician assistants and advanced practice nurses who can serve as first responders and primary care providers, and recruitment and training programs focused on retention of EMS providers.

The apparent relationship between injury mortality and community level measures of age and per capita income suggests that the level and quality of EMS services in a community depends, at least in part, on EMS resources, caseloads, and system demands. Future research, including qualitative studies of EMS provider experience, should examine the relationship between community demographics, EMS patient load, quality of care, and patient outcomes. EMS medical directors should reassess allocation of EMS resources on a regular basis, to ensure that EMS providers have adequate resources and that resources are distributed appropriately to meet the changing needs of the communities they serve. Policymakers should also consider tailored training and resources for EMS providers serving communities with unique needs, such as those with a high proportion of older residents. For example, EMS medical directors might consider additional training in geriatric medical needs for paramedics serving older communities, or implementation of comorbidities screening programs in low income communities where undiagnosed comorbid conditions may impact injury outcomes.

Despite hypothesized injury risk associated with agricultural/industrial, commercial, and institutional land use,[32] these spaces appear to be associated with reduced injury mortality, while residential and transportation land use spaces are associated with increased mortality. These patterns may result from the types of injuries occurring in specific land use areas, the demographic and health characteristics of people injured in specific land use areas, or patterns of prehospital care associated with land use type. Future studies should examine patterns of injury incidence and treatment associated with land use type. Consideration of land use as it relates to injury incidence and mortality may be helpful when distributing EMS resources, including personnel and specialized equipment.

TABLES AND FIGURES

Figure 2.1: Inclusion Flow Chart

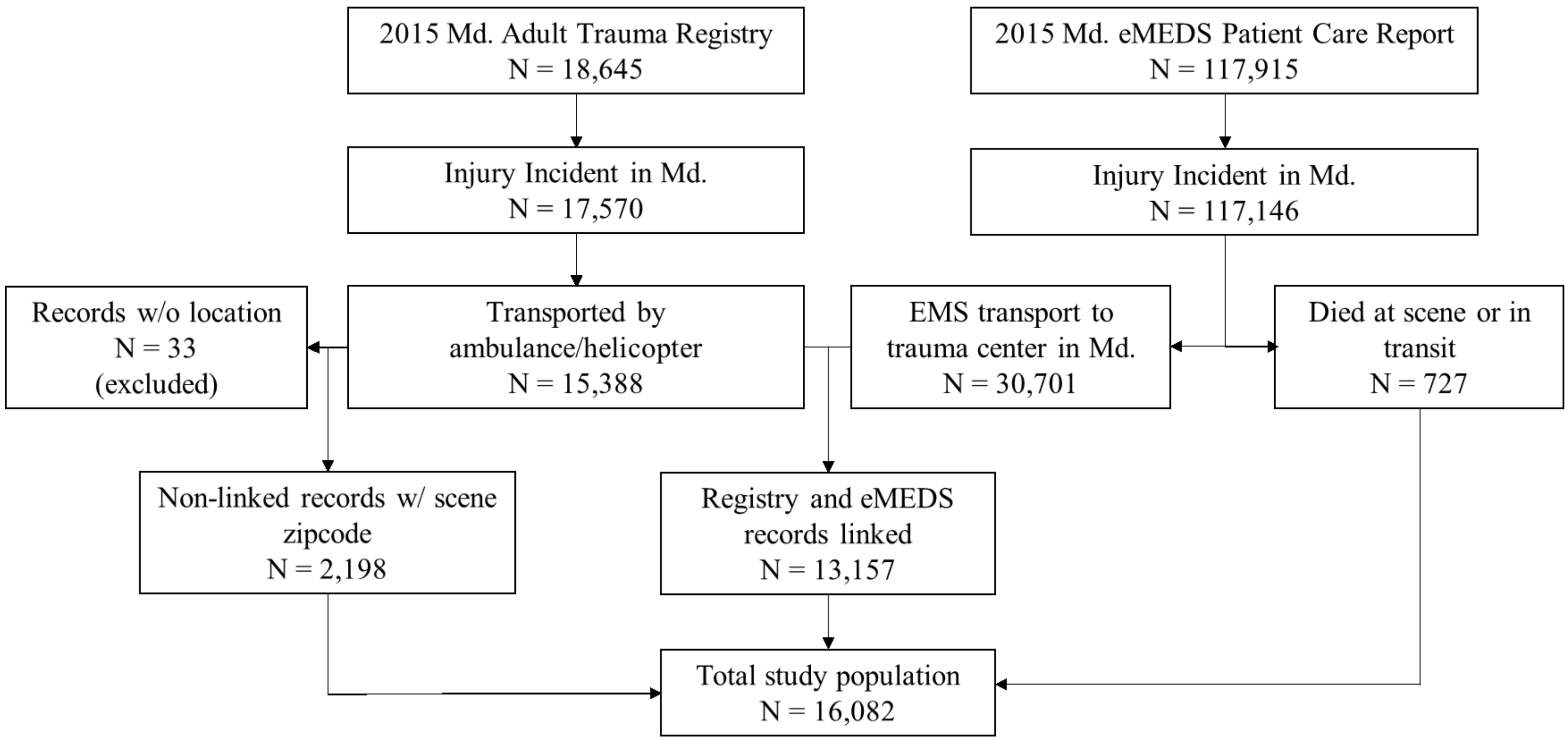

Figure 2.2: Spatial Distribution of ZCTA-Level Injury Incidence

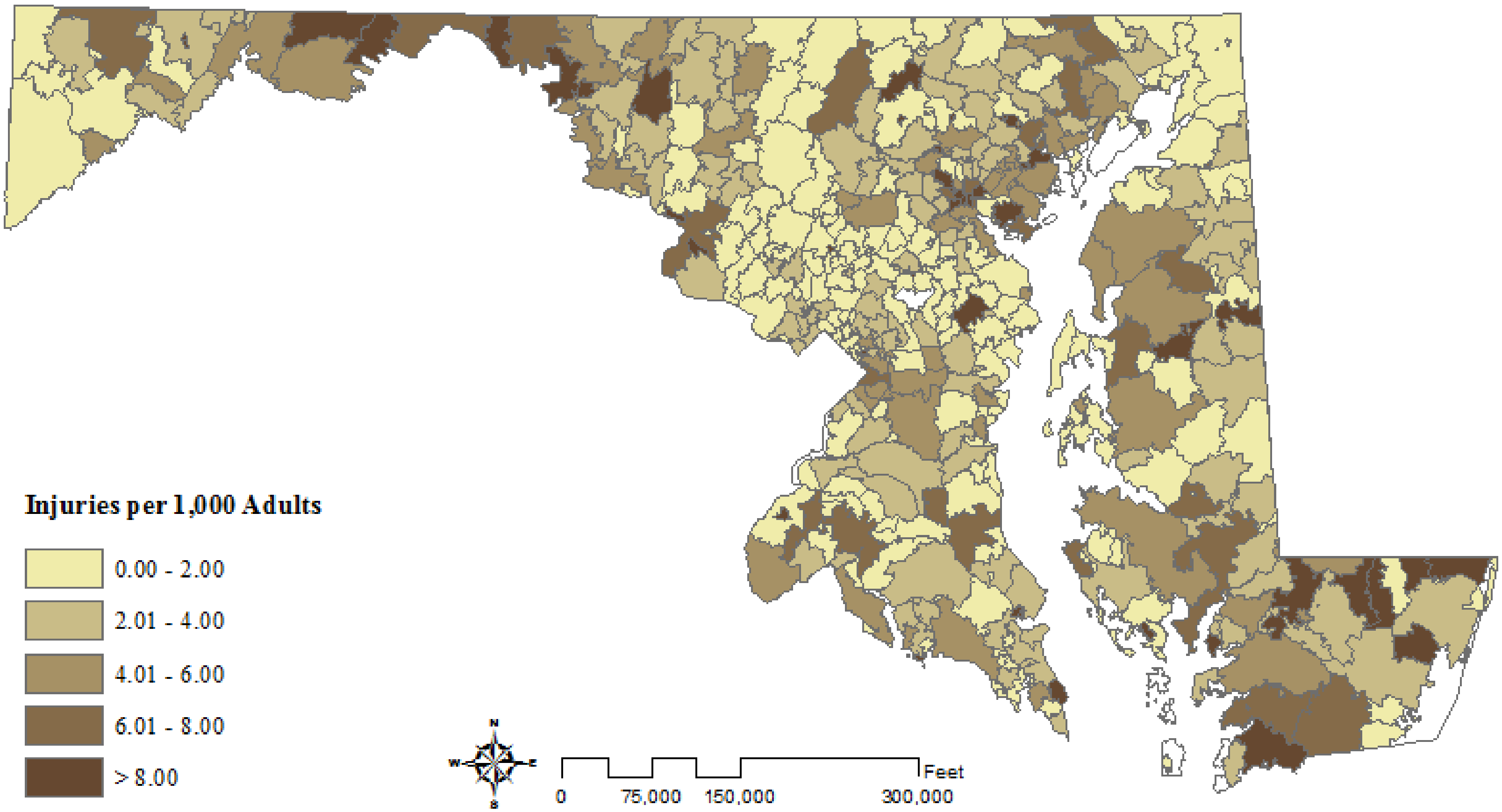

Table 2.1: Observed and MI estimated sample characteristics				
	Missing (%)	Observed (%/mean)	MI Estimated (%/mean)	95% CI for MI Estimates
Age	1.07			
18-24		15.56	15.59	15.02, 16.15
25-34		20.49	20.47	19.84, 21.10
35-44		13.24	13.23	12.71, 13.76
45-54		14.39	14.39	13.84, 14.93
55-64		13.34	13.32	12.79, 13.85
65-74		8.57	8.58	8.14, 9.02
75+		14.41	14.42	13.87, 14.97
Sex	0.00			
Male		65.79	65.79	65.06, 66.53
Female		34.21	34.21	33.47, 34.94
Race and/or ethnicity	1.98			
White		52.46	52.43	51.64, 53.22
African American		36.26	36.28	35.52, 37.04
Hispanic		5.99	6.01	5.64, 6.38
Other		5.28	5.28	4.93, 5.63
Injury Severity	5.22			
Mild		91.84	89.76	89.11, 90.41
Moderate		3.22	3.65	3.32, 3.97
Severe		3.03	4.41	3.94, 4.88
Critical		1.91	2.18	1.95, 2.41
Injury Mechanisms	0.00			
Blunt		81.94	81.94	81.34, 82.54
Penetrating		12.82	12.82	12.30, 13.33
Blunt & Penetrating		2.43	2.43	2.19, 2.66
Other		2.82	2.82	2.56, 3.07
Charlson Index	4.52			
0		94.56	94.62	94.23, 95.02
1-4		5.02	4.96	4.58, 5.34
5+		0.42	0.42	0.32, 0.52
Insurance status	14.82			
Private		40.59	39.58	38.76, 40.41
Public		40.28	40.34	39.46, 41.22
None		19.13	20.08	19.29, 20.87
Hospital type	31.13			
Private, Level I/II		43.97	44.00	43.09, 44.91
Public, Level I/II		41.51	42.05	41.21, 42.90
Private, Level III		14.52	13.94	13.19, 14.69
Land use	31.15			
Residential		33.43	41.14	40.13, 42.15
Commercial		9.12	11.96	11.32, 12.60
Industrial/Agricultural		3.28	4.38	3.96, 4.79
Undeveloped		3.78	4.98	4.57, 5.38
Transport		44.15	30.81	30.09, 31.53
Institutional		6.25	6.74	6.28, 7.19
ZCTA Per capita income	0.02			
< $25,000		25.72	25.71	25.04, 26.39
> $25,000		74.28	74.29	73.61, 74.96
ZCTA median age (mean years)	0.02	38.15	38.15	38.07, 38.23
Miles to trauma center (mean)	31.13	9.12	9.90	9.65, 10.15
Prehospital time (mean minutes)	27.09	51.17	64.55	63.16, 65.95

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Table 2.2: Coefficients (log odds) from bivariate logistic regression on mortality			
	β	95% CI	*p*
Age			
18-24	Ref	--	--
25-34	0.029	-0.182, 0.239	0.789
35-44	0.001	-0.227, 0.229	0.993
45-54	-0.044	-0.265, 0.177	0.697
55-64	0.074	-0.151, 0.298	0.520
65-74	0.230	-0.024, 0.484	0.076
75+	0.202	-0.009, 0.412	0.061
Sex			
Male	Ref	--	--
Female	-0.728[a]	-0.864, -0.593	<0.001
Race and/or ethnicity			
White	Ref	--	--
African American	0.195[b]	0.054, 0.337	0.007
Hispanic	-0.556[b]	-0.906, -0.207	0.002
Other	-0.472[b]	-0.893, -0.051	0.028
Injury Severity			
Mild	Ref	--	--
Moderate	-0.650[b]	-1.156, -0.143	0.002
Severe	1.039[a]	0.811, 1.266	<0.001
Critical	4.048[a]	3.714, 4.381	<0.001
Injury Mechanisms			
Blunt	Ref	--	--
Penetrating	1.843[a]	1.716, 1.971	<0.001
Blunt & Penetrating	0.700[a]	0.352, 1.048	<0.001
Other	2.232[a]	2.021, 2.444	<0.001
Charlson Index			
0	Ref	--	--
1-4	-0.438	-1.143, 1.033	0.224
5+	0.511	-0.294, 1.317	0.213
Insurance status			
Private	Ref	--	--
Public	0.838[a]	0.644, 1.033	<0.001
None	1.492[a]	1.208, 1.777	<0.001
Hospital type			
Private, Level I/II	Ref	--	--
Public, Level I/II	0.227[b]	0.096, 0.358	0.001
Private, Level III	0.198[b]	0.009, 0.387	0.039
Land use			
Residential	Ref	--	--
Commercial	-0.487[a]	-0.712, -0.262	<0.001
Industrial/Agricultural	-0.647[b]	-1.004, -0.289	0.000
Forest/Barren/Open	-0.150	-0.426, 0.126	0.286
Transport	-0.496[a]	-0.635, -0.357	<0.001
Institutional	-0.477[b]	-0.767, -0.187	0.001
ZCTA Per capita income			
< $25,000	Ref	--	--
> $25,000	-0.337[a]	-0.458, -0.217	<0.001
ZCTA median age (years)	0.004	-0.006, 0.015	0.436
Miles to trauma center	0.010[a]	0.005, 0.016	<0.001
Prehospital time (minutes)	0.003[b]	0.001, 0.006	0.002

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Table 2.3: Coefficients (log odds) from individual, location, and combined regression models						
	Model 1		Model 2		Model 3	
	Individual measures		Built/Social Environment		Full model	
	β	95% CI	β	95% CI	β	95% CI
Constant	-4.175	-4.608, -3.743	-2.349	-3.156, -1.358	-5.512	-6.578, -4.446
Individual Measures						
Age						
18-24	Ref	--			Ref	--
24-34	-0.015	-0.333, 0.302			-0.008	-0.326, 0.310
34-44	0.161	-0.189, 0.511			0.184	-0.166, 0.534
45-54	0.094	-0.262, 0.451			0.126	-0.235, 0.486
55-64	0.623[b]	0.258, 0.986			0.673[a]	0.310, 1.035
65-74	1.104[a]	0.650, 1.439			1.105[a]	0.711, 1.499
75+	1.312[a]	0.947, 1.678			1.458[a]	1.087, 1.828
Sex						
Male	Ref	--			Ref	--
Female	-0.507[a]	-0.726, -0.289			-0.504[a]	-0.726, -0.283
Race and/or ethnicity						
White	Ref	--			Ref	--
African American	-0.181	-0.460, 0.098			-0.196	-0.474, 0.082
Hispanic	-0.709[b]	-1.221, -0.197			-0.747[b]	-1.259, -0.234
Other	-0.763[b]	-1.383, -0.142			-0.795[b]	-1.412, -0.178
Severity						
Mild	Ref	--			Ref	--
Moderate	-0.560	-1.217, 0.097			-0.611	-1.272, 0.050
Severe	1.292[a]	0.959, 1.626			1.329[a]	0.992, 1.666
Critical	4.146[a]	3.633, 4.658			4.106[a]	3.597, 4.615
Mechanism						
Blunt	Ref	--			Ref	--
Penetrating	1.356[a]	0.920, 1.792			1.663[a]	1.185, 2.140
Blunt & Penetrating	-1.173	-2.716, 0.369			-0.952	-2.538, 0.633
Other	1.994[a]	1.363, 2.626			2.111[a]	1.464, 2.758
Charlson Score						
0	Ref	--			Ref	--
1-4	-0.188	-0.980, 0.604			-0.254	-1.025, 0.597

5+	0.498	-0.783, 1.779			0.461	-0.826, 1.747
Insurance						
Private	Ref	--			Ref	--
Public	0.494[a]	0.244, 0.745			0.547[a]	0.290, 0.804
None	1.364[a]	0.976, 1.751			1.398[a]	1.010, 1.785
Prehospital time	0.002	-0.002, 0.007			0.002	-0.002, 0.007
Prehospital time X Mechanism						
Blunt	Ref	--			Ref	--
Penetrating	0.009[b]	0.003, 0.015			0.009[a]	0.003, 0.015
Penetrating & Blunt	0.030[b]	0.010, 0.051			0.026[b]	0.005, 0.048
Other	0.007[b]	0.000, 0.014			0.007	-0.000, 0.014
Social/Built Environment						
Trauma designation						
Private, Level I/II			Ref	--	Ref	--
Public, Level I/II			0.443[a]	0.218, 0.668	0.591[a]	0.332, 0.850
Private, Level III			0.294	-0.007, 0.596	0.405[b]	0.061, 0.749
Land use						
Residential			Ref	--	Ref	--
Commercial			-0.443[b]	-0.713, -0.173	-0.394[b]	-0.710, -0.079
Industrial/Agricultural			-0.739[b]	-1.202, -0.275	-0.467	-1.107, 0.173
Undeveloped			-0.089	-0.446, 0.267	0.113	-0.348, 0.575
Transport			-0.551[a]	-0.736, -0.366	0.531[a]	0.273, 0.788
Institutional			-0.640[b]	-1.064, -0.216	-0.253	-0.763, 0.257
ZCTA Median age (< 30 years)			0.015	-0.005, 0.035	0.030[b]	0.006, 0.053
ZCTA Per capita income						
< $25,000			Ref	--	Ref	--
> $25,000			-0.500[a]	-0.770, -0.230	-0.309[b]	-0.617, 0.000
Distance to trauma center			0.021[a]	0.012, 0.030	0.015[b]	0.002, 0.028
ZCTA SD	0.679		0.493		0.472	
ICC	0.171		0.130		0.125	
Moran's I	0.014[a]		0.149[a]		0.000	
AIC	3540.38		3508.73		1131.21	

