Between-hospital and between-neighborhood variance in trauma outcomes: Cross-sectional observational evidence from the Detroit metropolitan area

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-022090
Article Type:	Research
Date Submitted by the Author:	01-Feb-2018
Complete List of Authors:	Sall, Lauren; St. John Hospital & Medical Center, Surgery Hayward, R. David; St. John Hospital & Medical Center, Surgery Fessler, Mary; St. John Hospital & Medical Center, Surgery Edhayan, Elango; St. John Hospital & Medical Center, Surgery
Keywords:	ACCIDENT & EMERGENCY MEDICINE, Quality in health care < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, PUBLIC HEALTH, TRAUMA MANAGEMENT

Between-hospital and between-neighborhood variance in trauma outcomes: Cross-sectional observational evidence from the Detroit metropolitan area

Lauren Sall, MD

R. David Hayward, PhD*

Mary M. Fessler, BA

Elango Edhayan, MD, FACS

St. John Hospital & Medical Center

Department of Surgery

Detroit, MI

USA

WORD COUNT: 1,883

KEY WORDS: traumatic injury; health inequalities; neighborhoods; trauma outcomes

Direct Correspondence to:
R. David Hayward, PhD
Senior Medical Researcher
Department of Surgery
St. John Hospital & Medical Center
22151 Moross Rd., PB 1, Suite. 212
Detroit, MI 48236
USA
Phone: (313) 343-3485
Email: Richard.Hayward@ascension.org

ABSTRACT

OBJECTIVES: Disparities in treatment outcomes for traumatic injury are an important concern for care providers and policy makers. Factors that may influence these disparities include differences in risk exposure based on neighborhood of residence, and differences in quality of care between hospitals in different areas. This study examines geographic disparities within a single region: the Detroit metropolitan area.

DESIGN: Data on all trauma admissions between 2006 and 2014 were obtained from the Michigan State Inpatient Database. Admissions were grouped by patient neighborhood of residence and admitting hospital. Generalized Linear Mixed Modeling procedures were used to determine the extent of shared variance based on these two levels of categorization on three outcomes. Patients with trauma due to common mechanisms (falls, firearms, and motor vehicle traffic) were examined as additional subgroups.

SETTING: 143 hospitals admitting patients for traumatic injury in the Detroit metropolitan area during the period from 2006 – 2014.

PARTICIPANTS: 404,675 adult patients admitted for treatment of traumatic injury.

OUTCOME MEASURES: In-hospital mortality, length of stay, and cost of care.

RESULTS: Intraclass correlation coefficients indicated that there was substantial shared variance in outcomes based on hospital, but not based on neighborhood of residence. Among all injury types, hospital-level differences accounted for 15.4% of variance in mortality risk, 36.2% of variance in length of stay, and 37.7% of variance in cost of care. Hospital variance in mortality was highest for firearm trauma (20.1%).

CONCLUSIONS: Based on these data, geographic disparities in trauma treatment outcomes were more strongly attributable to differences in access to quality hospital care than to risk

factors in the neighborhood environment. Transfer of high-risk cases, particularly firearm-related trauma, to hospitals with greater institutional experience in the relevant area may help address mortality disparities in particular.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- Data covers all hospital admissions in a major metropolitan area over a 9-year period
- Multi-level analysis allows decomposition of differences in patient outcomes shared within neighborhood of residence and hospital of treatment
- Range of outcomes including mortality, length of stay, and cost of care
- Cannot assess mortality occurring before hospital admission
- Differences in intake patterns may increase between-hospital variance

INTRODUCTION

The persistence of disparities in patient outcomes is a serious challenge for the US health care system[1]. People with low incomes and members of racial and ethnic minority groups experience worse health outcomes across a broad spectrum, from lower birth weight[2] to greater risk of functional disability in older adulthood[3]. The causes of these disparities are complex and multifaceted, including differing levels of environmental exposure to health hazards[4], cultural differences in health behaviors[5], and unequal access to quality care[6]. Within the field of health disparities research, traumatic injury has received relatively little attention in comparison to areas such as chronic disease and infection[7]. Nevertheless, there is a significant body of evidence finding that factors including race[7,8] and socioeconomic status[9,10] may affect patients' risk of negative outcomes following trauma treatment.