[a] $p < 0.001$, [b] $p < 0.05$

Figure 2.3: Semivariogram of Standardized Residuals – Null Model

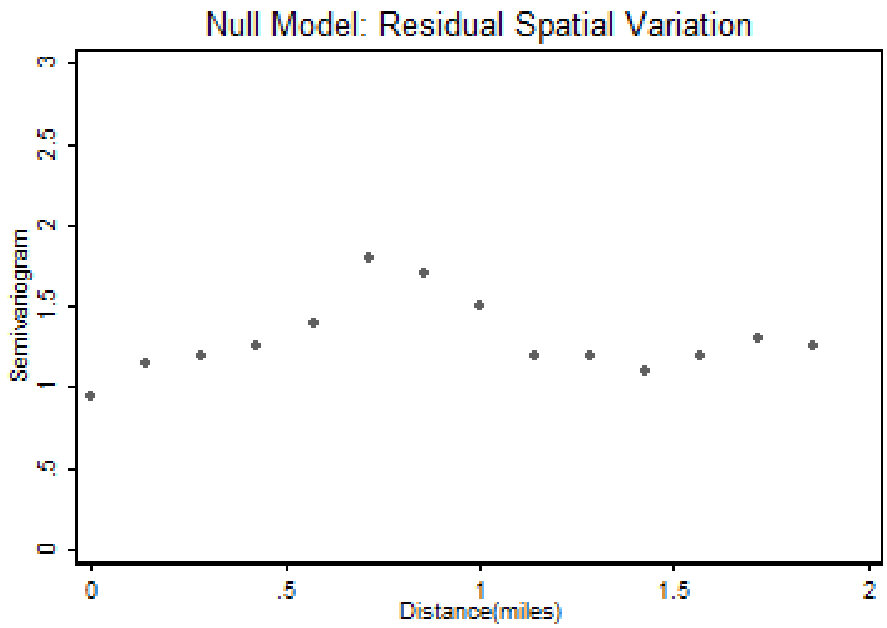


Figure 2.4: Semivariogram of Standardized Residuals – Model 1

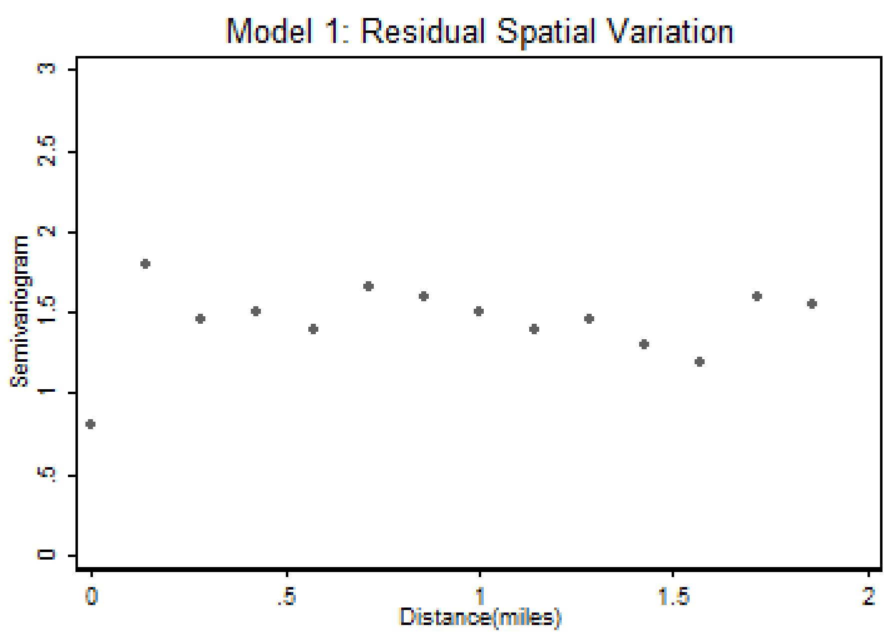


Figure 2.5: Semivariogram of Standardized Residuals – Model 2

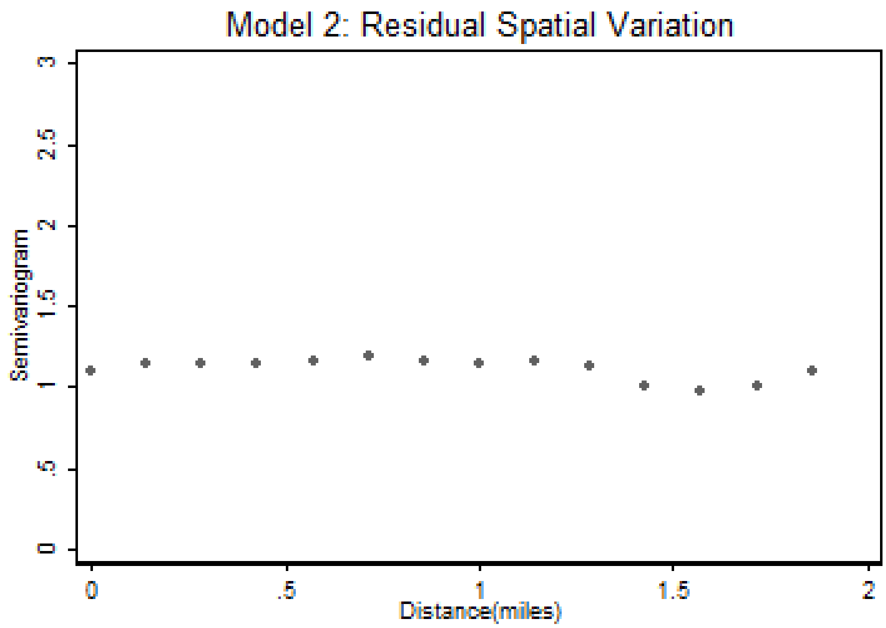


Figure 2.6: Semivariogram of Standardized Residuals – Model 3

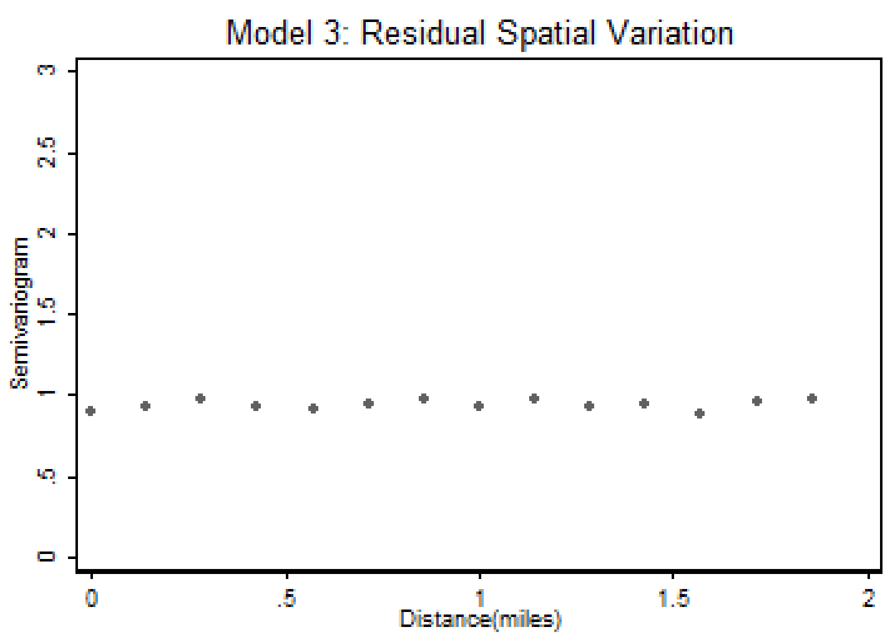
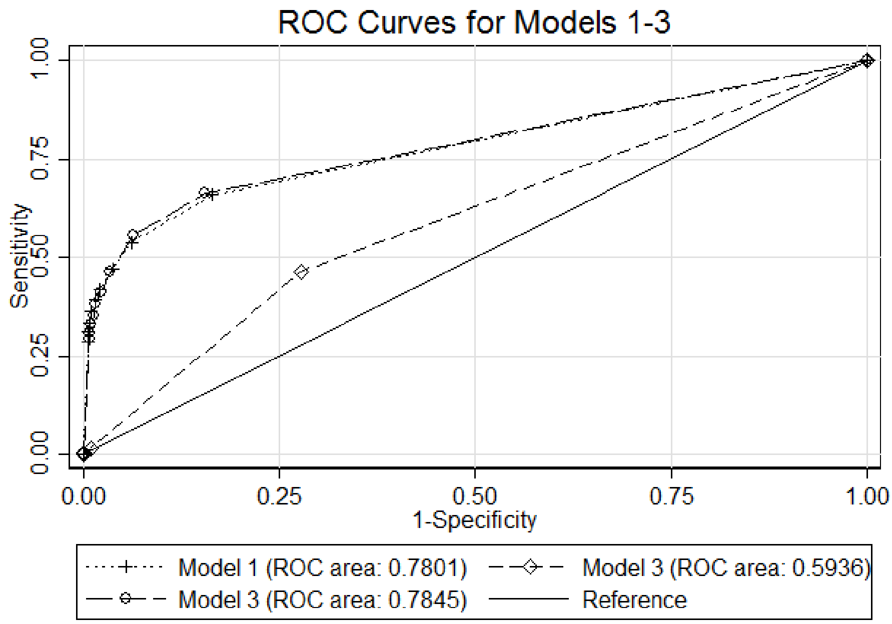


Figure 2.7: ROC Curves – Predicted vs. Observed Mortality



CHAPTER THREE: MANSCRIPT TWO

Mapping Areas with Concentrated Risk of Trauma Mortality

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ABSTRACT

Background: A disproportionate number of rural residents, historically underrepresented minorities, and people with low income lack access to timely trauma center care following traumatic injuries due to geographic barriers to care. These barriers to trauma center care may contribute to disparities in injury mortality. There is evidence that features of the physical environment and social context also contribute to injury disparities. Together with geographic barriers, the spatially defined determinants of mortality may compound the risk associated with individual demographic and injury characteristics. The primary objective of this study was to classify injury events based on features of the built and social environment at the injury scene using latent class analysis (LCA), and to examine patterns in individual demographics, injury characteristics, and injury mortality by location class.

Methods: Data from the 2015 MTR and eMEDS PCRS (n = 16,082) were used in a LCA of injury scene characteristics (trauma center distance, trauma center type, land use, ZCTA per capita income, and ZCTA median age). Distributions of individual characteristics and outcomes were examined by location class assignment, and logistic regression models were used to assess location class as a determinant of mortality, with and without adjustment for individual demographics and injury characteristics.

Results: Eight latent classes were identified: rural, exurban, young middle suburbs, aging middle suburbs, inner suburbs, urban fringe, high income urban core, and low income urban core. Individual demographic and injury characteristics varied across latent class groups. Odds of death varied by location class, with and without adjustment for individual demographic and injury characteristics, with the highest odds of death observed for rural, middle suburban, and low income urban core locations. Individual characteristics appear to confound the relationship between location class and mortality, with marked changes in estimated odds of death for several location classes after adjustment.

Conclusion: Characteristics of injury scenes can be categorized into distinguishable classes, and mortality risk varies across location classes. Identification of location classes may be useful for targeted primary prevention and treatment interventions, both by identifying geographic areas with the highest risk of injury mortality, and by identifying patterns of individual risk factors within location classes.

INTRODUCTION

EMS and trauma care providers in the United States adhere to a system of regionalization and accreditation in order to provide the highest level of injury care to as many people as possible,[6,7] based on the hypothesis that timely delivery of appropriate medical care following injury can reduce a patient's risk of death.[13-16] The primary aim of this approach if to maximize the number of people living within an hour of a Level I or II trauma center.[46,150] Under this system, injury scene location is the primary determinant of care received, and 90% of the United States population have timely access to medical care at a Level I or II trauma center.[151] Unfortunately, rural communities,[1-4] low income populations,[3,4] and historically underrepresented minority groups[3-5] are over represented among the 10% of the population without timely access to care. These disparities in access to care represent one of the greatest limitations of the United States emergency medical care system.[18] There is evidence that disparities in access to care contribute to disparities in injury outcomes, with an increased injury mortality among populations without access to timely trauma center care.[32-34]

Residential communities tend to cluster by socioeconomic status.[152] Most injury incidents in the United States occur within 10-miles of the patient's residence.[153] Together, these patterns suggest significant variation in the social context at injury incident locations. While little is known about the relationship between social context at injury incident locations and mortality, there is evidence that social context at trauma centers impacts outcomes for all patients, regardless of their individual characteristics.[84] Given known disparities in access to care,[1-5] it is possible that incident locations with increased risk due to social context also face increased risk due to geographic barriers to care. Unfortunately, our understanding of the relationship between incident scene location and mortality is limited, and the current approach to trauma system organization does not account for geographic variation in need for trauma care due to social context.

To address the limitations of the current approach to trauma system organization and guide trauma center designation decisions, the American College of Surgeons developed the Needs Based Assessment of Trauma Systems (NBATS) tool. The NBATS tool expands the distance-based assessment of trauma service need to include population density, injury incidence rates, presence of existing trauma centers, and community support for new trauma services.[150] While the NBATS tool represents a move towards a more comprehensive definition of trauma care need at the population level, it does not consider the potential for social and environmental risk factors related to injury incidence or mortality, nor does it offer guidance for delivery of prehospital care.

In Aim 1 of this dissertation (chapter two), I identified a set of social and environmental factors associated with injury mortality in Maryland, in addition to prehospital travel time. The primary objective of this study was to develop a profile of ecological factors associated with concentrated risk of mortality from traumatic injury through a LCA of incident location characteristics, and to examine the role of geographically concentrated risk as a determinant of injury mortality.

METHODS

Data Sources, Population, and Setting

This study used data from the 2015 MTR and eMEDS PCRS, as well as data from the Maryland Geographic Information Office and the United States Census Bureau. A full description of the data sets and exclusion criteria is available in chapter two of this dissertation.

Variables

The environmental and community level variables used in the development of latent class profiles were identified based on logistic regression results presented in chapter two, including distance from the injury scene to the nearest trauma center, the characteristics of the nearest trauma center (ownership and designation), land use at the injury scene, ZCTA per capita income, and ZCTA median age. Distance to the nearest trauma center was measured in miles, as described in chapter two. For use in this analysis, distance was categorized as 0-5-miles, 5-10-miles, 10-15-miles, 15-20 miles, or greater than 20 miles. Hospital type was categorized as private Level I/II, public Level I/II, or private Level III. ZCTA income was categorized as less than $20,000, $20,000-$30,000, $30,000-$40,000, or greater than $40,000. Median age was categorized as less than 30 years, 30-39 years, or greater than 40 years. Land use was categorized as residential, transportation, or other. Individual level variables used in regression models were age, sex, race and/or ethnicity, injury severity, injury mechanism, CCI, insurance status, and prehospital time. All individual variables were measured using the same definitions as described in chapter two.

Analytic Approach

The LCAs in this study were conducted using Stata 13[144] and the LCA Stata Plugin developed by Lanza, et al.[154] LCA was used to identify latent variables based on the categorical nature of the primary outcome (mortality), as well as the use cases associated with identification of discrete latent classes based on incident location characteristics. Alternatively, factor analysis could have been used to develop a continuous risk score based on probability of death associated with incident location characteristics; however, use cases for a continuous risk score are limited due to the spatial organization of EMS and trauma center service areas. As discussed in chapter two, missingness in this sample was addressed using multiple imputation with predicted mean matching. For the LCA, separate data sets were created for complete case data and for each imputed set of data. LCA models were initially tested using the complete-case data set, and the selected models were subsequently applied to each imputed data set. The number of classes tested ranged from two to thirteen. Model fit was assessed based Akaike Information Criterion (AIC), Consistent AIC (CAIC), Bayesian Information Criterion (BIC), adjusted BIC (aBIC), entropy, and visual examination of quantile-quantile plots of the standardized residuals for each model. AIC, CAIC, BIC, and aBIC are log likelihood-based measures that support comparison of statistical models and identification of the best fitting, most parsimonious model by balancing goodness of fit and model complexity.[155] Entropy is a measure of overlap across classes identified in a LCA, with values approach 1.0 indicating clear distinctions between classes.[156] While the information criteria and entropy are not sufficient to identify the best LCA model on their own, examination of the criteria together is useful for identification of a range of potential models that warrant further examination. After the range of potential models was narrowed based on the information criteria and entropy, quantile-quantiles plots of the standardized residuals provided a visual representation of changes in the distribution of residuals with increasing number of classes.[157] After identifying the best fitting, most parsimonious model, the LCA model was applied to each imputed data set and distributions of class membership and conditional probabilities were pooled using the guidelines for multiple imputation proposed by Rubin et al.[158] The probability of mortality for each class and conditional probabilities of class membership for each item were examined, then posterior probabilities were used to assign each pattern of location features to the most likely LCA class. A fishnet grid with quarter mile squares was overlaid on a map of Maryland, and latent classes were applied to each square based on the observed pattern of spatial measures. Class labels were developed based on conditional probabilities of class membership, visual assessment of the geographic distribution of location classes, and comparison of the geographic distribution of location classes with the classification of Maryland counties by the American Communities Project.[159] MI estimates of the distribution of individual characteristics were calculated for each class and logistic regression models were used to examine class membership as a determinant of mortality with and without adjustment for individual characteristics. Semivariograms of the standardized residuals were used to assess both regression models for residual spatial dependence at the individual level, and Moran's I was used to assess residual spatial dependence at the ZCTA level.[145]

Sensitivity analyses were used to assess the impact of historic events on injury mortality patterns during the study period. Baltimore City experienced a period of civil unrest in April 2015, which may have hindered EMS response, leading to increased injury mortality in the city. To assess the impact of the April 2015 events on study results, regression analyses were conducted on a subsample of injury incidents excluding locations in Baltimore City, as well as subsamples from March through January 2015 and May through December 2015.

RESULTS

Latent class model fit statistics are presented in Table 3.1 and the distribution of model fit statistics by number of classes is illustrated in Figure 3.1. Based on model fit statistics and the distribution of residuals, the eight-class model was selected as the best model for this analysis. While fit statistics for the nine, ten, and eleven class models do show improvement in model fit relative to the eight-class model, the improvements are relatively small. Visual examination of the quantile-quantile plots of the residuals (Figure 3.2) further suggests that the eight-class model is the best fitting, most parsimonious model.

Conditional probabilities and prevalence of class membership are presented in Table 3.2. Class 7 had the highest prevalence at 18.44%, followed by Class 5 (16.75%), Class 6 (15.73%), Class 8 (14.79%), Class 2 (11.19%), Class 4 (10.42%), Class 3 (9.66%), and Class 1 (3.02%). The geographic distribution of locations classes is illustrated in Figure 3.3. Class 1 locations were labeled as rural, and were mostly likely to be at non-residential locations more than 10-miles from a Level III trauma center, in communities with per capita income less than $30,000 and median age greater than 40 years. Class 2 locations were labeled as young middle suburbs, and were most likely to be between 5 and 15-miles from a Level I/II trauma center, in communities with per capita income greater than $30,000 and median age between 30 and 40 years. Class 3 locations were labeled as aging middle suburbs, with locations most likely to be more than 15-miles from a Level I/II trauma center, in communities with per capita income greater than $40,000 and median age greater than 40 years. Class 4 locations were labeled as low income urban core, and locations were most likely to be within 5-miles of a Level I/II trauma center, in communities with per capita income less than $20,000 and median age between 30 and 40 years. Class 5 locations were labeled as exurban, and locations were most likely to be more than 5-miles from the nearest trauma center regardless of designation, and in communities with per capita income between

$30,000 and $40,000, and median age greater than 40 years. Class 6 locations were labeled as high income urban core, and locations were most likely to be within 5-miles of a publicly-owned Level I/II trauma center, and in communities with per capita income between $20,000 and $30,000. Class 7 locations were labeled as urban fringe, and were most likely within 5-miles of a privately-owned Level I/II trauma center, and in communities with per capita income between $20,000 and $30,000. Finally, Class 8 locations were labeled as inner suburbs, and were most likely within 10-miles of a Level I/II trauma center, and in communities with per capita income greater than $30,000.

The MI estimated distributions of individual demographic, health, and injury characteristics are presented in Table 3.3. The case fatality rate was lowest for Class 8 (inner suburb); therefore, it was used as the reference class for examination of the distribution of individual characteristics. Case fatality rates for rural (11.61%) and low income urban core (12.93%) locations were higher than the case fatality rate observed for inner suburb locations (6.97%). People injured at low income urban core locations were more likely to be age 18-24 (19.72%) or age 25-34 (28.97%), compared to inner suburb locations (15.19% age 18-24 and 18.72% age 25-34), while those injured at high income urban core locations were more likely to be age 25-34 (25.11%). People injured at exurban locations were more likely to be age 55-64 (15.25%), compared to inner suburb locations (11.37%). People injured at Aging middle suburb locations were more likely to be age 65-74 (12.38%) while those injured at low income urban core locations were less likely to be age 65-74, compared to inner suburb locations (8.83%). People injured at rural, young middle suburb, low income urban core, high income urban core, and urban fringe locations were less likely to be age 75 or older (11.99%, 12.48%, 5.24%, 8.19%, and 14.88%, respectively), compared to inner suburb locations (19.92%). People injured at low and high income urban core locations were more likely to be male than those injured at inner suburb locations (75.29% and 71.67%, respectively, vs. 63.13%). Those injured at rural, aging middle suburb, and exurban locations were more likely to be White/Non-Hispanic than those injured at inner suburb (74.81%, 65.51%, and 79.73%, respectively, vs. 56.33%), while those injured at low and high income urban core locations were more likely to be African American (75.73% and 57.51%, respectively, vs. 31.25%). Compared to inner suburb locations, injuries at Aging middle suburb and exurban locations were more likely to be blunt (91.41% and 90.76%, respectively, vs. 84.07%) while injuries at Class low income urban core, high income urban core, and urban fringe locations were more likely to be penetrating (34.99%, 17.785, and 13.63%, respectively, vs. 10.66%). Injuries at Young middle suburb locations were less likely to be penetrating, compared to inner suburb locations (7.43% vs. 10.66%). People injured at low income urban core locations were less likely to have any comorbidities (2.95%), compared to inner suburb locations (4.85%), while those injured at rural and urban fringe locations were more likely to have CCI scores between 1 and 4 (9.06% and 6.74%, respectively, vs. 4.65%). Private insurance plans paid for 43.31% of inner suburb incidents, while 36.21% were paid with public insurance plans, and 20.48% of cases did not have insurance. People injured at rural and Aging middle suburb locations were more likely than inner suburb patients to have private insurance (56.28% and 48.77%) and less likely to be uninsured (10.38% and 14.04%). Those injured at low and high income urban core locations were more likely to have public insurance (49.74% and 44.465) or be uninsured (27.58% and 26.16%), compared to inner suburb locations, while those at low income urban core locations were also less likely to have private insurance (22.68%). People injured at exurban and urban fringe locations were more likely to have public insurance (41.45% and 40.53%), while those injured at exurban locations were less likely to be uninsured (12.64%) and those at urban fringe locations were less likely to have private insurance (38.33%). Finally, the mean prehospital time for inner suburb incidents was 61.53 minutes, which was longer than the mean prehospital interval for low and high income urban core locations (45.05-minutes and 54.11-minutes), and shorter than the mean prehospital intervals for Aging middle suburb and exurban locations (78.30 minutes and 91.78 minutes).

Figure 3.4 illustrates the estimated odds ratios and confidence intervals from logistic regression of latent class membership on mortality, with and without adjustment for individual characteristics. Class 8 (inner suburbs) was used as the reference class for both models. In the unadjusted model, odds of death for patients injured at low income urban core locations were nearly twice that of patients injured at inner suburb locations (OR = 1.98, p <0.001) and odds of death for patients injured at rural locations were 75% greater than those injured at inner suburb locations (p = 0.004). Odds of death for other classes were not significantly different than inner suburb locations. After adjustment for individual age, sex, race and/or ethnicity, insurance status, CCI, injury mechanism, prehospital time, and mechanism/time interaction, Rural location odds of death were nearly twice that of inner suburb locations (OR = 1.98, p = 0.002), while odds of death were 57% higher for Young middle suburb locations (p = 0.001), 36% higher for aging middle suburb locations (p = 0.034), and 38% higher for low income urban core locations (p = 0.035). Odds of death for high income urban core and urban fringe locations were not significantly different than inner suburb locations. Semovariograms of the standardized residuals for the unadjusted and adjusted models are presented in Figure 3.5. The semivariogram for the unadjusted model indicates some residual spatial dependence, but there is no evidence of residual dependence in the adjusted model. Moran's I for the unadjusted model indicated modest residual spatial dependence at the ZCTA level (I = 0.008, p = 0.012), while Moran's I for the adjusted model did not indicate residual spatial dependence (I = 0.002, p = 0.153).

Sensitivity Analyses

The most prevalent locations classes observed in Baltimore City were low income urban core (36.28%), high income urban core (22.89%), urban fringe (26.66%), and inner suburb (10.24%). Results of sensitivity analyses for these classes are presented in Table 3.4. When Baltimore City locations are excluded from the analyses, the unadjusted and adjusted odds ratios for low income urban core location, compared to inner suburb, increase to 7.85 (p < 0.001) and 4.19 (p < 0.001), respectively. The unadjusted and adjusted effects of high income urban core (unadjusted OR = 1.05, $p = 0.742$; adjusted OR = 1.07, $p = 0.711$) and urban fringe (unadjusted OR = 0.99, $p = 0.978$; adjusted OR = 0.88, $p = 0.657$) location remain non-significant compared to inner suburb locations. When the analyses are limited to incidents occurring between January 1, 2015 and March 31, 2015, the unadjusted effect of low income urban class is similar to the effect observed in the total sample (OR = 2.33, $p = 0.031$). The adjusted effect of low income urban class during the March-January time period (OR = 1.33) was similar to the effect observed for the total sample; however, the effect for the March-January time period was not statistically significant ($p = 0.613$). The effects of high income urban class (unadjusted OR = 0.97, $p = 0.926$; adjusted OR = 0.95, $p = 0.919$), and urban fringe (unadjusted OR = 0.96, $p = 0.897$; adjusted OR = 0.81, $p = 0.654$) were comparable to those observed for the total sample. For incidents occurring between May 1, 2015 and December 31, 2015, the effects of low income urban core (unadjusted OR = 1.91, $p < 0.001$; adjusted OR = 1.47, $p = 0.044$), high income urban core (unadjusted OR = 1.10, $p = 0.493$; adjusted OR = 1.19, $p = 0.355$), and urban fringe (unadjusted OR = 1.04, $p = 0.793$; adjusted OR = 0.98, $p = 0.930$) were comparable to the effects observed for the total sample.

DISCUSSION

The results of this study suggest that regions with high risk of injury mortality can be identified based on clustering of built environment and community-level social features at the injury scene. While prior studies have examined the built environment and community-level social measures as determinants of injury mortality,[1,32,35,45,46,84] this is the first study to identify patterns of clustering based on incident location characteristics, and to examine location classes as determinants of mortality. Eight distinct classes of injury location were identified in Maryland based on distance to the nearest trauma center, characteristics of the nearest trauma center, land use, ZCTA income and median age, with classes varying in the distribution of demographic, health, and injury characteristics, as well as case fatality rate. Inner suburb locations, marked by high ZCTA income and proximity to Level I/II trauma centers, had the lowest estimated odds of death in both the adjusted and unadjusted regression models.

Rural, middle suburban (young and aging), and exurban locations all appeared to have some barriers to care based on trauma center distance, with varying levels of income and age across locations. Rural locations had the second highest case fatality rate, and the highest odds of death after adjustment for individual characteristics. Estimated odds of death for rural locations increased following adjustment, suggesting that individual characteristics mask some of the risk associated with the location class. This is most likely explained by the low proportion of rural incidents with penetrating injuries, as well as the relatively large proportion of subjects with private insurance, despite the low median income associated with class membership. While odds of death for young middle suburb and aging middle suburb locations were not significantly different than those for inner suburbs in the unadjusted model, odds of death for both were significantly higher than inner suburban locations after adjustment for individual characteristics. The effects of both middle suburb classes were likely masked by high proportions of blunt injuries and individuals with private insurance, while higher proportions of female and White patients further masked the effect of Aging middle suburb locations. Odds of death for exurban locations were similar to inner suburb, despite barriers to care indicate by distances associated with class membership. Individuals injured at exurban locations were more likely to be White, have private insurance, and have blunt injuries, which are all associated with reduced injury mortality risk,[26,30,59,102] and may mitigate the effect of distance and prehospital time.

Low income urban core, high income urban core, and urban fringe locations were identified as high access based on distance, as were inner suburb locations. High income urban core and urban fringe locations were among the lowest risk classes identified based on case fatality rate, and adjusted estimates of mortality odds, and were not significantly different than inner suburb locations in terms of mortality. Compared to inner suburb locations, high income urban core and urban fringe locations had higher proportions of critical and penetrating injuries;

however, the mortality risk associated with the injury characteristics appears to be mitigated by shorter prehospital times, consistent with the relationship between injury mechanism, prehospital time, and mortality demonstrated in the literature[26,30] and in Chapter Two of this dissertation. Low income urban core locations had the highest case fatality rate of all location classes; however, the estimated odds of death decreased substantially after adjustment for individual characteristics, suggesting that high proportions of individual characteristics associated with increased mortality (e.g. African American race, male sex, and penetrating injury[26,30,57-71,102]) confounded the relationship between location class and odds of death. While adjustment for individual characteristics did significantly reduced the mortality effect attributed to low income urban core locations, it was the only urban location class with estimated odds of death that remained significantly greater than inner suburb locations after adjustment.

Based on the observed patterns in mortality and individual characteristics, location class assignments may be useful when tailoring primary prevention and injury response interventions. For example, the case fatality rate for incidents at low income urban core locations was especially high, despite proximity of Level I/II trauma centers. Low income urban core locations were also identified as having very low income at the community level, and very high incidence of penetrating injury. These characteristics suggest that low income urban core locations should be high priority targets for violence prevention interventions, as well as EMS efforts designed to respond to penetrating injuries. Rural locations were characterized primarily by lack of access to trauma care, with locations in the class most likely being more than 10-miles from a Level III trauma center. While individuals injured at rural locations were less likely to have penetrating injuries and more likely to have private insurance, compared to the total population, the case fatality rate for rural incidents was higher than expected, potentially due to extended prehospital times. This suggests that rural locations would benefit from primary prevention interventions to reduce blunt injuries, as well as EMS efforts to support patients with blunt injuries during prolonged response and transport intervals.

The results of this study confirm the need to consider factors other than distance and time to treatment when designating trauma centers and allocating hospital resources. The American College of Surgeon's NBATS effort[150] is a valuable first step towards a more comprehensive assessment of trauma center need. Population level measures of income, age, and other indicators of social context are readily available through many of the same sources used to measure population density, including the United States Census Bureau. The American College of Surgeons and other policymakers responsible for trauma center designation and system organization should consider inclusion of additional social measures when assessing need for additional trauma centers in a community.

Limitations

Generalizability of this study is limited to Maryland due to the unique structure of EMS and trauma care services in the state, as well as the geographic distribution of social and environmental factors related to injury mortality; however, it may be possible to validate these findings for other states and regions using publicly available data. With limits of generalizability in mind, the results of this study are still useful as a starting point for inquiry into the use of spatially defined data as predictors of injury mortality at the population level. Future studies should examine clustering of spatial risk factors in other regions, both as they are related to mortality and in relation to other injury characteristics and outcomes.

The potential for unmeasured confounding is also a concern, particularly for measures of prehospital service, trauma center quality, and community-level social measures. The social measures included in this analysis were identified as determinants of injury mortality in Aim 1 of this dissertation. While a full range of ZCTA and county level measures were considered in Aim 1 and excluded based on model fit and lack of significance, it is possible that additional social measures are related to injury outcomes at a more granular level than could be captured in this study.

Finally, there are concerns for internal and external validity due to historic events during the study period. This study used data from 2015 MTR, including data from Baltimore City during a period of civil unrest in the spring of 2015, and a subsequent rise in homicide incidence. There is considerable overlap between the low income urban core location class identified in this analysis and the neighborhoods most impacted by the unrest and increased homicide rate. It is possible that safety concerns for first responders, residual unrest, or other unmeasured factors impacted the delivery of care and injury outcomes in these areas. Low income urban core locations were observed in regions of the state not impacted by civil unrest, and the effect of low income urban core location increased when Baltimore City locations were excluded from analyses, , indicating that historic events cannot entirely explain the relationship between location and mortality for low income urban core locations, and mitigating concerns regarding internal validity. The unadjusted effect of low income urban core was similar for the months before and after the period of civil unrest. The adjusted effect of low income urban core location was also similar before and after the unrest, though the adjusted effect was not statistically significant for the January-March time period, likely to the decreased sample size. This stability in observed effect before and after the period of unrest suggests that the events of April 2015 did not significantly impact the geographic distribution of fatal injury incidents in the state. Homicide incidence rates have remained elevated in the two years following the 2015 unrest, supporting the continued relevance of these results for short term practice and policy, despite potential limitations for long term generalizability of the mortality risk attributed to low income urban core locations.

CONCLUSION

This study confirms that clusters of spatially defined risk factors for injury mortality are identifiable using LCA, and that the population of people experiencing injuries varies across location classes. The results of the regression analyses in this study suggest that the protective benefit of some location classes may compensate for the effect of individual characteristics, while individual characteristics may mask the effect of location in some instances.

The results of this study may be useful for planning and implementation of prevention and treatment efforts, including targeted efforts to reduce injury incidence, and identification of regions in need of additional prehospital or trauma center resources. For example, several neighborhoods in Baltimore City that fall within the low income urban core class are included in the Safe Streets program.[160] Public health and law enforcement officials from Baltimore City and other jurisdictions with low income urban core locations should consider further expansion of Safe Streets or other interventions following the Cure Violence model.[161] Motor vehicle crashes account for a substantial proportion of injury deaths in communities that fall within the rural location class. Policymakers with the Maryland Highway Administration and municipal transportation departments can use the map of location classes produced in this study to target roadway upgrades and behavioral interventions to the highest risk communities. Exurban locations were identified as having the longest prehospital intervals, indicating a need for reevaluation of EMS transport protocols by state and local EMS directors.

Public health practitioners at the state and local levels may be able to supplement these models used in this study with additional data not available to researchers, such as EMS narratives identifying specific barriers to treatment and transport, to support more nuanced tailoring of prevention and treatment efforts. Researchers should attempt to replicate this study in other regions, both to enhance our understanding of geographic concentration of injury risk factors, and to identify additional environmental and social factors that may improve our ability to identify regions with elevated injury mortality risk. Policymakers and practitioners should consider community level measures of income and age when making decisions regarding the allocation and designation of trauma centers.

TABLES AND FIGURES

Table 3.1: Model fit statistics					
# Classes	AIC (% change)	CAIC (% change)	BIC (% change)	aBIC (% change)	Entropy
1	14362.56	14475.47	14462.47	14421.16	1.00
2	8147.82 (43.27)	8382.33 (42.09)	8355.33 (42.23)	8269.52 (42.66)	0.68
3	6483.14 (20.43)	6839.24 (18.41)	6798.24 (18.64)	6667.95 (19.37)	0.73
4	4941.42 (23.78)	5419.12 (20.76)	5364.12 (21.10)	5189.34 (22.17)	0.79
5	3775.33 (23.60)	4374.63 (19.27)	4305.63 (19.73)	4086.35 (21.25)	0.73
6	2953.90 (21.76)	3674.79 (16.00)	3591.79 (16.58)	3328.03 (18.56)	0.81
7	2684.64 (9.12)	3527.13 (4.02)	3430.13 (4.50)	3121.87 (6.19)	0.82
8	2190.84 (18.39)	3154.92 (10.55)	3043.92 (11.26)	2691.17 (13.80)	**0.85**
9	2010.34 (8.24)	3096.03 (1.87)	2971.03 (2.39)	2573.78 (4.36)	0.81
10	1771.92 (11.86)	2979.20 (3.77)	2840.20 (4.40)	2398.47 (6.81)	0.84
11	1577.09 (11.00)	**2905.96 (2.46)**	**2752.96 (3.07)**	**2266.74 (5.49)**	0.80
12	**1529.69 (3.01)**	2980.16 (+2.55)	2813.16 (+2.19)	2282.44 (+0.69)	0.82
13	1565.76 (+2.36)	3137.83 (+5.29)	2956.83 (+5.11)	2381.62 (+4.35)	0.80

Figure 3.1: Model Fit Statistics by Number of Classes

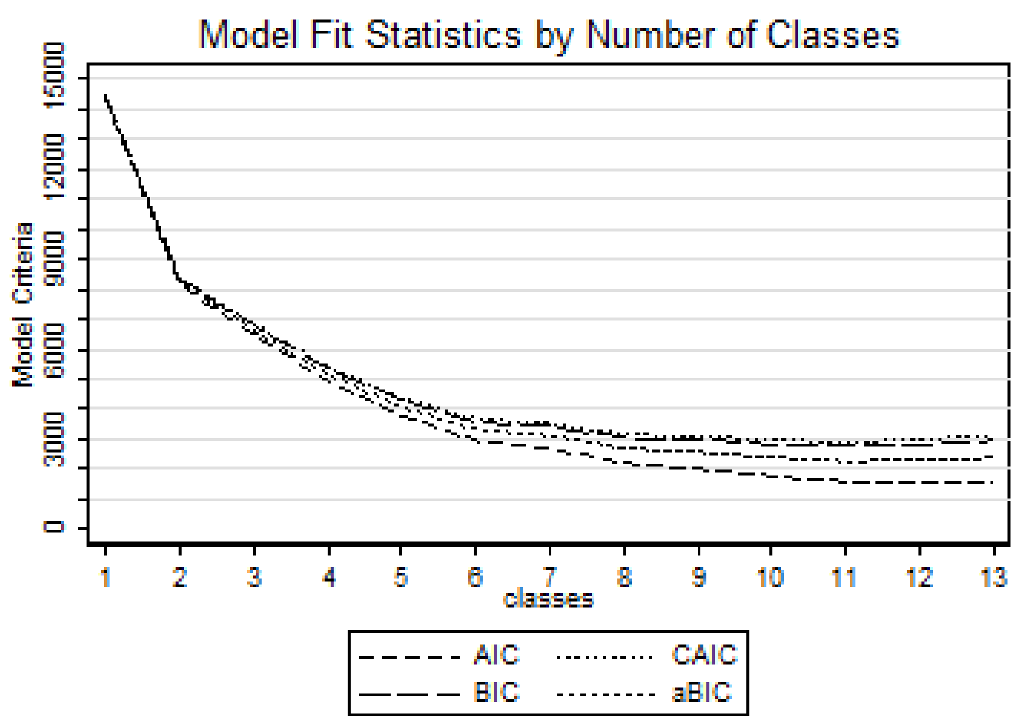


Figure 3.2: Quantile-Quantile Plots of LCA standardized residuals

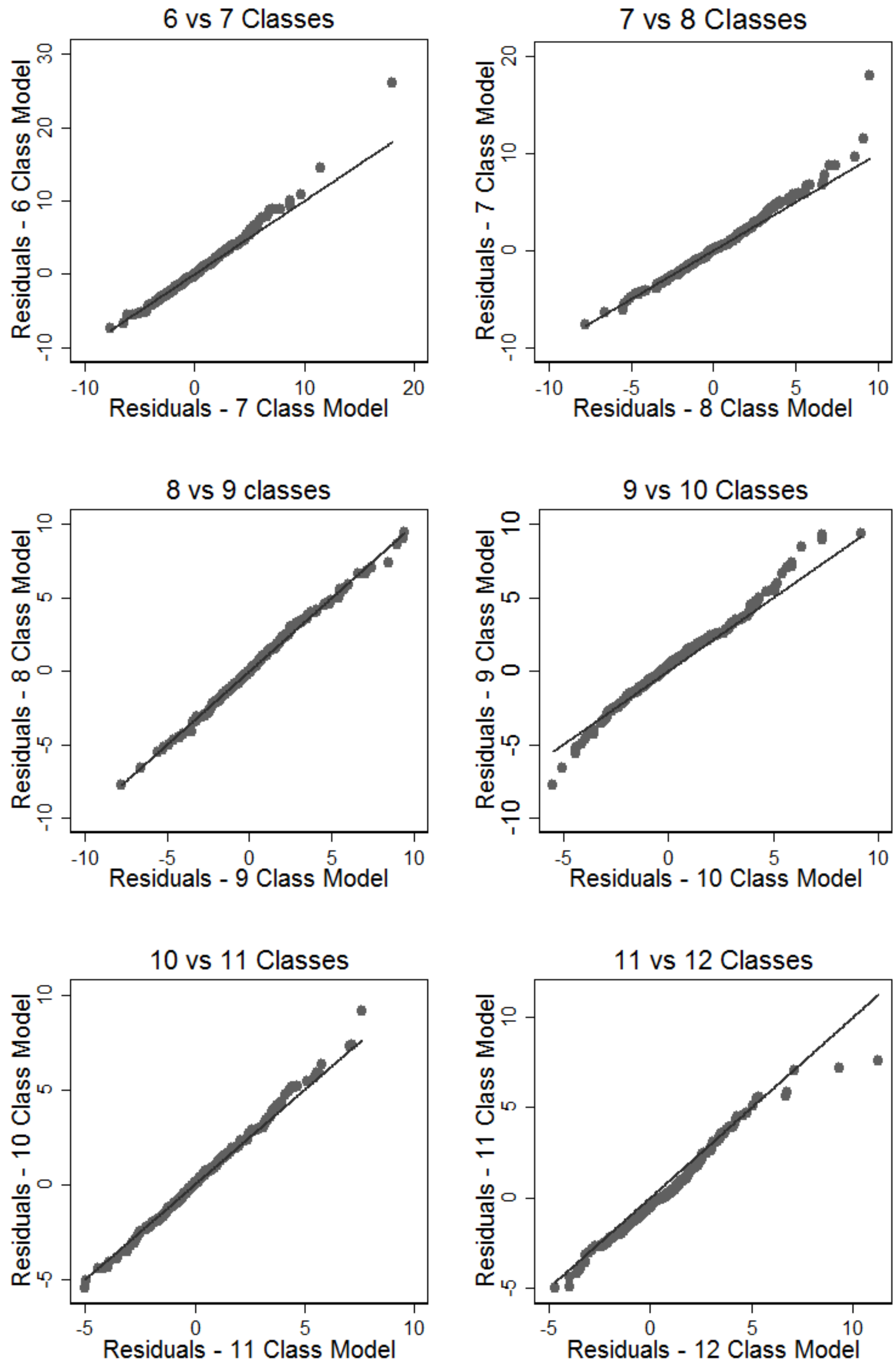


Table 3.2: Conditional Probabilities for Latent Classes

Class Label	Rural		Young Middle Suburb		Aging Middle Suburb		Low Income Urban Core		Exurban		High Income Urban Core		Urban Fringe		Inner Suburbs	
Class Number	1		2		3		4		5		6		7		8	
	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD	%	SD
% Observations	3.02	0.32	11.19	1.03	9.66	1.09	10.42	0.53	16.75	1.20	15.73	0.64	18.44	1.02	14.79	1.65
Hospital Type																
Private - I/II	0.078	0.040	0.009	0.028	0.420	0.024	0.630	0.020	0.568	0.021	0.035	0.010	0.740	0.031	0.633	0.045
Public - I/II	0.002	0.008	0.990	0.028	0.553	0.048	0.365	0.018	0.089	0.027	0.965	0.010	0.000	0.029	0.348	0.046
Private - III	0.920	0.041	0.000	0.003	0.026	0.032	0.006	0.004	0.343	0.020	0.000	0.002	0.260	0.013	0.020	0.010
Miles to Hospital																
1-5-miles	0.019	0.026	0.151	0.021	0.145	0.016	0.979	0.010	0.084	0.010	0.679	0.021	0.704	0.021	0.345	0.022
5-10-miles	0.204	0.037	0.217	0.046	0.187	0.014	0.018	0.007	0.197	0.015	0.236	0.018	0.158	0.019	0.464	0.022
10-15-miles	0.301	0.033	0.338	0.026	0.146	0.016	0.002	0.005	0.149	0.012	0.059	0.009	0.009	0.010	0.117	0.014
15-20 miles	0.189	0.025	0.068	0.010	0.208	0.015	0.000	0.001	0.130	0.012	0.006	0.003	0.033	0.009	0.072	0.011
20+ miles	0.287	0.044	0.182	0.036	0.315	0.017	0.000	0.001	0.440	0.021	0.020	0.006	0.096	0.008	0.001	0.006
Per capita income																
< $20K	0.216	0.029	0.001	0.003	0.011	0.008	0.869	0.040	0.002	0.004	0.052	0.012	0.000	0.001	0.000	0.001
$20K-$30K	0.781	0.030	0.007	0.017	0.000	0.001	0.071	0.032	0.111	0.023	0.948	0.013	0.979	0.051	0.168	0.063
$30K-$40K	0.001	0.003	0.451	0.076	0.009	0.034	0.000	0.001	0.637	0.048	0.000	0.000	0.001	0.036	0.534	0.046
>$40K	0.002	0.008	0.491	0.022	0.980	0.031	0.060	0.029	0.250	0.049	0.000	0.001	0.020	0.021	0.298	0.027
Median age																
< 30 years	0.131	0.020	0.001	0.001	0.000	0.001	0.004	0.003	0.000	0.000	0.313	0.015	0.001	0.001	0.000	0.000
30-40 years	0.342	0.049	0.795	0.032	0.002	0.009	0.598	0.015	0.136	0.016	0.686	0.016	0.761	0.013	0.997	0.015
> 40 years	0.527	0.044	0.225	0.044	0.998	0.009	0.397	0.016	0.864	0.016	0.000	0.001	0.238	0.013	0.003	0.015
Land use																
Residential	0.210	0.030	0.314	0.023	0.369	0.028	0.624	0.013	0.391	0.016	0.373	0.018	0.393	0.017	0.491	0.020
Transport	0.503	0.039	0.378	0.030	0.320	0.020	0.231	0.011	0.288	0.013	0.253	0.010	0.346	0.014	0.285	0.017
Other	0.287	0.032	0.292	0.023	0.311	0.024	0.145	0.011	0.321	0.014	0.374	0.017	0.261	0.012	0.224	0.014