The local geography of cities may play an important role in forming these disparities. Cities in the US remain heavily segregated by both race and socioeconomic status, with sharp differences in the demographic makeup of neighborhoods that may be in close proximity to one another[11]. These neighborhoods may differ in terms of the risks they pose for traumatic injury. For example, socioecomically-disadvantaged neighborhoods may have higher rates of trauma from causes like assault, which may entail greater risks of poorer outcomes. More broadly, residents of marginalized neighborhoods may face greater background health challenges, leaving them more likely to suffer from multiple comorbidities that are likely to complicate recovery from traumatic injury[12,13].

A related facet of metropolitan geography potentially impacting trauma outcomes relates to hospital quality and access. Quality of care issues are an increasing concern in the realm of public policy[14]. Large cities contain numerous hospitals providing emergency trauma care, and

most trauma patients are likely to be receive treatment at facilities in close proximity to the places in which they live. Hospitals and other health care facilities serving primarily poor and marginalized local populations may face challenges with funding levels and patient demands that inhibit care quality[6,15]. Insurance issues and patient familiarity may also serve to funnel high-risk patients towards under-resourced hospitals, as patients may be more likely to opt to seek care at institutions with which they are more familiar, and which they may perceive as less costly[16].

The extent to which these two aspects of local geography within metropolitan areas– residential neighborhood and care facility – may be related to trauma outcomes has not been thoroughly assessed. In this study, we use data from all trauma patients admitted for traumatic injury to hospitals in the Detroit metropolitan area between 2006 and 2014 and apply statistical techniques to determine the extent to which three outcomes (mortality, length of hospital stay, and cost of care) differ as a function of (a) the neighborhoods in which patients reside, and (b) the hospital providing care. The Detroit metropolitan area has some of the highest levels of residential racial and ethnic segregation in the US, as well as some of the most extreme economic inequalities[17]. As a region that has experienced a historical pattern of economic decline and rejuvenation, as well as successive waves of movement between urban and suburban neighborhoods, it serves to exemplify a number of the socioeconomic challenges facing policy makers and health care providers in numerous US cities.

METHOD

Individual-level admissions data for this project were obtained from the Healthcare Cost and Utilization Project (HCUP), sponsored by the Agency for Health Research and Quality (AHRQ). One element of the HCUP is the compilation of an annual database including medical details of all hospital discharges in each state, known as the State Inpatient Database (SID).

Ethical approval for use of the data was granted by the Institutional Review Board of St. John Hospital and Medical Center. Because the data were derived from clinical patient records and were fully anonymous and de-identified, participant consent was not required.

Data for the present analyses come from the Michigan SID for the period of years from 2006 to 2014[18]. Patients residing in the Detroit Metropolitan Statistical Area (MSA) were identified using the US Census Bureau definition as consisting of Wayne, Lapeer, Livingston, Macomb, Oakland, and St. Clair counties. Trauma cases were identified using ICD-9 diagnostic codes present at admission.

Hospitals. Each record in the SID includes a unique, anonymized, identification code corresponding to the hospital to which the patient was admitted. This allows patients to be clustered according to hospital. There were a total of 143 hospitals represented in the data, with a median of 63 observations in each cluster.

Neighborhoods. Patient residence was identified by ZIP code in the SID, and in this study each ZIP code is treated as a separate neighborhood. There were a total of 214 neighborhoods represented in the data, with a median of 1,633 observations in each.