Figure 3.3: Geographic Distribution of Latent Classes

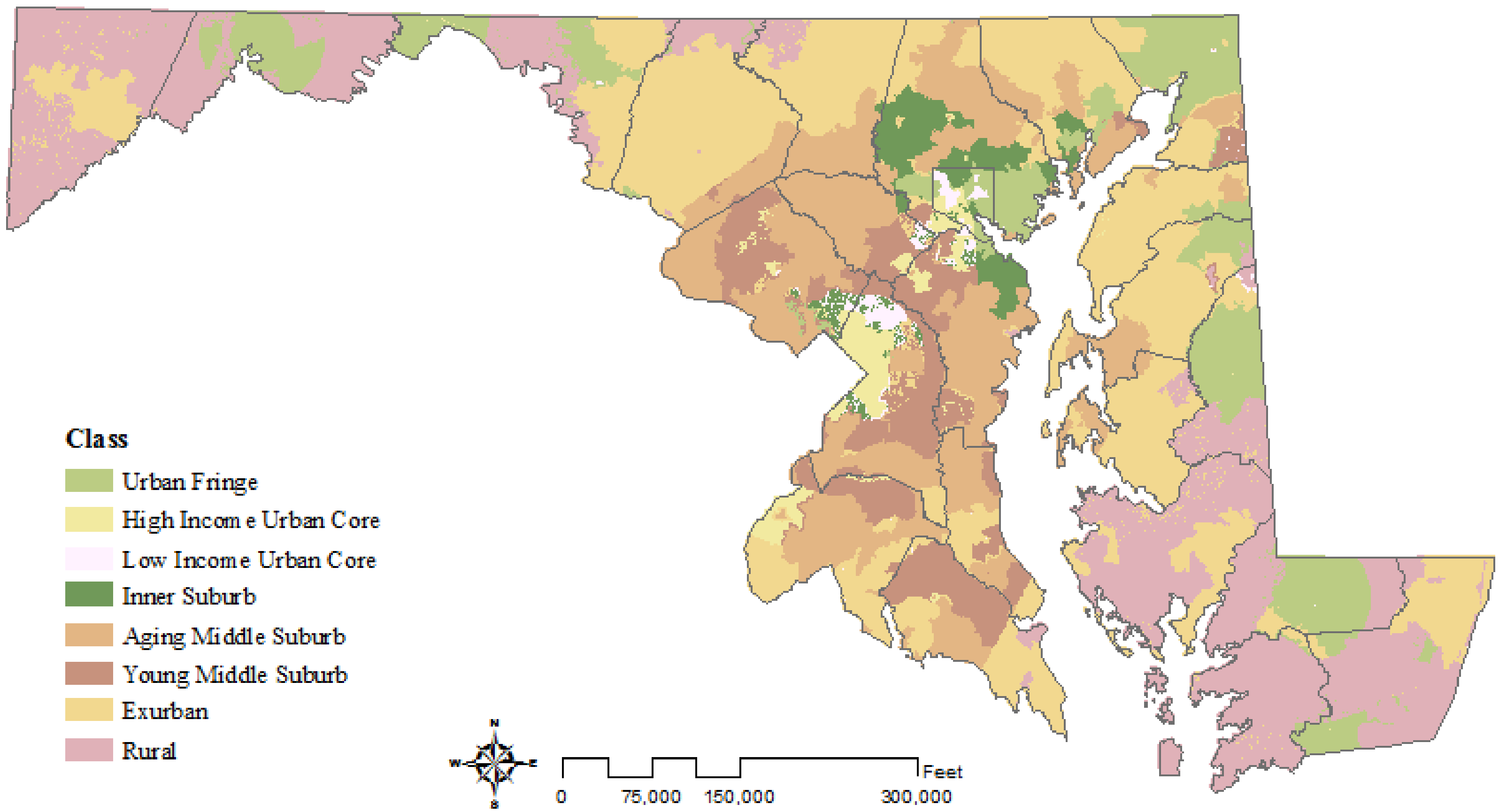
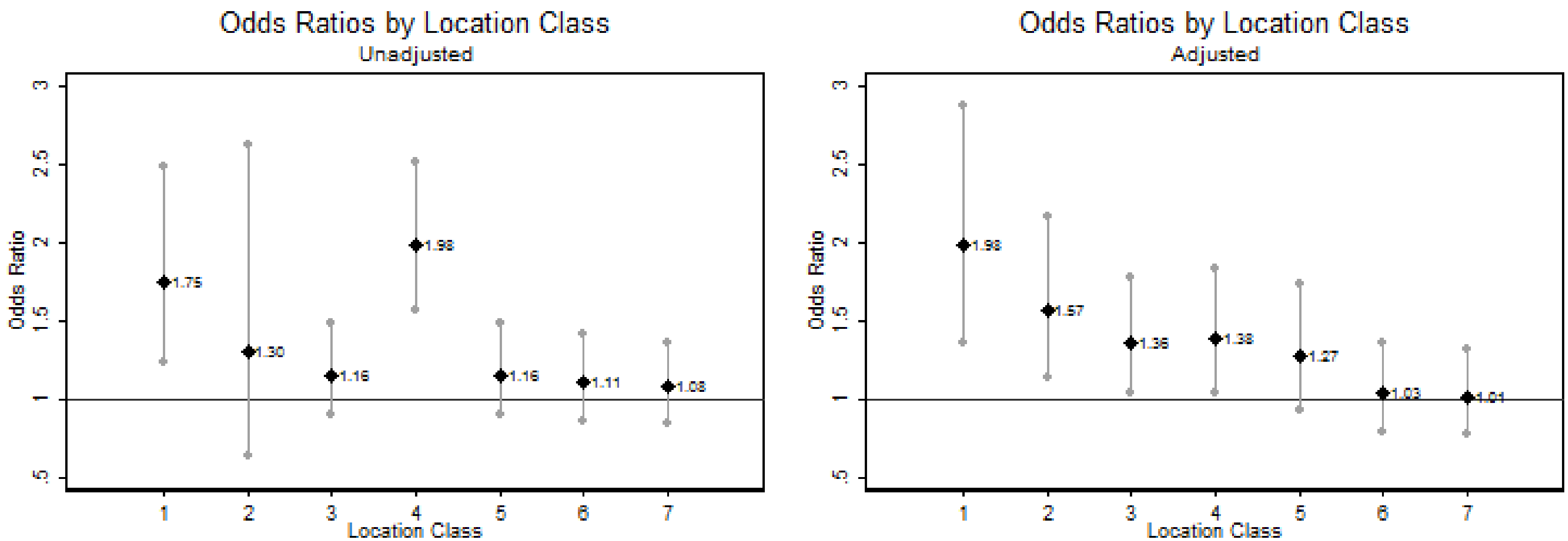


Table 3.3: Distribution of Individual Characteristics by Location Class								
	Rural	Young Middle Suburb	Aging Middle Suburb	Low Income Urban Core	Exurban	High Income Urban Core	Urban Fringe	Inner Suburbs
	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)
Died								
No	88.39 (85.49, 91.29)	91.12 (89.35, 92.89)	92.03 (90.83, 93.23)	87.07 (85.39, 88.75)	92.02 (90.81, 93.24)	92.35 (91.30, 93.40)	92.54 (91.62, 93.45)	93.03 (91.79, 94.27)
Yes	11.61 (8.71, 14.51)	8.88 (7.11, 10.65)	7.97 (6.77, 9.17)	12.93 (11.25, 14.61)	7.98 (6.76, 9.19)	7.65 (6.63, 8.70)	7.46 (6.55, 8.38)	6.97 (5.73, 8.21)
Age								
18-24	16.43 (12.95, 19.91)	16.56 (14.59, 18.53)	12.23 (10.74, 13.73)	19.72 (17.71, 21.73)	14.00 (12.44, 15.56)	17.02 (15.53, 18.52)	15.29 (14.03, 16.55)	15.19 (13.47, 16.91)
25-34	19.73 (15.91, 23.55)	20.12 (17.41, 22.84)	15.25 (13.55, 16.94)	28.97 (26.67, 31.26)	16.10 (14.39, 17.81)	25.11 (23.37, 26.84)	20.31 (18.89, 21.73)	18.72 16.28, 21.17)
35-44	13.09 (10.11, 16.08)	15.28 (13.56, 17.00)	11.90 (10.47, 13.33)	15.03 (13.22, 16.83)	10.57 (9.20, 11.93)	15.66 14.14, 17.17)	12.16 (10.92, 13.40)	12.97 (11.43, 14.50)
45-54	13.84 (10.69, 16.99)	14.55 (12.67, 16.43)	14.08 (12.50, 15.66)	14.70 (12.92, 16.48)	13.77 (12.15, 15.40)	14.40 (12.94, 15.86)	15.70 (14.35, 17.05)	13.00 (11.45, 14.56)
55-64	14.12 (10.46, 17.79)	13.17 (11.42, 14.93)	14.87 (13.28, 16.45)	11.50 (9.88, 13.11)	15.25 (13.62, 16.88)	12.83 (11.47, 14.20)	13.47 (12.28, 14.66)	11.37 (9.73, 13.01)
65-74	10.79 (7.66, 13.91)	7.83 (6.44, 9.22)	12.38 (10.87, 13.90)	4.68 (3.58, 5.77)	10.38 (8.92, 11.84)	6.79 (5.75, 7.82)	8.18 (7.19, 9.17)	8.83 (7.27, 10.39)
75+	11.99 (8.73, 15.25)	12.48 (10.66, 14.30)	19.29 (17.50, 21.08)	5.42 (4.24, 6.60)	19.93 (18.15, 21.71)	8.19 (7.05, 9.34)	14.88 (13.57, 16.19)	19.92 (17.37, 22.47)
Sex								
Male	63.74 (59.29, 68.19)	65.25 (62.76, 67.74)	62.36 (60.18, 64.53)	75.29 (73.11, 77.47)	60.12 (57.87, 62.37)	71.67 (69.91, 73.44)	64.86 (63.11, 66.60)	63.13 (60.49, 65.76)
Female	36.26 (31.81, 40.71)	34.75 (32.26, 37.24)	37.64 (35.47, 39.82)	24.71 (22.53, 26.89)	39.88 (37.63, 42.13)	28.33 (26.56, 30.09)	35.14 (33.40, 36.89)	36.87 (34.24, 39.51)
Race/Ethnicity								
White	74.81 (70.89, 78.72)	45.06 (39.94, 50.17)	65.51 (63.00, 68.02)	18.77 (16.76, 20.78)	79.73 (77.53, 81.94)	27.40 (25.56, 29.25)	59.95 (58.12, 61.77)	56.33 (50.90, 61.76)
African American	18.40	37.12	20.08	75.73	12.72	57.51	32.13	31.25

	(14.79, 22.01)	(33.50, 40.73)	(18.18, 21.98)	(73.54, 77.92)	(10.95, 14.49)	(55.49, 59.54)	(30.34, 33.91)	(27.78, 34.71)
Hispanic	4.02 (2.17, 5.88)	9.78 (7.31, 12.24)	6.95 (5.73, 8.17)	2.36 (1.55, 3.17)	2.99 (2.20, 3.79)	9.69 (8.46, 10.92)	4.16 (3.44, 4.87)	6.46 (4.27, 8.66)
Other	2.77 (1.08, 4.46)	8.05 (6.63, 9.46)	7.46 (6.21, 8.71)	3.14 (2.26, 4.02)	4.55 (3.42, 5.69)	5.39 (4.44, 6.35)	3.77 (3.04, 4.50)	5.96 (4.71, 7.21)
Injury Severity								
Mild	89.85 (87.11, 92.60)	90.68 (88.86, 92.50)	90.66 (89.15, 92.17)	89.59 (87.98, 91.20)	90.81 (89.08, 92.55)	91.78 (90.55, 93.02)	90.51 (89.03, 91.98)	91.34 (89.71, 92.97)
Moderate	4.22 (2.34, 6.09)	4.15 (3.10, 5.20)	4.37 (3.37, 5.37)	3.00 (1.53, 4.47)	3.56 (2.61, 4.51)	3.38 (2.62, 4.14)	3.71 (2.90, 4.52)	3.20 (2.34, 4.05)
Severe	4.85 (2.82, 6.87)	4.41 (3.28, 5.55)	4.17 (3.10, 5.24)	4.93 (3.76, 6.09)	4.63 (3.50, 5.75)	3.63 (2.61, 4.65)	4.59 (3.48, 5.69)	4.61 (3.40, 5.83)
Critical	1.08 (0.13, 2.03)	0.76 (0.24, 1.28)	0.80 (0.36, 1.24)	2.49 (1.03, 3.94)	1.00 (0.00, 2.27)	1.21 (0.68, 1.74)	1.20 (0.76, 1.65)	0.85 (0.31, 1.38)
Injury Mechanism								
Blunt	86.94 (83.93, 89.95)	86.76 (84.91, 88.61)	91.41 (90.03, 92.79)	59.55 (57.10, 62.00)	90.76 (89.44, 92.07)	76.87 (75.21, 78.53)	80.08 (78.59, 81.56)	84.07 (82.33, 85.82)
Penetrating	7.22 (4.78, 9.66)	7.43 (5.89, 8.96)	4.88 (3.78, 5.97)	34.99 (32.61, 37.37)	5.11 (4.07, 6.14)	17.75 (16.25, 19.25)	13.63 (12.38, 14.87)	10.66 (9.23, 12.09)
Blunt & Penetrating	1.50 (0.41, 2.60)	2.37 (1.64, 3.09)	1.34 (0.84, 1.85)	3.20 (2.32, 4.07)	1.67 (1.09, 2.26)	2.25 (1.66, 2.84)	3.49 (2.86, 4.13)	2.49 (1.79, 3.19)
Other	4.34 (2.47, 6.21)	3.44 (2.52, 4.36)	2.37 (1.69, 3.06)	2.26 (1.51, 3.00)	2.46 (1.76, 3.17)	3.12 (2.42, 3.83)	2.80 (2.20, 3.41)	2.78 (2.02, 3.54)
Charlson Index								
0	90.70 (87.93, 93.48)	95.24 (94.07, 96.41)	95.12 (94.07, 96.17)	97.05 (96.20, 97.90)	93.30 (92.15, 94.45)	95.80 (94.97, 93.08)	93.08 (92.15, 94.00)	95.15 (94.15, 96.15)
1-4	9.06 (6.34, 11.79)	4.32 (3.22, 5.41)	4.31 (3.30, 5.32)	2.56 (1.77, 3.35)	5.90 (4.81, 6.98)	3.72 (2.95, 4.50)	6.74 (5.84, 7.64)	4.65 (3.65, 5.64)
5+	0.23 (0.00, 0.72)	0.45 (0.09, 0.80)	0.57 (0.24, 0.90)	0.39 (0.07, 0.71)	0.80 (0.42, 1.19)	0.48 (0.21, 0.75)	0.18 (0.02, 0.35)	0.20 (0.00, 0.42)
Insurance Status								
Private	56.28 (51.44, 61.12)	44.08 41.44, 46.73)	48.77 46.26, 51.27)	22.68 (20.36, 24.99)	45.91 (43.05, 48.76)	29.38 (27.52, 31.24)	38.33 (36.37, 40.29)	43.31 (41.05, 45.57)
Public	33.34 (28.28, 38.39)	34.90 (31.84, 37.97)	37.19 (34.22, 40.16)	49.74 (46.96, 52.52)	41.45 (38.95, 43.96)	44.46 (42.28, 46.63)	40.53 (38.66, 42.40)	36.21 (33.88, 38.55)

None	10.38 (7.02, 13.75)	21.01 (18.49, 23.53)	14.04 (12.18, 15.90)	27.58 (24.94, 30.22)	12.64 (10.95, 14.32)	26.16 (24.16, 28.17)	21.14 (19.61, 22.68)	20.48 (18.27, 22.69)
Prehospital time (mean minutes)	68.70 (61.99, 75.42)	66.91 (62.42, 71.40)	78.30 (73.25, 83.36)	45.05 (42.64, 47.46)	91.78 (85.95, 97.61)	59.16 (56.14, 62.19)	54.11 (51.65, 56.58)	61.53 (58.65, 64.40)

Figure 3.4: Mortality Odds Ratios by Location Class



Class 8 (Inner Suburb) is the reference class for odds ratios. Adjusted model included age, sex, race/ethnicity, insurance status, CCI, severity, mechanism, prehospital time, and mechanism/time interaction. Class 1 = Rural, Class 2 = Young Middle Suburb, Class 3 = Aging Middle Suburb, Class 4 = Low Income Urban Core, Class 5 = Exurban, Class 6 = High Income Urban Core, Class 7 = Urban Fringe.

Figure 3.5: Semivariograms of Standardized Residuals for Unadjusted and Adjusted Regression Models

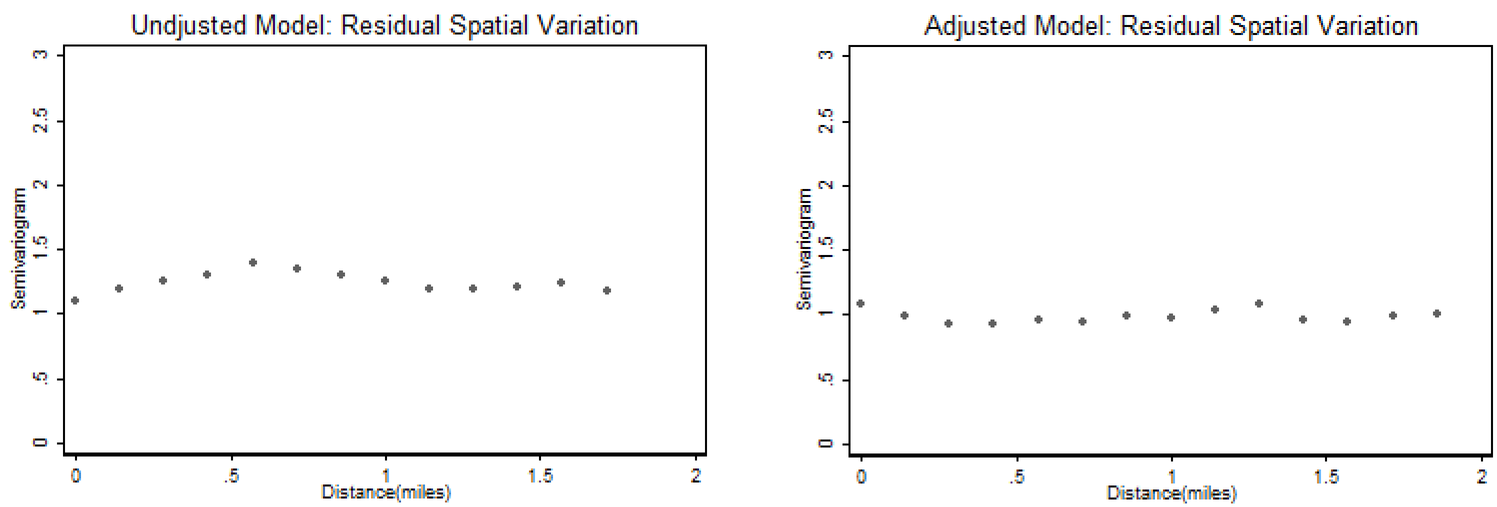


Table 3.4: Odds Ratios from Sensitivity Analyses						
	Unadjusted			Adjusted		
	Odds Ratio	95% CI	*p*	Odds Ratio	95% CI	*p*
Excl. Baltimore City						
Low Income Urban Core	7.85	4.94, 12.48	< 0.001	4.19	2.20, 7.99	< 0.001
High Income Urban Core	1.05	0.79, 1.38	0.742	1.07	0.74, 1.55	0.711
Urban Fringe	0.99	0.76, 1.30	0.978	0.88	0.88, 0.52	0.657
Jan-March Only						
Low Income Urban Core	2.33	1.13, 4.80	0.031	1.33	0.45, 3.89	0.613
High Income Urban Core	0.97	0.49, 1.92	0.926	0.95	0.36, 2.49	0.919
Urban Fringe	0.96	0.49, 1.87	0.897	0.81	0.33, 1.02	0.654
May-December Only						
Low Income Urban Core	1.91	1.48, 2.47	< 0.001	1.47	1.03, 2.09	0.044
High Income Urban Core	1.10	0.84, 1.44	0.493	1.19	0.83, 1.72	0.355
Urban Fringe	1.04	0.80, 1.34	0.793	0.98	0.56, 1.69	0.930

CHAPTER FOUR: MANUSCRIPT THREE

Factors Mediating Demographic Determinants of Injury Mortality

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ABSTRACT

Introduction: Disparities in injury mortality by race, ethnicity, and sex are well documented. While differences in injury incidence can partially explain these disparities, little is known about the factors that contribute to differences in outcomes following traumatic injury. This study sought to examine the clinical, spatial, and social factors that mediate the relationships between individual demographic characteristics and injury mortality.

Methods: Using data from the 2015 MTR (n = 16,082), potential mediators were identified based on their bivariate relationships with each independent variable (race, ethnicity, sex), as well and their relationships with injury mortality, while controlling for the relevant independent variable. Multivariate mediation models were then used to estimate the total and direct effects of African American race, Hispanic ethnicity, and male sex on injury mortality, as well as the indirect effects of each mediating variable.

Results: The effect of race was fully mediated by the combined effects of prehospital time, trauma center distance, injury mechanism and insurance status. The direct effect of race was modestly protective (c' = -0.058, CI: -0.105, -0.011), while the total effect of race demonstrated a slight increase in odds of death for African American patients, relative to White patients (c = 0.055, CI: 0.016, 0.095). The effect of ethnicity was partially mediated by penetrating injury and lack of insurance, and inconsistently mediated by trauma center distance and Medicare enrollment. Both the direct effect (c' = -0.144, CI: -0.202, -0.085) and the total effect (c = -0.121, CI: -0.176, -0.066) of ethnicity indicate reduced odds of death for Hispanic patients, relative to White patients. The effect of sex was partially mediated by injury severity, injury mechanism, and lack of insurance, while Medicare enrollment and prehospital time inconsistently mediated the effect of sex. The direct effect of male sex was modestly protective (c' = -0.058, CI: -0.105, -0.011), while the total effect (c = 0.055, CI: 0.016, 0.095) represented a small increase in odds of death.

Conclusion: Access to care, injury characteristics, and insurance type mediate the effects of race, ethnicity, and sex as determinants of injury mortality. These relationships suggest that social, spatial, and clinical factors may contribute to disparities in injury outcomes. Policymakers and providers should address differences in access to and quality of trauma care as determinants injury mortality.

INTRODUCTION

Disparities in injury mortality by race,[5,37-43] ethnicity,[38,43,44] and sex[57-59] are a troubling presence in the United States trauma care system. While injury incidence patterns can partially explain differences in injury mortality, differences in injury outcomes also contribute to injury disparities. Little is known about factors mediating the relationships between individual demographics and injury mortality, which limits the effectiveness of public health and medical interventions to reduce disparities.

Disparities in Injury Incidence and Outcomes

The current body of literature consistently demonstrates high injury mortality and worse long-term outcomes for African American[5,37-43] and Hispanic[38,43,44] patients, compared to Non-Hispanic White injury patients. Disparities in injury mortality are most pronounced among African American patients with mild to moderate injuries,[37] though race and ethnicity appear to modify the relationship between injury severity and death, with the effect of severity increasing for African American and Hispanic patients.[42] There is also evidence that insurance status may modify the roles of race and ethnicity as determinants of injury mortality, with lack of insurance further increasing the odds of death for African American and Hispanic patients.[39,40] The causes of racial and ethnic disparities in trauma outcomes are not clear. Among patients who receive treatment in trauma centers, there are no racial or ethnic differences in initial management of injury,[80] but African American and Hispanic patients may be less likely to reach trauma centers following injury due to geographic barriers to trauma center care.[4,75] There is evidence of disparities in injury care after the initial assessment and treatment in the ED. African Americans have shorter hospital stays,[44] are more likely to be transferred to nursing homes upon hospital discharge,[44] and are less likely to receive rehabilitation care following traumatic injury.[38,81] In addition to individual disparities in care, there is evidence that racial and ethnic disparities may stem from hospital-level differences, with higher mortality rates at hospitals with a large proportion of African American patients, compared to hospitals with mostly White trauma patients.[82-84]

Men are more likely than women to experience traumatic injury[57] and die from injuries,[58,59] though the relationship between sex and injury mortality appears to vary by age and type of injury.[59,62-68] Among patients with blunt injuries, men are more likely to die than women, but there is no apparent disparity in mortality between men and women with penetrating injuries.[66] Men are more likely to experience complications following injury,[65] and differences in body composition and hormones may support faster healing among women.[70,71] These differences do not fully explain observed differences in injury outcomes.

Demographics as Determinants of Care

Residential areas in the United States tend to be segregated by race and ethnicity,[152] making these characteristics direct determinants of the geographic spaces where people live, work, and play. While residential spaces generally are not segregated by sex, differences in occupation and recreation[146] do lead to differences in the places where men and women spend time. By determining where people spend their time, race, ethnicity, and sex indirectly determine prehospital time, trauma center distance, and the trauma center delivering medical care. Injury severity, injury mechanism,[10] and insurance status[162] also vary by race, ethnicity, and sex due to a broad range of social and cultural practices, both historic and contemporary.

In order to identify clinical, spatial, and social factors that contribute to disparities in injury outcomes, this study used data from the 2015 MTR and eMEDS PCRS records to conduct mediation analyses for race, ethnicity, and sex as determinants of mortality.

METHODS

Data Sources, Population, and Setting

This study used data from the 2015 MTR and eMEDS PCRS, as well as data from the Maryland Geographic Information Office and the United States Census Bureau. A full description of the data sets and exclusion criteria is available in chapter two of this dissertation.

Variables and Measures

Variables included in the mediation analyses for this study were identified based on logistic regression models described in chapter two of this dissertation. The independent variables of interest were race (African American vs. White), ethnicity (Hispanic vs. White), and sex (male vs. female). All three independent variables were coded as binary yes/no measures, based on patient self-report and/or provider assessment. The dependent variable of interest was mortality following traumatic injury. Potential mediating variables included insurance status, injury mechanism, injury severity, prehospital time, distance from the injury scene to the nearest trauma center, per capita income for the ZCTA of the injury scene, and ZCTA median age. Insurance status was coded as private, Medicare, Medicaid, or no insurance, based on the primary source of payment for trauma care services. Injury mechanism was coded as penetrating or not penetrating, based on external cause of injury codes. Injury severity was coded as mild, moderate, severe, or critical based on ISS and RTS, as described in chapter two. Prehospital time was measured in minutes based on the time of the initial 911 call for assistance and the time of arrival at the trauma center delivering definitive care. Distance was measured in miles based on the Euclidian distance between the injury incident scene and the nearest trauma center. ZCTA income was measured in dollars and ZCTA median age was measured in years, both based on data from the American Community Survey.[163]

Analytic Approach

Multiply imputed data were used for this analysis, as described in chapter two. Distributions and means of mediating measures were examined by race, ethnicity, and sex using MI estimated proportions for categorical variables and MI estimated means for continuous measures. For all regression analyses, parameters and standard errors were estimated separately for each imputation data set, then pooled using Rubin's methods for multiple imputation.[158]

Baron and Kenny's process for identifying mediation[164] was used to assess potential mediators and select variables for inclusion in each mediation model. Coefficients from bivariate regressions of independent variables on potential mediating variables ("a path") were estimated with simple linear regression for continuous mediators, and with simple logistic regression for binary mediators and binary dummy variables based on categorical mediators. Coefficients for the relationships between mediating variables and mortality were estimated using logistic regression while controlling for the relevant independent variable. Mediating variables were selected for inclusion in multivariate mediation models if the relationships with both the independent and dependent variables were statistically significant at $\alpha = 0.05$. Fully adjusted models were then estimated and likelihood ratio tests used to assess model fit. Variables that met the criteria for mediation but did not improve model fit were removed from the final mediation model. Semivariograms of standardized residuals were examined to assess each model for residual spatial dependence. No ZCTA level measures were included in the final mediation models; therefore, Moran's I was not calculated to assess residual spatial dependence at the ZCTA level.

Once variables were selected for each mediation model, multivariate logistic regression models were used to obtain estimates of the direct effect of the independent variable on mortality ("c' path"), and the "b path" effects of mediating variables on mortality. Parameters were estimated separately for each imputation data set, then pooled. Pooled estimates were used to calculate the scaled estimates and variance of the a, b, c, and c' paths using the method proposed by MacKinnon and Dwyer.[165] Standard errors for the direct, total, and indirect effects were estimated with bootstrapping using 500 repetitions, then pooled to estimate 95% confidence intervals.

RESULTS

Mediation of Race

MI estimated distributions and means of mediating variables by race, ethnicity, and sex are presented in Table 4.1. Private insurance and Medicare were less common among African American patients, compared to White patients (29.61% vs. 47.29%, and 6.36% vs. 19.72%), while a larger proportion of African American patients had Medicaid (37.70% vs. 20.58%) or were uninsured (26.33% vs. 12.41%). Penetrating injuries were more common for African American patients, compared to White patients (26.87% vs. 7.91%), while mean prehospital time and distance to the nearest trauma center were shorter for African American patients (55.99 minutes vs. 72.14 minutes; 6.55-miles vs. 12.34 miles). The mean per capita income for ZCTAs where African American patients were injured ($29,336) was lower than ZCTA level income for White patients ($35,112).

Table 4.2 presents coefficients from simple linear and logistic regression of independent variables on mortality and mediating variables on independent variables, as well as coefficients from multiple regression of mediating variables on mortality while controlling for respective independent variables. African American patients were 21.53% more likely to die than White patients ($p = 0.016$). Compared to White patients, prehospital intervals were 16.15-minutes shorter ($p < 0.001$) for African American patients, while trauma center distances were 5.79 miles shorter ($p < 0.001$). Per capita income at the injury scene was $5,775 less for African American patients ($p < 0.001$), and ZCTA median age was 2.98 years lower ($p <0.001$). African American patients were 4.28 times more likely than White patients to have a penetrating injury ($p < 0.001$), 3.97 times more likely to be near a Level I/II trauma center ($p < 0.001$), 2.33 times more likely to have Medicaid ($p < 0.001$), and 2.52 times more likely to be uninsured ($p < 0.001$). African American patients were 72.34% less likely to have Medicare ($p < 0.001$). Controlling for race, time was associated with a 1.71% increase in odds of death for every 5-minute increase in prehospital time ($p = 0.008$) while distance was associated with a 7.36% increase in odds of death for every 5-mile increase ($p < 0.001$) in distance to the nearest trauma center. Patients with severe injuries were 7.40 times more likely to die than those with mild injuries ($p < 0.001$), while odds of death increased by more than 50 times for patients with critical injuries (OR = 52.14, $p <$ 0.001). Patients without insurance were 3.04 times more likely to die that those with private insurance ($p < 0.001$). Based on these estimated coefficients, penetrating injury, prehospital time, trauma center distance, insurance status, and ZCTA income were further examined as mediators for the relationship between race and injury mortality.

While ZCTA income was associated with both race and mortality, there was no effect of income when also controlling for distance. Likelihood ratio testing indicated that ZCTA income did not improve model fit when other mediators were included ($p = 0.250$), and ZCTA income was excluded from the final mediation model. The semivariogram of the standardized residuals from the multivariate model did not indicate residual spatial dependence (Figure 4.1). The multivariate mediation model for the relationship between race and injury mortality is illustrated in Figure 4.2 and indirect effects of mediating variables are presented in Table 4.3. The effect of race was fully mediated by the combined effects of time (a*b = -0.075, CI: -0.124, -0.023) distance (a*b = -0.122, CI: -0.179, -0.065), penetrating injury (a*b = 0.104, CI: 0.092, 0.115), Medicaid enrollment (a*b = 0.028, CI: 0.016, 0.041), Medicare enrollment (a*b = -0.046, CI: -0.062, -0.030), and lack of insurance (a*b = 0.007, CI: 0.003, 0.010), resulting in a modestly protective direct effect of race (c' = -0.058, CI: -0.105, -0.011). The total effect (c = 0.055, CI: 0.016, 0.095) demonstrated a slight increase in odds of death for African American patients, relative to White patients.

Mediation of Ethnicity

The proportions of Hispanic patients with private insurance or Medicare were lower than the proportions observed for White patients (31.65% vs. 47.29%; 3.32% vs. 19.72%; Table 4.1), while a larger proportion of Hispanic patients were uninsured (45.34% vs. 12.41%). The proportion of injuries with penetrating mechanism was higher for Hispanic patients than for White patients (13.36% vs. 7.91%). Mean prehospital time and distance to the nearest trauma center were both shorter for Hispanic patients, compared to White patients (54.84 minutes vs. 72.14 minutes; 8.45-miles vs. 12.34).

Based on regression estimates, Hispanic patients were 42.65% less likely to die than White patients ($p = 0.005$; Table 4.2). Compared to White patients, prehospital times for Hispanic patients were 17.30 minutes shorter ($p < 0.001$), trauma center distances were 3.89 miles shorter ($p < 0.001$), and ZCTA median ages were 2.77 years younger ($p < 0.001$). Hispanic patients were 79.95% more likely than White patients to have penetrating injuries ($p < 0.001$), and 2.38 times more likely to be near a Level I/II trauma center. Hispanic patients were 86.03% less likely to have Medicaid coverage ($p < 0.001$), compared to White patients, and 5.85 times more likely to be uninsured ($p < 0.001$). When controlling for ethnicity, patients with severe injuries were 7.53 times more likely to die than those with mild injuries ($p < 0.001$), while critical injuries were associated with a more than 30-fold increase in odds of death (OR = 34.37, $p < 0.001$). Odds of death increased by 4.63 times for penetrating injuries, compared to non-penetrating injuries ($p < 0.001$). Medicaid coverage was associated with a 29.56% increase in odds of death ($p = 0.040$), while odds of death increased by 26.36% for Medicare patients ($p = 0.043$), and by 2.78 times for patients without insurance ($p < 0.001$). Finally, odds of death increased by 10.01% for every 5-mile increase in distance to the nearest trauma center ($p < 0.001$). Based on these estimated coefficients, trauma center distance, injury mechanism, insurance status, and ZCTA median age were further examined as mediators of the relationship between ethnicity and injury mortality.

While ZCTA median age was associated with both ethnicity and mortality, there was no effect of median age when controlling for distance. Likelihood ratio testing indicated that ZCTA age did not improve model fit when other mediators were included ($p = 0.056$), and ZCTA median age was excluded from the final mediation model. The semivariogram of the standardized residuals for the multivariate model did not indicate residual spatial dependence in the model (Figure 4.3). The mediation model for ethnicity is illustrated in Figure 4.4, and indirect effects are presented in Table 4.3. The effect of ethnicity on mortality was partially mediated by penetrating injury (a*b = 0.020, CI: 0.012, 0.028) and lack of insurance (a*b = 0.073, CI: 0.050, 0.095), and inconsistently mediated by trauma center distance (a*b = -0.070, CI: -0.094, -0.045) and Medicare enrollment (a*b = -0.055, CI: -0.075, -0.036). While the total indirect effect suggested an increase in odds of death for Hispanic patients via mediated variables, both the direct effect (c'

= -0.144, CI: -0.202, -0.085) and the total effect (c = -0.121, CI: -0.176, -0.066) of ethnicity indicate reduced odds of death for Hispanic patients, relative to White patients.

Mediation of Sex

The proportions of male patients with private insurance or Medicare (37.43% and 9.34%; Table 4.1) were smaller than the proportions observed for female patients (43.72% and 21.34%,), while the proportions of males with Medicaid (29.72%) or without insurance (23.51%) were greater than the proportions observed for female patients (21.47% and 13.47%). Penetrating injuries were more common for male patients, compared to female patients (20.23% vs. 5.74%), as were critically severe injuries (6.90% vs. 3.28%). Mean prehospital time and trauma center distance were shorter for males than for females (62.36 minutes and 9.54 miles vs. 70.35-minutes and 10.47 miles).

Male patients were 2.07 times more likely to die than female patients ($p < 0.001$; Table 4.2). Prehospital times for male patients were 8.00 minutes shorter than for female patients ($p < 0.001$), while trauma center distances were 2.18 miles shorter ($p < 0.001$). Males were 2.18 times more likely to have critical injuries ($p < 0.001$), compared to females, and 4.16 times more likely to have penetrating injuries ($p < 0.001$). Compared to females, ZCTA per capita income at the injury scene was $1,644 less for males ($p < 0.001$), and ZCTA age was 0.78 years lower ($p < 0.001$). Male patients were 15.03% more likely to be near a Level I/II trauma center, compared to female patients. Males were 54.65% more likely to have Medicaid, 97.59% more likely to be uninsured ($p < 0.001$), and 62.05% ($p < 0.001$) less likely to have Medicare, compared to females. Controlling for sex, odds of death increased by 1.92% for every 5-minute increase in prehospital time ($p < 0.001$), and by 5.97% for every 5-mile increase in distance to the nearest trauma center ($p < 0.001$). Patients with severe injuries were 6.97 times more likely to die than those with mild injuries ($p < 0.001$), and odds of death were nearly 55 times greater for with critical injuries (OR = 54.60, $p < 0.001$). Odds of death were 4.18 times greater for patients with penetrating injuries ($p < 0.001$) than for those without penetrating injuries, and odds of death were 2.51 times greater for those without insurance ($p < 0.001$), compared to patients with private insurance. Based on these estimates, prehospital time, trauma center distance, injury severity insurance status, and ZCTA income were further examined for inclusion in the multivariate mediation model.

While ZCTA income and trauma center distance were associated with both sex and mortality, neither effect was statistically significant when also controlling for prehospital time. Likelihood ratio testing indicated that neither ZCTA income ($p = 0.647$), nor trauma center distance ($p = 0.663$) improved model fit when other mediators were included, and both variables were excluded from the final mediation model. The semivariogram of the standardized residuals (Figure 4.5) did not indicate any residual dependence. The multivariate mediation model for the relationship between male sex and injury mortality is illustrated in Figure 4.6 and indirect effects of mediating variables are presented in Table 4.4. The effect of sex was partially mediated by critical injury (a*b = 0.114, CI: 0.089, 0.138), penetrating injury (a*b = 0.069, CI: 0.057, 0.080), and lack of insurance (a*b = 0.024, CI: 0.017, 0.031). Medicare enrollment (a*B = -0.040, CI: -0.051, -0.029) and prehospital time (a*b = -0.023, CI: -0.045, 0.001) inconsistently mediated the effect of sex, reducing the total effect of sex, and masking the direct effect. The direct effect of male sex was modestly protective (c' = -0.058, CI: -0.105, -0.011), while the total effect (c = 0.055, CI: 0.016, 0.095) represented a small increase in odds of death for male patients, relative to female patients.

DISCUSSION

This study demonstrates the role of trauma center distance, prehospital time, injury characteristics, and insurance coverage as mediators in the relationships between individual demographic characteristics and injury mortality. While prior studies have controlled for many of these factors when examining differences in mortality associated with race, ethnicity, and sex, this is the first study to examine these factors as part of the causal pathway between individual demographic characteristics and mortality. These findings provide valuable insight into potential causes of injury mortality, which can inform efforts to reduce disparities through primary prevention and improved treatment of injuries.

Prior studies of racial disparities in injury mortality controlled for individual health and injury characteristics, but did not control for prehospital time or trauma center distance.[5] While prehospital times and trauma center distances observed in this study were shorter for African American patients in Maryland, average travel times are longer for African Americans in the United States as a whole.[1,2,106] Shorter prehospital times and trauma center distances reduced the effect of race on mortality in this study; however, the role of prehospital time and trauma center distance as mediators suggests that differences in access to care in other parts of the United States may partially explain disparities observed in national samples. Injury mechanism also appears to mediate the effect of race on mortality, consistent with known differences in the incidence of intentional penetrating injury by race.[10] The role of insurance type as a mediator for the effect of race on mortality may indicate differences in quality of care by payment type. While the Emergency Medical Treatment and Active Labor Act (EMTALA) and other regulations prohibit denial of trauma care based on insurance status,[166] there is evidence of differences in the trauma care experience by insurance status, including longer wait times[167] and fewer diagnostic tests[168] for uninsured patients. Insurance status may also act as a proxy for other markers of socioeconomic status that could influence injury outcomes, such as undiagnosed comorbidities.[74]

As with the effect of race, trauma center distance appears to mediate the relationship between ethnicity and mortality. Interestingly, while prehospital time did vary by ethnicity in this analysis, time was not associated with mortality when controlling for ethnicity, and time did not mediate the relationship between ethnicity and mortality. This suggests that ethnicity may confound the relationship between prehospital time and mortality. No prior studies have examined differences in the prehospital experience by ethnicity, and the patterns observed in this study indicate a need for additional research as variation in prehospital care may explain the apparent protective effect of Hispanic ethnicity in Maryland. Also, similar to the effect of race, penetrating injuries appear to mediate the relationship between ethnicity and mortality, which is consistent with known patterns in injury mechanism.[10] Finally, insurance status mediates the relationship between ethnicity and mortality, with a particularly large indirect effect of uninsurance. As with African American populations, this may suggest differential treatment due to insurance status, as well as unmeasured differences in health status. Given the magnitude of the effect of uninsurance as a mediator, and the large proportion of Hispanic injury patients without insurance, this is an important area for policy and practice interventions.

As with race and ethnicity, the relationship between sex is mediated by prehospital time, with male patients benefiting from shorter prehospital intervals. Similar to the pattern observed for Hispanic patients, trauma center distance did not mediate the relationship between sex and mortality, again suggesting that the effect of sex confounds the relationship between distance and mortality, which may indicate differences in the prehospital experience for men and women. There is evidence of differences in prehospital triage by sex,[129] with male patients generally receiving higher priority assessments, which may explain the effects observed in this study. Penetrating and critically severe injuries also mediate the effect of sex. There is evidence of physiologic differences in injury recovery for male and female patients,[70,71] which may contribute to the indirect effects of both mechanism and severity as determinants of elevated mortality among men. Finally, insurance status mediates the relationship between sex and injury mortality. The indirect effect of Medicare appears to reduce mortality due to the small proportion of men enrolled in Medicare; however, this benefit is offset by the increase in odds of death for men due to a higher proportion of patients without health insurance. As with race and ethnicity, this may indicate differences in the trauma care experience, as well as unmeasured differences in health status, and warrants further investigation in future studies.

Limitations

This study used data from the 2015 MTR and eMEDS PCRS. The Maryland trauma care system is highly structured and standardized, making this a unique setting for injury outcomes research, and potentially limiting generalizability to other settings. While African American and Hispanic patients experience longer prehospital times in many parts of the United States, prehospital times in Maryland are shorter for both groups, compared to White patients. This limits the causal conclusions related to time and distance as determinants of injury disparities that can be drawn from this study as they apply to populations outside of Maryland. The results of this study indicate that shorter times and distances provide a protective effect for African American and Hispanic patients in Maryland, and it logically follows that longer prehospital times and trauma center distances for African American and Hispanic patients may contribute to diminished outcomes in other settings. Future studies should examine time and distance as mediators of the effects of race and ethnicity in other regions of the United States, or using nationally representative data.

The variables examined as potential mediators were limited to the measures available in the MTR, the eMEDS PCRS, or through publicly available data associated with injury locations. There are likely unmeasured variables that also fall in the causal pathways between race, ethnicity, sex, and injury mortality. Future studies should attempt to expand the domains examined, either through use of additional secondary data sources, or through primary data collection.

CONCLUSION

This study identifies several factors that mediate the roles of race, ethnicity, and sex as determinants of injury mortality, including access to trauma center care, insurance status, and injury characteristics. Identification of factors that lie in the causal pathway between individual characteristics and injury mortality is an important first step towards improving injury outcomes through changes in health policy and clinical practice.

The results of this study suggest that shorter prehospital intervals and trauma center distances may reduce injury mortality. Future studies should examine the role of these factors in other settings as the unique geographic distribution of race and ethnicity in Maryland make it difficult to identify these factors as determinants of injury disparities. This is especially important as the American College of Surgeons implements their NBATS tool[150] to guide trauma center allocation and placement. While population density and system capacity are important considerations, it is also essential to consider differential access to care for vulnerable populations when discussing trauma system expansion. This study also suggests that the prehospital experience may vary by sex and ethnicity, which warrants additional study. Stakeholders should also consider alternative approaches to care, such as expanded and enhanced EMS services, to address the limitations of trauma care systems within the practical limitations of trauma center expansion.