Patient outcomes. Patient outcomes include in-hospital mortality, length of stay, and total cost of care. Mortality was derived from the case disposition code (0 = did not die, 1 = died). Length of stay is given by the number of days between admission and discharge. Total cost is a dollar amount corresponding to the total amount billed to any payer for each admission.

Trauma mechanism. Trauma mechanisms are derived from ICD-9 diagnosis codes included for each admission case in the SID. The three most common specific mechanisms in this sample were examined in these analyses: falls, firearms, and motor vehicle traffic.

Analytical approach

In this study, we use a generalized linear mixed modeling (GLMM) framework to estimate the proportion of variance in individual outcomes that is attributable to each of three levels: hospitals, neighborhoods, and individuals (i.e., residual variance after hospital and neighborhood variance has been accounted for). The GLMM method[19] is a statistical modeling technique which includes a mixture of fixed and random effects. Random effects represent shared group-level linear relationships. Individual outcome values are allowed to vary at random around a group mean, allowing for an estimate of the part of the outcome that varies between groups and that varying between individuals. In these analyses, random intercept effects are specified for both hospital and neighborhood, meaning that individual outcomes are allowed to vary at random around both a hospital mean and a neighborhood mean. The group-level design matrix is specified as cross-classified, meaning that both sets of higher-level clusters are included in the same model, with each individual belonging to both a hospital and neighborhood cluster. Because the distributions of the outcome variables are not the same, different linking functions are used in GLMM models with different outcomes. Mortality is a binary variable, and uses a binary linking function. Length of stay and total cost both have highly skewed continuous distributions, making the use of a longnormal linking function appropriate.

The proportion of variance at the group level is given by the intra-class correlation coefficient (ICC) corresponding to the level of clustering (in this case, hospital and neighborhood). For outcomes with a non-binary function (i.e., length of stay and total cost), the ICC is computed by dividing the group-level variance parameter by the sum of the group and residual variance parameters. For binary GLMM (i.e., mortality), the ICC is given by dividing the group-level variance parameter by the sum of the group-level parameter and 3.29, an estimate of the theoretical variance in the binomial distribution[20]. In the results, these figures are expressed as a percentage of the total variance at each level. Cases with missing outcome data were excluded on a pairwise basis.

RESULTS

Descriptive statistics for group and sample sizes for each analysis are included in Table 1, along with relative variance estimates. There were a total of 404,675 admissions for traumatic injury during the time period included in this study. The three largest subgroups based on mechanism were falls (N = 117,931), motor vehicle traffic (N = 22,755), and firearms (N = 6,512). All patients were included in analyses of mortality. Sample sizes for analyses of length of stay were somewhat smaller, likely reflecting patients who were transported to a hospital but died before admission (1.8% of the full sample was lost at this stage). Total charge data were available for only a subset of patients, due to under-reporting of this variable by hospitals (31.4% of the total sample was lost at this stage).

There was significant variance at the hospital level across outcomes and trauma mechanism, although the extent of this variance ranged from 2.9% for mortality due to falls to 37.7% for total cost across all injury mechanisms. Neighborhood variance was minimal across outcomes and mechanism as well, with the highest estimate being 1.1% for motor vehicle traffic mortality.

DISCUSSION

The persistence of disparities in health outcomes is an important concern for public policy makers and for hospital administrators. This analysis addresses two important issues. First, the extent of disparity in outcomes from trauma treatment has received relatively little attention, with most research focusing primarily on treatment of acute and chronic disease. Second, a longstanding question has been the relative importance of placement of care facilities versus neighborhood risk factors and individual differences in creating patterns of geographic health inequality – i.e., do marginalized neighborhoods suffer because they have access to hospitals that have worse outcomes; because they exhibit environmental risk factors like exposure to greater violence, more toxic substances, and generally unsanitary and stressful conditions; or because their populations have other underlying risk factors, like higher rates of chronic disease and lower levels of insurance coverage, unrelated to specific neighborhood conditions.