The role of insurance coverage demonstrated in this study suggests that insurance status may contribute to disparities in injury mortality. While implementation of the Affordable Care Act substantially reduced the proportion of United States citizens and permanent residents who lack insurance, it did not fully address disparities in insurance coverage for African American and Hispanic populations.[169] Policymakers should consider alternative approaches to payment for trauma center care, including population based payment models, to reduce concerns about cost and payment that may contribute to differences in treatment based on insurance status. Trauma care providers should also be mindful of undiagnosed comorbidities and other health factors associated with Medicaid enrollment or lack of insurance, as these factors may change the needs of individual patients and contribute to disparities in injury mortality.

Finally, injury mechanism and severity are important mediators of effects of race, ethnicity, and sex on injury mortality, indicating a critical need for primary prevention to reduce demographic differences in injury mortality. While expanded and enhanced trauma systems can improve trauma care services for populations with a high incidence of penetrating and/or critical injuries, some injuries are not survivable, regardless of the quality and timeliness of trauma care. Primary prevention strategies, including gun violence prevention, are essential to fully address disparities in injury mortality. Designated trauma centers are obligated to provide injury prevention services in the communities they serve as part of the American College of Surgeons accreditation process,[132] and should consider these results when planning and implementing prevention programs. Finally, researchers should continue to explore physiologic factors as mediators of the relationship between sex and injury mortality, while providers should consider differences in trauma care needs for male and female patients.

TABLES AND FIGURES

Table 4.1: MI Estimated Distribution of Mediating Variables by Independent Variables

	White	African American	Hispanic	Female	Male
	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)	% (95% CI)
Insurance					
Private	47.29 (46.09, 48.49)	29.61 (28.41, 30.81)	31.65 (28.55, 34.75)	43.72 (42.41, 45.03)	37.43 (36.50, 38.37)
Medicaid	20.58 (19.64, 21.52)	37.70 (36.39, 39.02)	19.69 (17.01, 22.38)	21.47 (20.36, 22.58)	29.72 (28.72, 30.71)
Medicare	19.72 (18.89, 20.56)	6.36 (5.74, 6.99)	3.32 (2.22, 4.43)	21.34 (20.27, 22.41)	9.34 (8.79, 9.88)
None	12.41 (11.57, 13.25)	26.33 (25.06, 27.59)	45.34 (42.05, 48.62)	13.47 (12.55, 14.39)	23.51 (22.51, 24.52)
Penetrating					
No	92.09 (91.53, 92.66)	73.13 (72.04, 74.21)	86.64 (84.57, 88.72)	94.26 (93.67, 94.84)	79.77 (79.04, 80.49)
Yes	7.91 (7.34, 8.47)	26.87 (25.79, 27.96)	13.36 (11.28, 15.43)	5.74 (5.16, 6.33)	20.23 (19.51, 20.96)
Severity					
Mild	85.96 (84.99, 86.92)	85.79 (84.78, 86.81)	88.24 (86.15, 90.33)	89.36 (88.44, 90.28)	84.68 (83.88, 85.49)
Moderate	3.71 (3.30, 4.13)	3.74 (3.25, 4.24)	3.43 (2.30, 4.56)	3.38 (2.90, 3.86)	3.79 (3.39, 4.18)
Severe	4.62 (3.96, 5.29)	4.22 (3.67, 4.76)	4.33 (3.03, 5.63)	3.98 (3.35, 4.62)	4.63 (4.12, 5.15)
Critical	5.71 (5.14, 6.28)	6.25 (5.49, 7.00)	4.01 (2.66, 5.35)	3.28 (2.80, 3.75)	6.90 (6.43, 7.36)
	Mean (95% CI)	Mean (95% CI)	Mean (95% CI)	Mean (95% CI)	Mean (95% CI)
Time	72.14 (22.52, 121.76)	55.99 (54.69, 57.30)	54.84 (51.89, 57.79)	70.35 (68.35, 72.35)	62.36 (60.99, 63.73)
Distance	12.34 (12.08, 12.34)	6.55 (6.32, 6.78)	8.45 (7.81, 9.09)	10.47 (10.17, 10.77)	9.54 (9.34, 9.75)
ZCTA					
Income ($)	35,112 (34,840, 35,384)	29,336 (29,075, 29,597)	35,329 (34,417, 36,241)	34,216 (33,899, 34,534)	32,572 (32,337, 32,808)
Age	39.47 (28.58, 50.36)	36.49 (25.33, 47.66)	36.70 (5.00, 68.39)	38.65 (25.69, 51.61)	37.88 (28.39, 47.37)

Table 4.2: Coefficients for IVs, MVs, and DV Associations									
	Independent Variables								
	African American			**Hispanic**			**Male**		
	β	95% CI	*p*	β	95% CI	*p*	β	95% CI	*p*
IV→ DV (c path)									
Died[a]	0.195	0.049, 0.341	0.016	-0.556	-0.904, -0.208	0.005	0.728	0.593, 0.864	<0.001
IV→ MV (a path)									
Time (5 min)[b]	-3.229	-3.726, -2.733	<0.001	-3.460	-4.296, -2.624	<0.001	-1.599	-1.987, -1.210	<0.001
Moderate[a]	0.009	-0.172, 0.190	0.925	-0.084	-0.456, 0.289	0.663	0.117	-0.072, 0.306	0.239
Severe[a]	-0.096	-0.286, 0.095	0.334	-0.069	-0.452, 0.313	0.726	0.159	-0.019, 0.337	0.093
Critical[a]	0.096	-0.108, 0.299	0.367	-0.374	-0.749, 0.000	0.062	0.783	0.604, 0.962	<0.001
Penetrating[a]	1.454	1.353, 1.556	<0.001	0.585	0.381, 0.790	<0.001	1.426	1.303, 1.549	<0.001
ZCTA Income ($1,000)[b]	-5.775	-6.194, -5.357	<0.001	0.217	-0.694, 1.128	0.645	-1.644	-2.065, -1.224	<0.001
ZCTA age[b]	-2.975	-3.146, -2.805	<0.001	-2.772	-3.134, -2.411	<0.001	-0.768	-0.938, -0.597	<0.001
Miles (5-miles)[b]	-1.158	-1.236, -1.080	<0.001	-0.777	-0.945, -0.609	<0.001	-0.185	-0.257, -0.113	<0.001
Trauma level[a]	1.380	1.234, 1.527	<0.001	0.866	0.623, 1.109	<0.001	0.140	0.034, 0.246	0.016
Medicaid[a]	0.848	0.768, 0.928	<0.001	-0.056	-0.242, 0.130	0.561	0.436	0.352, 0.520	<0.001
Medicare[a]	-1.285	-1.409, -1.162	<0.001	-1.968	-2.334, -1.601	<0.001	-0.969	-1.053, -0.885	<0.001
No Insurance[a]	0.925	0.829, 1.021	<0.001	1.767	1.610, 1.924	<0.001	0.681	0.585, 0.776	<0.001
MV → DV (b path)									
Time (5 min)[a]	0.017	0.006, 0.029	0.008	0.011	-0.003, 0.026	0.167	0.019	0.008, 0.029	0.001
Severity									
Mild	Ref.	--	--	Ref.	--	--	Ref.	--	--
Moderate[a]	0.287	-0.226, 0.800	0.283	0.213	-0.636, 1.062	0.628	0.250	-0.258, 0.758	0.344
Severe[a]	2.001	1.751, 2.251	<0.001	2.019	1.676, 2.363	<0.001	1.941	1.699, 2.183	<0.001
Critical[a]	3.954	3.573, 4.335	<0.001	3.538	2.924, 4.151	<0.001	4.000	3.603, 4.397	<0.001
Penetrating[a]	1.579	1.440, 1.717	<0.001	1.532	1.334, 1.730	<0.001	1.431	1.308, 1.553	<0.001
ZCTA Income ($1,000)[a]	-0.007	-0.012, -0.001	0.034	-0.002	-0.008, 0.004	0.500	-0.008	-0.013, -0.003	0.001
ZCTA Age[a]	0.009	-0.002, 0.021	0.128	0.017	0.002, 0.031	0.025	0.008	-0.002, 0.019	0.111
Miles (5-miles)[a]	0.071	0.042, 0.100	<0.001	0.096	0.063, 0.129	<0.001	0.058	0.0320, 0.085	<0.001
Trauma Level[a]	-0.141	-0.320, 0.037	0.134	-0.171	-0.370, 0.028	0.107	-0.103	-0.274, 0.067	0.246
Insurance									
Private[a]	Ref.	--	--	Ref.	--	--	Ref.	--	--
Medicaid[a]	0.004	-0.190, 0.198	0.968	0.259	0.026, 0.493	0.040	0.014	-0.172, 0.201	0.087
Medicare[a]	0.117	-0.079, 0.313	0.135	0.234	0.020, 0.449	0.043	0.271	0.087, 0.456	0.095

No Insurance[a]	.111	0.866, 1.355	<0.001	1.023	0.694, 1.352	<0.001	0.921	0.684, 1.158	<0.001
[a]log odds ratio; [b]linear coefficient									

Table 4.3: Indirect Effects of Mediating Variables

	African American		Hispanic		Male	
	β	95% CI	β	95% CI	β	95% CI
Total	0.113	0.092, 0.134	0.022	-0.001, 0.044	0.181	0.016, 0.150
Time	-0.075	-0.127, -0.023	--	--	-0.023	-0.045, -0.001
Distance	-0.122	-0.179, -0.065	-0.070	-0.093, -0.046	--	--
Penetrating	0.104	0.092, 0.115	0.020	0.012, 0.028	0.069	0.057, 0.080
Moderate Injury	--	--	--	--	0.001	-0.001, 0.003
Severe Injury	--	--	--	--	0.007	-0.001, 0.015
Critical Injury	--	--	--	--	0.114	0.089, 0.138
Medicaid	0.028	0.016, 0.041	-0.001	-0.006, 0.003	0.003	-0.003, 0.008
Medicare	-0.046	-0.062, -0.030	-0.055	-0.075, -0.036	-0.040	-0.051, -0.029
No Insurance	0.007	0.003, 0.010	0.073	0.050, 0.095	0.024	0.017, 0.031

Figure 4.1: Semivariogram of Standardized Residuals for Race Mediation Model

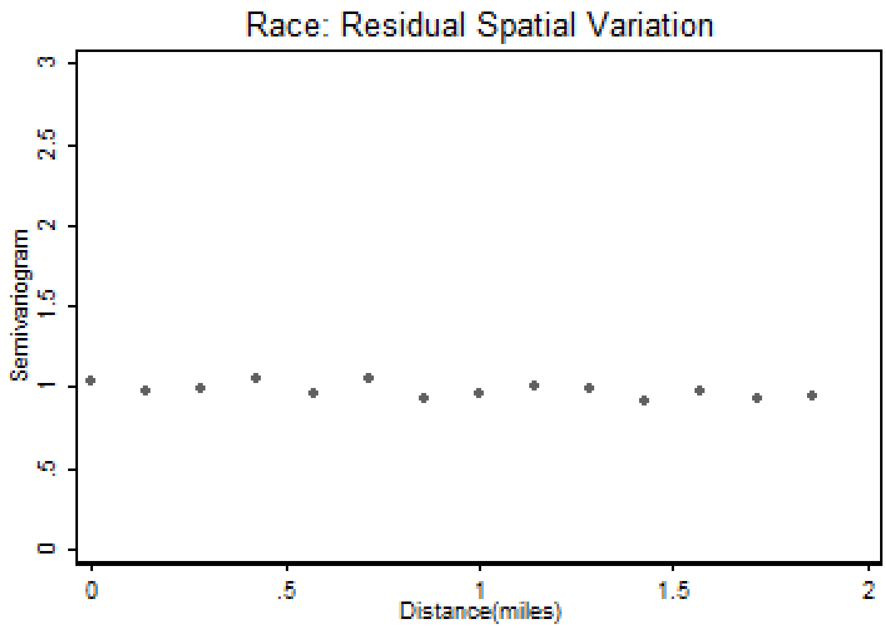
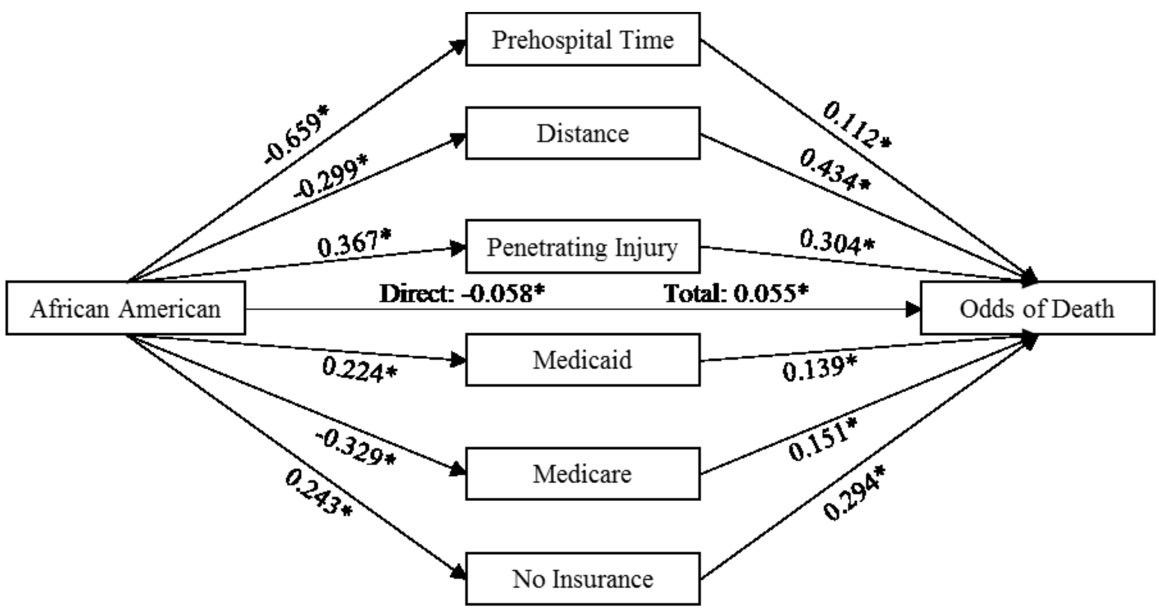


Figure 4.2: Mediation Model, African American vs. White



Standardized coefficients from mediation model for race (African American vs. Non-Hispanic White).
***significant as determined by 95% confidence interval**

Figure 4.3: Semivariogram of Standardized Residuals for Ethnicity Mediation Model

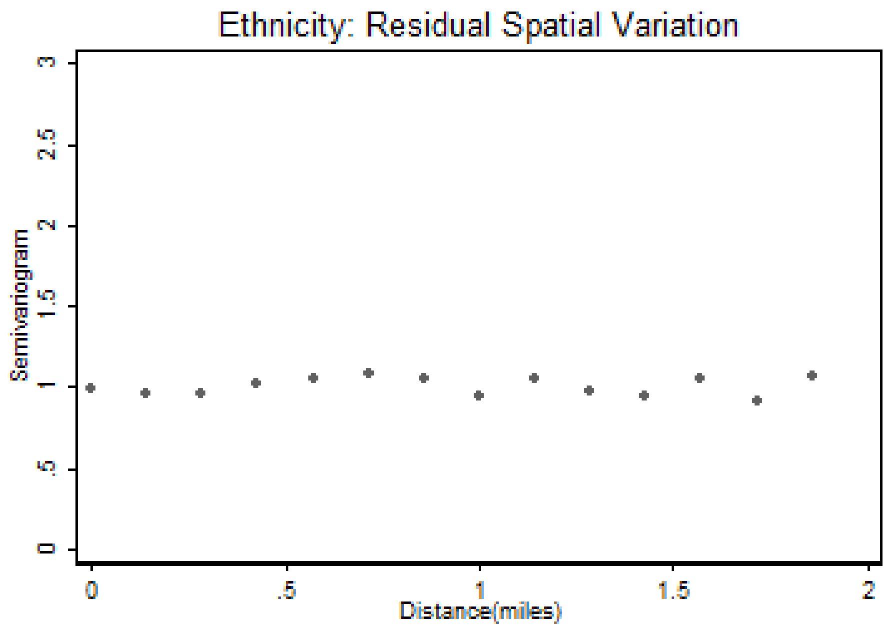


Figure 4.4: Mediation Model, Hispanic vs. White

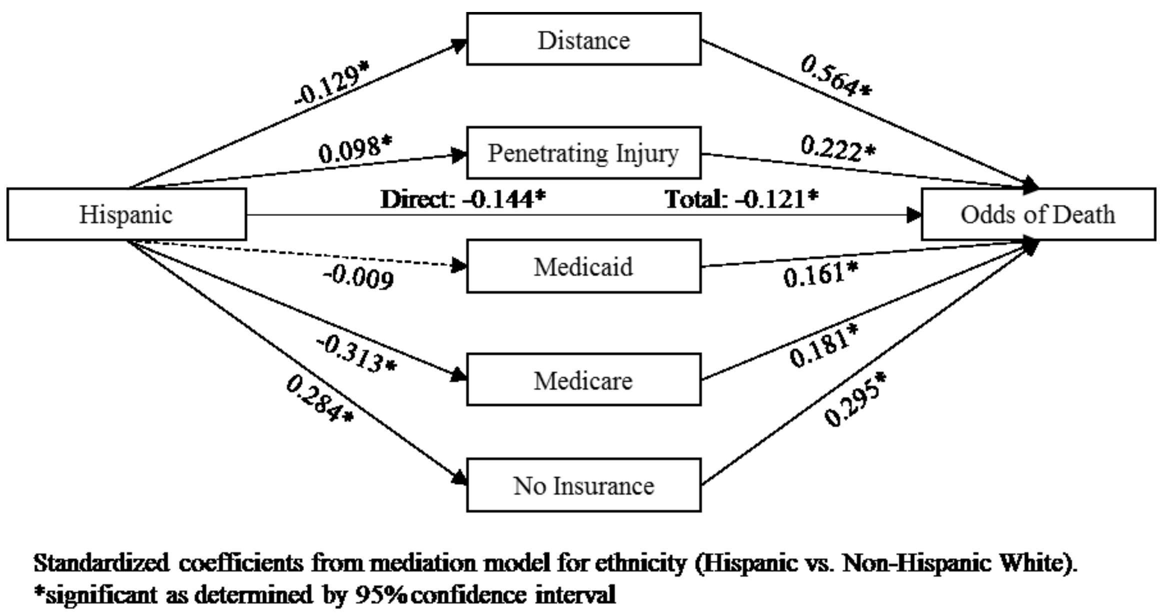


Figure 4.5: Semivariogram of Standardized Residuals for Sex Mediation Model

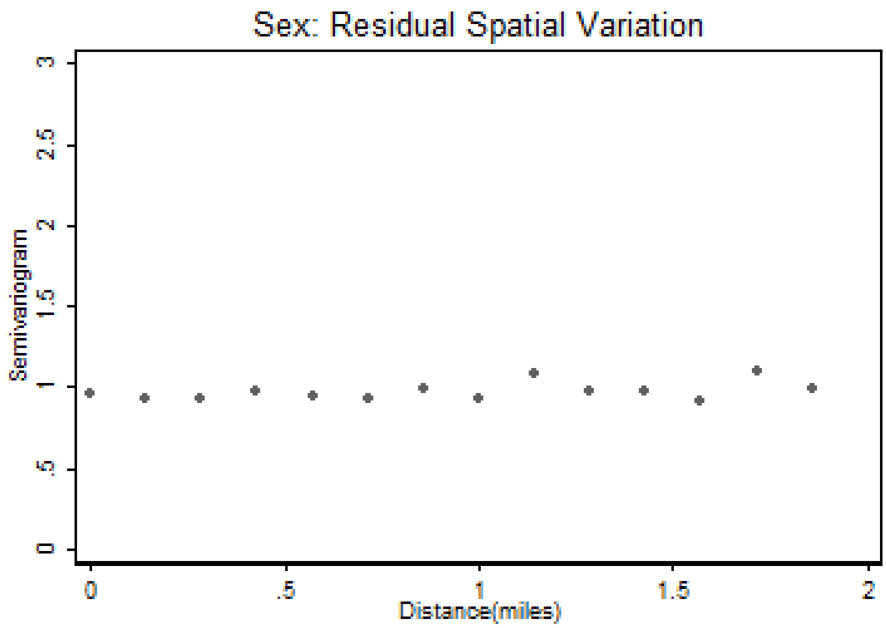
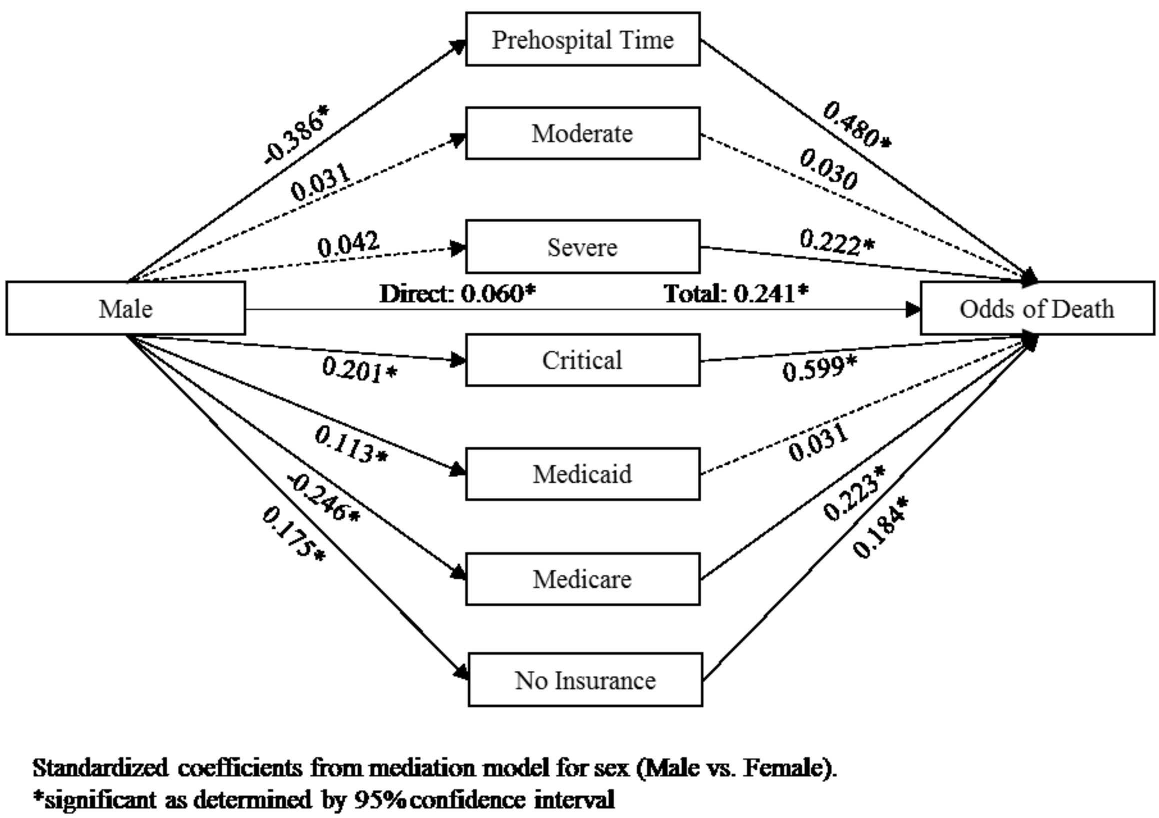


Figure 4.6: Mediation Model, Male vs. Female



CHAPTER FIVE: CONCLUSION

Summary of Findings

Aim 1: Examine the role of environmental and community-level variables at the injury incident scene as determinants of injury mortality in Maryland using multilevel logistic models, while controlling for patient and hospital characteristics.

The results of this analysis suggested that several features of injury scene locations were associated with odds of death following a traumatic injury. Odds of death increased with increasing distance from the injury scene to the nearest trauma center, even when controlling for prehospital time. The characteristics of the nearest trauma center were also associated with injury mortality. Proximity to a privately-owned, Level I/II trauma centers was associated with improved outcomes, relative to public hospitals and Level III centers. Compared to residential land use, transportation land use was associated with increased mortality, while commercial land use appeared to reduce odds of death. At the ZCTA level, low income and older median age were both associated with increased mortality.

Aim 2: Develop a profile of injury scene characteristics associated with concentrated risk of mortality from traumatic injury, and identify regions in Maryland with concentrated risk of injury mortality.

The results of the LCA suggested that distinct classes can be identified based on the characteristics of injury incident locations, and that mortality, injury characteristics, and patient demographics varied across location classes. High risk location classes included both rural locations with limited access to trauma care, and locations in urban communities with very low income and high access to Level I/II trauma centers. Low risk locations included suburban and exurban communities, as well as wealthier urban communities. This analysis also indicated that individual characteristics may mediate and/or confound the relationship between injury event location and mortality.

Aim 3: Examine incident scene and individual characteristics mediating the effects of race, ethnicity, sex on injury mortality.

The results of the mediation analyses suggested the mortality effects of race, ethnicity, and sex were mediated by injury characteristics, insurance coverage, prehospital time, and trauma center distance. For African American patients, the indirect effects of race via shorter prehospital times and trauma center distances were associated with decreased mortality, while the indirect effect of race via penetrating injuries was associated with increased mortality. The indirect effects of race via Medicaid enrollment and uninsurance also increased odds of death for African American patients, while race indirectly decreased mortality via Medicare enrollment. For Hispanic patients, the indirect effects of ethnicity via trauma center distance and Medicare enrollment reduced mortality, while the indirect effects of ethnicity via penetrating injury and uninsurance increased mortality. Finally, for male patients, the indirect effects of sex via prehospital time and Medicare enrollment decreased mortality, while the indirect effects of sex via penetrating injury, critical injury, and uninsurance increased odds of death.

Limitations

The sample used for all three aims of this dissertation was limited to patients treated at designated trauma centers in Maryland, including those who were initially treated at a non-trauma center and subsequently transferred to a designated trauma center, as well as patients who died in EMS care at the injury scene or while in transit. Patients treated at non-trauma centers without transfer to a designated trauma center were not included in any analyses, nor were individuals who died prior to EMS arrival at the injury scene. These patients represent a small, but potentially meaningful, subset of the injury cases who potentially faced greater barriers to medical care than the general population, introducing some concerns regarding selection bias. Lack of injury outcomes data from community hospitals and medical examiner records is a well-documented limitation of trauma systems research.[48] In Maryland, these concerns are largely mitigated by the comprehensive protocols for patient triage and transport in place for EMS providers, an extensive network of public air ambulance services, and the relatively small geographic area of the state.

Together, these features of the state EMS and trauma care systems greatly reduce the number of high risk injury patients who are not captured in the MTR.

A large number of records in the sample lacked information regarding the exact location of the injury incident, and therefore could not be linked with measures of the built environment. Patterns of missingness were examined by county, mortality outcome, demographic characteristics, and month of incident to rule out likely causes of nonignorable nonresponse. The data appeared to be missing at random, and were imputed using predicted mean matching. A sensitivity analysis excluding records without exact location was conducted in Aim 1, with results suggesting that the missingness and imputation generally had minimal impact on the study results. It is possible that an unknown or unmeasured covariate was causally associated with missing location information.

The potential for unmeasured confounding is also a concern, particularly for measures of comorbid health conditions, prehospital service, trauma center quality, and community-level social measures. While a full range of community-level social measures were considered in Aim 1 and excluded based on model fit and lack of significance, it is possible that additional social measures are related to injury outcomes at a more granular level than could be captured in this study. The variables examined as potential mediators in Aim 3 were limited to the measures available in the MTR, the eMEDS PCRS, or through publicly available data associated with injury locations. There are likely unmeasured variables that also fall in the causal pathways between race, ethnicity, sex, and injury mortality. Future studies should attempt to expand the domains examined, either through use of additional secondary data sources, or through primary data collection.

Generalizability of the results presented in this dissertation to communities outside of Maryland is limited by the unique organization of EMS and trauma care systems and the relatively small size of the state. In many ways, the Maryland system represents a best-case scenario for the delivery of trauma care, with clear triage and treatment protocols that are implemented using a standardized approach throughout the state. It is likely that states with more variation in EMS and trauma care would see greater effects from features of the built environment and social factors that act as barriers to care. With limits of generalizability in mind, the results of these analyses are still useful as a starting point for inquiry into the use of spatially defined data as predictors of injury mortality at the population level. The analyses presented in this dissertation should be replicated with data from other states, ideally representing a range of approaches to EMS and trauma system organization.

While African American and Hispanic patients experience longer prehospital times in many parts of the United States, prehospital times in Maryland are shorter for both groups, compared to White patients. This limits the causal conclusions related to time and distance as determinants of injury disparities that can be drawn based on Aims 1 and 3 of this dissertation, as they apply to populations outside of Maryland. The results of Aim 3 indicate that shorter times and distances provide a protective effect for African American and Hispanic patients in Maryland, and it logically follows that longer prehospital times and trauma center distances for African American and Hispanic patients may contribute to diminished outcomes in other settings. Future studies should examine time and distance as mediators of the effects of race and ethnicity in other regions of the United States, or using nationally representative data.

Finally, there are internal and external validity concerns for these analyses due to historic events during the study period. All three dissertation aims used data from 2015 MTR, including data from Baltimore City during a period of civil unrest in the spring of 2015, and a subsequent rise in homicide incidence. There is considerable overlap between the low income urban core location class identified in Aim 2 and the neighborhoods most impacted by the unrest and increased homicide rate. It is possible that safety concerns for first responders, residual unrest, or other unmeasured factors impacted the delivery of care and injury outcomes in these areas. Sensitivity analyses conducted as part of Aim 2 suggest that injury mortality rates in high risk regions of Baltimore City were not higher than similar communities in other parts of the state, and that the relationship between location and injury mortality was stable over time before and after the period of unrest.

Policy Implications

The research presented in this dissertation has several important policy implications for trauma system organization, the delivery of prehospital emergency care, and primary prevention priorities. Together, the results of these analyses suggest that geographic barriers to trauma center care increase mortality, independent of prehospital time, and that access to care mediates the relationships between individual demographic characteristics and injury mortality. Given the practical and financial limitations of healthcare systems, it is not feasible to expand trauma center coverage to the point that all residents of the United States live within an hour of a Level I/II trauma center. Policymakers should consider alternatives such as enhanced EMS care and targeted trauma services at community hospitals to fill gaps in coverage that cannot be addressed with additional Level I/II trauma centers. Many state and local governments are implementing programs to deliver primary care services through EMS systems, in hopes that improved primary care for vulnerable populations will reduce the number of EMS calls for preventable acute illnesses.[170] Policymakers, including county EMS directors in Maryland, can leverage these initiatives to improve prehospital injury care in underserved communities by employing full time physician assistants and/or advanced practice nurses who can serve as both primary care providers and first responders with ALS capabilities. EMS directors should also consider recruitment and training programs focused on retention of EMS providers in underserved communities, such as tuition reimbursement programs and expedited transfer of credentials across jurisdictions, including transitions from military service to civilian EMS settings. State and local EMS directors can also tailor EMS training requirements to the unique needs of the communities in an EMS service area, including training in geriatric care for EMS providers serving older communities.

The results of this research also indicate that the social context at the injury scene is associated with injury outcomes. Policymakers, including hospital administrators, state medical directors, and professional organizations, responsible for trauma center designation and allocation of resources should consider community-level social measures, including income and age, when determining need for services. In particular, the American College of Surgeons should consider these factors as they finalize their NBATS tool, which is intended to support decisions regarding resource allocation and trauma center designation.[150] Policymakers should also pursue ongoing assessment of trauma system capacity and trauma care needs as the geographic distribution of the population changes over time.

The mediation analyses presented in chapter four indicated that injury mortality risk varies by insurance enrollment and type of coverage, which may contribute to disparities in injury mortality. One potential explanation for this effect is differential treatment based on insurance type, which has been demonstrated in prior studies. [167,168] While EMTALA and other regulations were enacted to ensure treatment for health emergencies regardless of ability to pay,[166] it is possible that providers alter their treatment plans or patients refuse treatments due to concerns about reimbursement for services. Policymakers should consider alternative payment models to reduce concerns about individual payment for services, including population based payment and expanded use of disproportionate share hospital payments. Specifically, Maryland can achieve this through increased integration of trauma care services into the existing Community Benefits model,[171] increasing incentives for hospitals serving communities with high rates of Medicaid enrollment and uninsurance.

Finally, the results of the analyses in this dissertation indicate a need for targeted primary prevention efforts to reduce the incidence of injuries that are not responsive to any level of trauma care. Penetrating and critically severe injuries are strongly associated with mortality, and appear to increase odds of death for African Americans, Hispanic, and male injury patients. In many cases, these injuries are not survivable, regardless of the available prehospital or trauma center services. Primary prevention is essential for overall reduction in injury mortality. Primary prevention of penetrating injuries should include interventions intended to reduce interpersonal violence, such as programs following the Cure Violence model,[161] as well as policy interventions intended to control the availability and lethality of firearms. Locations identified as low income urban core in Aim 2 of this dissertation have particularly high incident of injury mortality due to critical, penetrating injury, making them high priority locations for primary prevention efforts. Motor vehicle crashes are a significant source of critically severe, non-penetrating injuries that should also be addressed with prevention programs, especially in rural locations identified in Aim 2. Policymakers should consider changes to roadway design that reduce the frequency and severity of crashes in high risk communities, as well as changes to vehicle safety standards to reduce the severity of injuries during crashes.

Several limitations of this research are the result of barriers to data use for public health research. Through MIEMSS, Maryland trauma centers and EMS companies collect standard data elements for both the NTDB and NEMSIS research data sets; however, data elements from EMS and trauma center care are not easily linked at the state level due to incomplete integration of incident report numbers across both data collection platforms. This is a critical barrier to trauma care research and quality improvement identified by NASEM.[48] MIEMSS should work with the state health information exchange, Chesapeake Regional Information for Our Patients (CRISP), to link both the MTR and eMEDS with the state master patient index. Integration of the MIEMSS data sets with CRISP will facilitate linkage between the MTR and eMEDS without increased data collection responsibility for EMS and trauma care providers, and also support linkage between the MIEMSS data sets and other useful research data sets, including case mix data from the Maryland Health Services Cost Review Commission and vital records data from the Office of the Chief Medical Examiner. MIEMSS and EMS companies in Maryland should also consider automation of data collection for prehospital times and incident locations. Mobile communications devices with integrated Global Position Systems are increasingly common, and can be used to automatically record both the geographic coordinates of the injury scene and the exact time of critical prehospital events, including EMS dispatch, arrival on scene, departure from scene, and hospital arrival. Many EMS companies are using such technologies to collect location and routing information for internal quality control purposes, and MIEMSS should work to integrate these data into their research data sets.

Priorities for Future Research

All the injury incidents included in this research occurred and were treated in a single state. Researchers should replicate these analyses in other states with different geographic and population patterns. It may not be feasible to conduct the type of research at the national level due to state-level variation in the availability of trauma care and EMS data; however, purposeful selection of states that do provide comparable research data can improve our understanding of the relationships between injury incident location, individual characteristics, and injury mortality. Future studies should also examine these factors as determinants of outcomes other than mortality, including long term physical and psychological recovery of injury survivors.

The results of the studies presented in this dissertation suggest that the prehospital experience may change as distance from the nearest trauma center increases, and that prehospital treatment may differ by sex and ethnicity for patients injured in similar locations. Future studies should examine the timing and sequence of prehospital events and treatments to determine if the prehospital experience does vary by location and patient characteristics. Once patterns of care are identified, researchers should examine the relationships between patterns of prehospital care and injury mortality. Researchers should also examine the capacity of EMS systems, including spatial analyses of the correlation between intensity of EMS services and need for trauma care. Examination of prehospital treatment and EMS system capacity may be especially useful for understanding the effectiveness of ALS in prehospital settings, including variation in the effect of ALS by prehospital time, trauma center distance, and injury type. Qualitative research, including interviews with EMS providers, can improve our understanding of treatment decisions in prehospital settings. Ultimately, this research may support tailoring of EMS services based on the injury types and service needs that are prevalent in specific EMS service areas.

The social measures examined in this dissertation were limited to those available through the American Community Survey at the ZCTA level. Future studies should examine additional social measures, as well as measures available at more granular levels, to better understand the role of the social context of injury incidents as determinants of injury outcomes. The knowledge gained through this research may support policy decisions regarding EMS and trauma center services, as well as tailored injury prevention efforts.

Finally, the mediation models presented in Chapter Four of this dissertation suggest that insurance type contributes to differences in injury mortality by race, ethnicity, and sex. Prior studies have identified differences in trauma center treatment by insurance type,[167,168] as well as differences in prevalence of undiagnosed comorbid conditions.[74] Future studies should further examine differences in treatment by insurance type, including qualitative studies examining treatment decisions from the provider and patient perspective. Researchers should also continue to examine differences in comorbid health conditions by insurance type and the relationship between undiagnosed comorbidities and injury mortality, including examination of the pathways between specific comorbid conditions and injury outcomes.

Conclusion

The studies presented in this dissertation are the first to integrate EMS and trauma center data into a single data set for an entire state, regardless of treating hospital or payment type. These studies are also the first to examine a broad range of spatially-defined characteristics present at the injury scene as determinants of injury mortality, while controlling for individual patient characteristics. The results presented in this dissertation address critical gaps in our understanding of geographic barriers to trauma care, and the contributions of these barriers to disparities in injury mortality.

The relationships between injury incident location characteristics and injury mortality identified in this dissertation highlight several important areas for policy intervention, including changes to trauma system organization, resource allocation, workforce development, and primary prevention. These focus areas are consistent with recommendations from NASEM for integration of civilian and military trauma care services,[48] and with efforts by the American College of Surgeons to refine measures of trauma system capacity and demand for services.[150] Policymakers representing healthcare delivery systems and all levels of government should pursue interventions intended to increase access to and quality of trauma care for vulnerable and underserved populations, Such interventions are essential to the elimination of preventable injury deaths.

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APPENDICES

Appendix A: Injury incident counts, fatality counts, and case-fatality rate by county

County	Injury Incidents (N)	Injury fatalities (N)	Case fatality rate (%)
Allegany	279	23	8.24
Anne Arundel	874	101	11.56
Baltimore City	4,012	340	8.47
Baltimore County	2,664	150	5.63
Calvert	172	17	9.88
Caroline	56	9	16.07
Carroll	428	30	7.01
Cecil	91	26	28.57
Charles	267	25	9.36
Dorchester	100	8	8.00
Frederick	455	53	11.62
Garrett	55	10	18.18
Harford	794	106	13.35
Howard	404	28	6.93
Kent	57	7	12.28
Montgomery	1,219	87	7.14
Prince George’s	2,275	183	8.04
Queen Anne’s	117	9	7.69
Somerset	101	2	1.98
Saint Mary’s	232	24	10.34
Talbot	103	20	19.42
Washington	657	46	7.00
Wicomico	431	30	6.96
Worchester	239	13	5.44
Total	16,082	1,347	8.38

Appendix B: Injury incident counts, fatality counts, and case-fatality rate by month

Month	Injury Incidents (N)	Injury fatalities (N)	Case fatality rate (%)
January	1,097	113	10.30
February	949	66	6.95
March	1,098	100	9.11
April	1,199	114	9.51
May	1,499	123	8.21
June	1,287	95	7.38
July	1,415	130	9.19
August	1,465	127	8.67
September	1,368	132	1,368
October	1,315	122	9.28
November	1,270	92	7.24
December	1,312	113	8.61
Unknown date	808	20	2.48
Total	16,082	1,347	8.38

Appendix C: Trauma registry-eMEDS matching method and rates by county. Match types include patient care report number (PRN), probabilistic matching, EMS only (patient died in EMS care), and no match.

County	PRN N (%)	Probabalistic N (%)	EMS Only N (%)	No match N (%)
Allegany	196 (70.25)	41 (14.70)	13 (4.66)	29 (10.39)
Anne Arundel	525 (60.07)	145 (16.59)	66 (7.55)	138 (15.79)
Baltimore City	2,800 (69.79)	578 (14.41)	73 (1.89)	558 (13.91)
Baltimore County	1,911 (71.73)	350 (13.14)	83 (3.12)	320 (12.01)
Calvert	85 (49.42)	53 (30.81)	10 (5.81)	24 (13.95)
Caroline	34 (60.71)	8 (14.29)	9 (16.07)	5 (8.93)
Carroll	188 (43.93)	144 (33.64)	16 (3.74)	80 (18.69)
Cecil	32 (35.16)	24 (26.37)	23 (25.27)	12 (13.19)
Charles	145 (54.31)	67 (25.09)	14 (5.24)	41 (15.36)
Dorchester	47 (47.00)	30 (30.00)	5 (5.00)	18 (18.00)
Frederick	180 (39.56)	157 (34.51)	43 (9.45)	75 (16.48)
Garrett	36 (65.45)	6 (10.91)	8 (14.55)	5 (9.09)
Harford	480 (60.45)	134 (16.88)	86 (10.83)	94 (11.84)
Howard	216 (53.47)	96 (23.76)	24 (8.94)	68 (16.83)
Kent	19 (33.33)	21 (36.84)	4 (7.02)	13 (22.81)
Montgomery	697 (57.18)	279 (22.13)	36 (2.95)	204 (16.74)
Prince George's	1,595 (70.11)	273 (12.09)	115 (5.05)	290 (12.75)
Queen Anne's	62 (52.99)	29 (24.79)	7 (5.98)	19 (16.24)
Somerset	74 (73.27)	17 (16.83)	1 (0.99)	9 (8.91)
Saint Mary's	117 (50.43)	71 (30.60)	21 (9.05)	23 (9.91)
Talbot	25 (24.27)	36 (34.95)	15 (14.56)	27 (26.21)
Washington	452 (68.80)	106 (16.13)	30 (4.57)	69 (10.50)
Wicomico	268 (62.18)	84 (19.49)	14 (3.25)	65 (15.08)
Worchester	178 (74.48)	41 (17.15)	8 (3.35)	12 (5.02)
Total	10,362 (64.43)	2,795 (17.38)	727 (4.52)	2,198 (13.67)

Appendix D: Trauma registry-eMEDS matching method and rates by month. Match types include patient care report number (PRN), probabilistic matching, EMS only (patient died in EMS care), and no match.

Month	**PRN N (%)**	**Probabalistic N (%)**	**EMS Only N (%)**	**No match N (%)**
January	680 (61.99)	173 (15.77)	60 (5.47)	184 (16.77)
February	561 (59.11)	174 (18.34)	36 (3.79)	178 (18.76)
March	670 (61.02)	184 (16.76)	61 (5.56)	183 (16.67)
April	806 (67.22)	194 (16.18)	64 (5.34)	135 (11.26)
May	1,089 (72.65)	196 (13.08)	63 (4.20)	151 (10.07)
June	910 (70.71)	169 (13.13)	55 (4.27)	153 (11.89)
July	1,021 (72.16)	172 (12.16)	67 (4.73)	155 (10.95)
August	999 (68.19)	241 (16.45)	75 (5.12)	150 (10.24)
September	957 (69.96)	184 (13.45)	82 (5.99)	145 (10.60)
October	918 (69.81)	175 (13.31)	62 (4.71)	160 (12.17)
November	871 (68.58)	202 (15.91)	39 (3.07)	158 (12.44)
December	880 (67.07)	224 (17.07)	62 (4.73)	146 (11.13)
Unknown date	0 (0.00)	507 (62.75)	1 (0.12)	300 (37.13)
Total	10.362 (64.43)	2,795 (17.38)	727 (4.52)	2,198 (13.67)

Appendix E: Distribution of available geographic information by county. Encounters with point pattern data include those with exact coordinates in the MTR and those with coordinates from geocoded addresses. Spatial area level includes encounters mapped to the centroid of the incident zip code.

County	Point Pattern	Spatial Area
Allegany	209 (74.91)	70 (25.09)
Anne Arundel	590 (67.51)	284 (32.49)
Baltimore City	2,874 (71.64)	1,138 (28.36)
Baltimore County	1,991 (74.74)	673 (25.26)
Calvert	95 (55.23)	77 (44.77)
Caroline	43 (76.79)	13 (23.21)
Carroll	204 (47.66)	224 (52.34)
Cecil	55 (60.44)	36 (39.56)
Charles	159 (59.55)	108 (40.45)
Dorchester	52 (52.00)	108 (40.45)
Frederick	223 (49.01)	232 (50.99)
Garrett	44 (80.00)	11 (20.00)
Harford	566 (71.28)	228 (28.72)
Howard	240 (59.41)	164 (40.59)
Kent	23 (40.35)	34 (59.65)
Montgomery	733 (60.13)	486 (39.87)
Prince George's	1,707 (75.03)	568 (24.97)
Queen Anne's	69 (58.97)	48 (41.03)
Somerset	74 (73.27)	27 (26.73)
Saint Mary's	138 (59.48)	94 (40.52)
Talbot	40 (38.83)	63 (61.17)
Washington	481 (73.21)	176 (26.79)
Wicomico	279 (64.73)	152 (35.27)
Worchester	186 (77.82)	53 (22.18)
Total	11,075 (68.87)	5,007 (31.13)

Appendix F: Distribution of available geographic information by month. Encounters with point pattern data include those with exact coordinates in the MTR and those with coordinates from geocoded addresses. Spatial area level includes encounters mapped to the centroid of the incident zip code.

Month	Point Pattern	Spatial Area
January	737 (67.18)	360 (32.82)
February	597 (62.91)	352 (37.09)
March	867 (66.58)	367 (33.42)
April	867 (72.31)	332 (27.69)
May	1,151 (76.78)	348 (23.22)
June	965 (74.98)	322 (25.05)
July	1,087 (76.82)	328 (23.18)
August	1,073 (73.24)	392 (26.76)
September	1,039 (75.95)	329 (24.05)
October	979 (74.45)	336 (25.55)
November	907 (71.42)	363 (28.58)
December	941 (71.72)	371 (28.28)
Unknown date	1 (0.12)	807 (99.88)
Total	11,075 (68.87)	5,007 (31.13)

Appendix G: Distribution of key variables by imputation

Imputation:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Age (%)										
18-24	15.65	15.60	15.56	15.57	15.60	15.53	15.61	15.57	15.58	15.62
25-34	20.43	20.45	20.45	20.49	20.48	20.51	20.48	20.53	20.46	20.44
35-44	13.26	13.24	13.22	13.18	13.21	13.28	13.21	13.23	13.24	13.26
45-54	14.38	14.38	14.39	14.41	14.39	14.38	14.42	14.37	14.38	14.37
55-64	13.31	13.35	13.31	13.31	13.33	13.33	13.27	13.33	13.35	13.32
65-74	8.53	8.58	8.59	8.62	8.57	8.54	8.65	8.59	8.57	8.54
75+	14.44	14.41	14.48	14.41	14.43	14.42	14.37	14.38	14.40	14.45
Sex (%)										
Male	65.79	65.79	65.79	65.79	65.79	65.79	65.79	65.79	65.79	65.79
Female	34.21	34.21	34.21	34.21	34.21	34.21	34.21	34.21	34.21	34.21
Race and/or ethnicity (%)										
White	52.32	52.41	52.51	52.38	52.46	52.60	52.41	52.39	52.47	52.38
African American	36.38	36.32	36.16	36.34	36.20	36.20	36.36	36.34	36.24	36.29
Hispanic	5.99	5.99	6.04	6.01	6.04	5.99	5.98	6.01	5.98	6.03
Other	5.31	5.29	5.29	5.27	5.30	5.21	5.25	5.25	5.31	5.30
Injury Severity (%)										
Mild	91.10	90.89	91.80	90.64	90.97	90.62	90.73	90.75	90.87	90.39
Moderate	3.54	3.60	3.64	3.67	3.58	3.77	3.66	3.66	3.61	3.74
Severe	4.20	4.40	4.15	4.56	4.32	4.44	4.46	4.45	4.39	4.74
Critical	1.16	1.11	1.12	1.13	1.14	1.16	1.15	1.14	1.14	1.13
Injury Mechanisms (%)										
Blunt	81.94	81.94	81.94	81.94	81.94	81.94	81.94	81.94	81.94	81.94
Penetrating	12.82	12.82	12.82	12.82	12.82	12.82	12.82	12.82	12.82	12.82
Blunt & Penetrating	2.43	2.43	2.43	2.43	2.43	2.43	2.43	2.43	2.43	2.43
Other	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82
Charlson Index (%)										
0	94.68	94.54	94.48	94.76	94.55	94.65	94.52	94.66	94.68	94.70
1-4	4.90	5.04	5.09	4.83	5.03	4.94	5.04	4.92	4.92	4.89
5+	0.42	0.42	0.43	0.41	0.42	0.42	0.44	0.41	0.40	0.41
Insurance status (%)										
Private	39.73	39.42	39.58	39.84	39.42	39.57	39.68	39.75	39.49	39.36
Public	40.16	40.44	40.57	40.59	40.09	40.27	40.09	40.14	40.38	40.65

None	20.12	20.14	19.85	19.57	20.49	20.17	20.23	20.11	20.13	19.99
Hospital type (%)										
Private, Level I/II	44.14	43.96	44.02	44.22	43.48	44.32	43.88	43.82	44.07	44.12
Public, Level I/II	42.18	42.26	41.98	41.99	42.22	41.99	41.81	42.03	42.27	41.80
Private, Level III	13.68	13.79	13.99	13.79	14.30	13.69	14.31	14.15	13.66	14.07
Land use (%)										
Residential	41.17	41.14	40.60	41.73	41.27	41.28	41.36	40.75	40.88	41.23
Commercial	11.85	11.78	12.18	11.72	12.16	11.84	11.73	12.18	12.01	12.12
Industrial/Agricultural	4.46	4.20	4.55	4.30	4.24	4.34	4.56	4.43	4.43	4.25
Undeveloped	5.01	5.14	5.12	4.93	4.91	4.98	4.78	5.06	4.93	4.89
Transport	30.79	30.85	30.89	30.75	30.75	30.80	30.79	30.83	30.81	30.87
Institutional	6.72	6.90	6.65	6.57	6.67	6.75	6.78	6.75	6.93	6.63
ZCTA Per capita income (%)										
< $25,000	27.71	25.71	25.71	25.71	25.71	25.72	25.71	25.71	25.72	25.71
> $25,000	74.29	74.29	74.29	74.29	74.29	74.28	74.29	74.29	74.28	74.29
ZCTA median age (mean years)	38.15	38.15	38.15	38.15	38.15	38.15	38.15	38.15	38.15	38.15
Miles to trauma center (mean)	9.82	9.77	9.87	9.84	9.86	9.92	9.82	9.87	9.89	9.93
Prehospital time (mean minutes)	64.60	64.77	65.16	65.34	65.24	65.29	65.16	65.72	65.67	63.98

Appendix H: Log odds ratios for variables excluded from Aim 1 regression models. Coefficients are from bivariate logistic regression of variable on mortality.

Variable	**β**	**95% CI**	***p***
Roadway type			
Secondary road	reference	--	--
Primary road	0.191	-0.377, 0.756	0.508
Interstate/Controlled Access	0.369	-0.303, 1.043	0.282
Speed limit			
25-45 mph	0.183	-0.269, 0.635	0.420
46-55 mph	0.449	-0.197, 1.095	0.173
56-65 mph	0.359	-0.352, 1.069	0.322
> 65 mph			
EMS base distance	0.011	-0.017, 0.039	0.444
ZCTA Measures			
% White	0.002	-0.002, 0.005	0.438
% Male	-0.003	-0.033, 0.026	0.820
Aggregate income	0.000	0.000, 0.000	0.301
% below poverty line	-0.001	-0.015, 0.012	0.820
Income inequality (Gini)	-1.709	-3.627, 0.208	0.080
% employed	0.010	-0.006, 0.026	0.204
% Residents Insured	0.005	-0.016, 0.027	0.641
% with high school diploma	0.005	-0.006, 0.017	0.361
% with college degree	-0.003	-0.011, 0.004	0.414
% Housing units vacant	0.000	-0.012, 0.013	0.946
Median house age	-0.006	-0.014, 0.001	0.110
% using combustible fuel	-0.183	-2.635, 2.269	0.884
% with no private vehicle	0.044	-0.015, 0.103	0.146
% commuting by car	-0.381	-1.484, 0.721	0.498
% commuting by public transit	0.242	-1.070, 1.555	0.718

Appendix I: Standardized regression estimates (β), standard errors (SE), and 95% confidence intervals from multivariate mediation model for race

	β	**SE**	**95% CI**
a path			
Time	-0.659	0.052	-0.760, -0.557
Distance	-0.299	0.010	0.341, 0.392
Penetrating	0.367	0.013	-0.320, -0.279
Medicaid	0.224	0.011	0.203, 0.245
Medicare	-0.329	0.016	-0.361, -0.297
No Insurance	0.243	0.013	0.240, 0.628
b path			
Time	0.112	0.036	0.074, 0.182
Distance	0.434	0.099	0.329, 0.334
Penetrating	0.304	0.015	0.288, 0.628
Medicaid	0.139	0.031	0.107, 0.200
Medicare	0.151	0.025	0.124, 0.200
No Insurance	0.294	0.033	0.260, 0.358
c path	0.195	0.075	0.049, 0.341
c' path	-0.235	0.097	-0.424, -0.045

Appendix J: Standardized regression estimates (β), standard errors (SE), and 95% confidence intervals from multivariate mediation model for ethnicity

	β	**SE**	**95% CI**
a path			
Distance	-0.129	0.014	-0.157, -0.101
Penetrating	0.098	0.017	0.063, 0.132
Medicaid	-0.009	0.016	-0.040, 0.022
Medicare	-0.313	0.030	0.030, -0.371
No Insurance	0.284	0.013	0.259, 0.309
b path			
Distance	0.564	0.085	0.398, 0.731
Penetrating	0.222	0.016	0.191, 0.254
Medicaid	0.161	0.033	0.097, 0.224
Medicare	0.181	0.030	0.122, 0.240
No Insurance	0.295	0.046	0.204, 0.385
c path	-0.929	0.195	-1.311, -0.546
c' path	-0.556	0.178	-0.904, -0.208

Appendix K: Standardized regression estimates (β), standard errors (SE), and 95% confidence intervals from multivariate mediation model for sex

	β	**SE**	**95% CI**
a path			
Time	-0.386	0.048	-0.480, -0.292
Penetrating	0.349	0.015	0.319, 0.380
Medicaid	0.113	0.011	0.091, 0.135
Medicare	-0.246	0.011	-0.267, -0.224
No Insurance	0.175	0.013	0.151, 0.200
Moderate injury	0.031	0.025	-0.019, 0.080
Severe injury	0.042	0.024	-0.005, 0.088
Critical injury	0.201	0.023	0.155, 0.246
b path			
Time	-0.480	0.189	-0.851, -0.109
Penetrating	0.254	0.020	0.215, 0.294
Medicaid	0.031	0.035	-0.038, 0.100
Medicare	0.223	0.031	0.163, 0.283
No Insurance	0.184	0.029	0.128, 0.240
Moderate injury	0.030	0.028	-0.024, 0.084
Severe injury	0.222	0.014	0.195, 0.249
Critical injury	0.599	0.018	0.564, 0.634
c path	0.728	0.069	0.593, 0.864
c' path	0.318	0.115	0.093, 0.542

Appendix L: Data dictionary for analytic data set

Construct	Coding Scheme	Data Source(s)	Notes
Mortality	0 = did not die 1 = died	MTR & eMEDS	MTR is primary source. eMEDS used if MTR disposition unknown or missing. Coded as died if patient died at the injury scene, in transit, in the ED, or in the hospital during the admission associated with the injury incident. Coded as did not die if patient discharged alive from ED or hospital.
Age	1 = 18-24 years old 2 = 25-34 years old 3 = 35-44 years old 4 = 45-54 years old 5 = 55-64 years old 6 = 65-74 years old 7 = 75 years or older	MTR & eMEDS	MTR is primary source. eMEDS used if MTR date of birth and/or date of incident unknown or missing. Calculated based on date of birth and date of injury incident.
Race/Ethnicity	1 = White/Non-Hispanic 2 = African American/Non-Hispanic 3 = Hispanic 4 = Other race	MTR & eMEDS	MTR is primary source. eMEDS used if MTR race and/or ethnicity unknown or missing.
Injury Severity	1 = mild 2 = moderate 3 = severe 4 = critical	MTR & eMEDS	MTR is primary source. eMEDS used for patients who died in EMS care or with insufficient MTR data to calculate severity score. Severity categories coded based on ISS and RTS, with RTS used with ISS not available. ISS categorized as ≤ 9, 10-15, 16-24, and ≥ 25. RTS categorized as 12, 11, 4-10, and ≤ 3. ISS was calculated using the Stata ICDPIC module. RTS was calculated by MIEMSS at the time of data collection.
Injury Mechanism	1 = blunt 2 = penetrating 3 = blunt & penetrating 4 = other	MTR & eMEDS	MTR is primary source. eMEDS used for patients who died in EMS care or with unknown or missing mechanism in the MTR. Both the MTR and eMEDS data sets include injury mechanism variables. Other injury includes burn, drowning, hanging, inhalation, ingestion, crush, snake/spider bite, and animal/human bite.
Charlson Index	0 = CCI 0 1 = CCI 1-4 2 = CCI $\geq$ 5	MTR	CCI calculated based on limited comorbidity information in the MTR. No comorbidity information available in eMEDS.
Insurance Status	1 = private 2 = Medicare	MTR	Insurance status coded based on primary payor identified in the MTR. No payor information available in eMEDS. No

	3 = Medicaid 4 = no insurance		insurance includes self-pay, bad debt, and no charge. Private insurance includes all payors other than Medicare, Medicaid, and uninsured. Medicaid and Medicare were consolidated in a single public insurance category for Aim 1 and Aim 2.
Prehospital time	minutes	MTR & eMEDS	Calculate based on time of 911 call and time of arrival at final trauma center destination. MTR times used as primary. eMEDS times used when MTR times unknown or missing. Prehospital time for patients who died in EMS care calculated based on time of 911 call and time of death.
Trauma center distance	miles	MTR, eMEDS, & public records	Trauma center distance is the Euclidian distance, in miles, from the injury incident scene to the nearest trauma center. MTR was primary source of injury incident location. When exact coordinates of incident were not available in MTR, injury incident address in eMEDS used to geocode locations. Trauma center locations were geocoded using the trauma center address of record, according public records for MIEMSS trauma center designation.
Hospital Type	1 = private, Level I/II 2 = public, Level I/II 3 = Level III	MTR, eMEDS, & public records	Hospital type calculated based on characteristics of the trauma center closest to the injury incident location. Hospital ownership and trauma center designation determined based on public records searches of MIEMSS designated trauma centers in Maryland. MTR was primary source of injury incident location. When exact coordinates of incident were not available in MTR, injury incident address in eMEDS used to geocode locations.
Land use	1 = residential 2 = commercial 3 = industrial/agricultural 4 = undeveloped 5 = transport 6 = institutional	MTR, eMEDS, Maryland Geographic Information Office	Injury incident locations were linked with land use shape files maintained by the Maryland Department of Natural Resources, and distributed for public use through the Maryland Geographic Information Office. MTR was primary source of injury incident location. When exact coordinates of incident were not available in MTR, injury incident address in eMEDS used to geocode locations.
ZCTA per capita income	1 = < $25,000 2 = ≥ $25,000	MTR, eMEDS, US Census Bureau	Injury incident locations were linked with ZCTA shape files with data from the American Community Survey, provided by the US Census Bureau. MTR was primary source of injury incident location. When exact

			coordinates of incident were not available in MTR, injury incident address in eMEDS used to geocode locations.
ZCTA median age	years	MTR, eMEDS, US Census Bureau	Injury incident locations were linked with ZCTA shape files with data from the American Community Survey, provided by the US Census Bureau. MTR was primary source of injury incident location. When exact coordinates of incident were not available in MTR, injury incident address in eMEDS used to geocode locations.

CURRICULUM VITAE

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PERSONAL DATA

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EDUCATION

2017 (Candidate)	Johns Hopkins Bloomberg School of Public Health, Baltimore, MD Ph.D. in Health Services Research and Policy Advisor: Renan Castillo, Ph.D. Thesis (proposed): Concentrated trauma risk: examining social and environmental determinants of injury mortality
2006	University of North Carolina at Chapel Hill, Chapel Hill, NC M.P.H. in Health Behavior and Health Education Thesis: An analysis of alcohol use and dangerous drinking at the University of North Carolina
2004	University of North Carolina at Chapel Hill, Chapel Hill, NC B.A. in Anthropology Minor: Chemistry

PROFESSIONAL EXPERIENCE

2016 –	Research Assistant PI: Jonathan Weiner and Brendan Saloner (PRECOG Study) Johns Hopkins Center for Population Health IT, Baltimore, MD
2016 –	Research Assistant PI: Hadi Kharrazi (B'Friend Study) Johns Hopkins Center for Population Health IT, Baltimore MD
2014 –	Research Assistant PI: Renan Castillo Johns Hopkins Center for Injury Research and Policy, Baltimore, MD
2007 – 2013	Social/Clinical Research Specialist PI: Bonnie Yankaskas and Louise Henderson Carolina Mammography Registry, Chapel Hill, NC
2006 – 2007	Wellness Program Coordinator UNC-CH Campus Health Services, Chapel Hill, NC

PUBLICATIONS

2016	**Jarman MP,** Castillo RC, Carlini AR, Kodadek LM, Adil AH. Rural Risk: Geographic Disparities in Trauma Mortality. *Surgery*. August 2016; ePub ahead of print. PMID: 26506860.
2012	**Jarman MP**, Bowling JM, Dickens P, Luken K, Yankaskas BC. Factors facilitating acceptable mammography services for women with disabilities. *Women's Health Issues.* September 2012;22(5):e412-8. PMID: 22818248.
2011	Yankaskas BC, May RC, Matuszewski J, Bowling JM, **Jarman MP**, Schroeder BF. Effect of observing change from comparison mammograms on performance of screening mammography in a large community-based population. *Radiology.* December 2011;261(3):762-70. PMID: 22031709.
2010	Yankaskas BC, Dickens P, Bowling JM, **Jarman MP**, Luken K. Barriers to adherence to screening mammography among women with disabilities. *American Journal of Public Health.* May 2010;100(5):947-53. PMID: 19834002.

HONORS AND AWARDS

2017	HPM Student Conference Presentation Award; JHSPH
2016	The William Haddon Jr. Fellowship; JHSPH
2016	HPM Student Conference Presentation Award; JHSPH
2015	HPM Student Conference Presentation Award; JHSPH
2004	James R. Briley Scholarship for Excellence in Health Education; UNC-CH

GRANTS AND FELLOWSHIPS

2013 – 2015	AHRQ National Research Service Award Trainee (T32); JHSPH

CONFERENCE PRESENTATIONS

2016	**Jarman MP**, Castillo RC. Environmental and Community Determinants of Injury Mortality. Academic Surgical Congress. Encore Hotel and Resort, Las Vegas, NV. February 8, 2017. Podium presentation.
2016	**Jarman MP**, Castillo RC. Rural Risk: Geographic Disparities in Trauma Mortality. AHRQ NRSA Trainees Conference. Sheraton Boston Hotel, Boston, MA. June 24, 2016. Podium presentation.
2016	**Jarman MP**, Castillo RC, Carlini AR, Haider AH. Rural Risk: Geographic Disparities in Trauma Mortality. Academic Surgical Congress. Hyatt Regency, Jacksonville, FL. February 2, 2016. Podium presentation.
2015	**Jarman MP**, Castillo RC, Carlini AR, Haider AH. Geographic disparities in Mortality Following Head Trauma. AcademyHealth Annual Research Meeting. Minneapolis Convention Center, Minneapolis, MN. June 14, 2015. Poster presentation.

2015 **Jarman MP**, Castillo RC, Carlini AR, Haider AH. Geographic disparities in Mortality Following Head Trauma. Academic Surgical Congress. Encore Resort, Las Vegas, NV. February 4, 2015. Podium presentation.

TEACHING EXPERIENCE

Guest Lectures

"Reviewing the Bardach Process." Public Health Policy, Department of Health Policy and Management, Johns Hopkins School of Public Health (August 2016).

Teaching Assistantships

Public Health Policy (Summer term: 2014, 2015, 2016*)
Research and Evaluation Methods for Health Policy I (3rd term: 2016, 2017)
Research and Evaluation Methods for Health Policy II (4th term: 2016, 2017)
Managed Care and Health Insurance (3rd term: 2015, 2016*)
Assessing Health Status and Patient Outcomes (2nd term: 2014, 2015)
Introduction to Health Policy (1st term: 2014, 2015)
(*lead TA)

ACADEMIC SERVICE

2015 – 2017 Student Representative
Academic Policy and Appointment Committee
Department of Health Policy and Management

Johns Hopkins School of Public Health

2014 – 2015 Student Representative
Research Committee
Department of Health Policy and Management
Johns Hopkins School of Public Health

TECHNICAL SKILLS

Statistical packages: Stata (advanced), R (novice), SAS (novice)
Graphics and mapping: ArcMap (intermediate)

CERTIFICATIONS

2012 Certificate in Field Epidemiology, Gillings School of Global Public Health, UNC-CH

2011 Visual Design and Layout of Questionnaires, Odum Institute, UNC-CH

2010 Introduction to Qualtrics, Odum Institute, UNC-CH

PROFESSIONAL AFFILIATIONS

2014 – AcademyHealth
2004 – American Public Health Association