With respect to the first question, these results suggest that there are substantial disparities in trauma outcomes related to factors outside of the facts of the trauma case and individual differences in trauma patients. Ideally, these individual factors (represented here as part of the residual variance) should account for all of the variance in outcomes – patient outcomes should be equal across hospitals and across neighborhoods. Regarding the second question, these data indicate that identifiable inequalities account for between 3% and 36% of outcomes, depending on the outcome and trauma type examined. They also suggest that most of these disparities in trauma outcomes appear to be due to hospital-level disparities, with the independent influence of neighborhood being comparatively trivial. This lends support to the view that geographic disparities in trauma outcomes (at least within the specific context of the Detroit metropolitan area) seem to be mainly due to differences in care provided by facilities available in these areas.

This suggests that, at least in the case of trauma outcomes, policy should focus on reducing disparities in treatment quality between hospitals in order to reduce community-level disparities in outcomes. More broadly, it suggests that factors influencing geographic disparities in trauma outcomes may arise at the point of treatment, rather than being the result of different levels of risk derived from the neighborhood environment, at least when considered within a single metropolitan area. Disparities in treatment quality may have a number of causes, including differences in investment, differences in resource allocation, and differences in institutional experience with treating trauma. In addition to addressing funding and investment disparities, ways of addressing these differences might include transferring high risk cases to hospitals with more extensive institutional experience in the relevant field.

Limitations of this study include the inherent inability to differentiate hospital-level variance that may be caused by differences in the patient population served at different institutions. For example, some institutions may admit a larger volume of more serious traumas, which may have less favorable outcomes. Additionally, because the database used includes only patients who were admitted, it is not possible to assess geographical differences in mortality among those who had a traumatic injury but died before they could be admitted for treatment. It is plausible that neighborhood disparities would be larger if these cases were included.

As policy-makers look for ways to reduce both disparities in trauma outcomes and the cost of providing care for traumatic injury, it is important to have a clear picture of the extent to which they differ as a function of local geography. This study represents a step towards addressing that question, indicating that differences between hospitals may play an important role in determining the extent of these differences.

CONFLICT OF INTEREST STATEMENT:

The authors have no conflicting interests to declare.

AUTHOR CONTRIBUTIONS

LS, RH, and MF drafted the manuscript. RH conducted the statistical analyses. LS and EE developed the research questions. All authors reviewed and revised the manuscript.

DATA STATEMENT

Data from the State Inpatient Database (SID for the state of Michigan for the years 2006 – 2014 were obtained from the Agency for Health Research and Quality's (AHRQ) Healthcare Cost and Utilization Project (HCUP). These data are available for purchase from AHRQ at http://www.hcup-us.ahrq.gov/

FUNDING

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

References

1. Adler, N. E. & Rehkopf, D. H. U.S. Disparities in Health: Descriptions, Causes, and Mechanisms. *Annu. Rev. Public Health* **29,** 235–252 (2008).

2. Howell, E. A., Hebert, P., Chatterjee, S., Kleinman, L. C. & Chassin, M. R. Black/white differences in very low birth weight neonatal mortality rates among New York City hospitals. *Pediatrics* **121,** e407–e415 (2008).

3. Freedman, V. A., Martin, L. G. & Schoeni, R. F. Recent trends in disability and functioning among older adults in the united states: A systematic review. *J. Am. Med. Assoc.* **288,** 3137–3146 (2002).

4. Juarez, P. D. *et al.* The public health exposome: a population-based, exposure science approach to health disparities research. *Int. J. Environ. Res. Public. Health* **11,** 12866–12895 (2014).

5. Jackson, J. S., Knight, K. M. & Rafferty, J. A. Race and Unhealthy Behaviors: Chronic Stress, the HPA Axis, and Physical and Mental Health Disparities Over the Life Course. *Am. J. Public Health* **100,** 933–939 (2010).

6. Dimick, J., Ruhter, J., Sarrazin, M. V. & Birkmeyer, J. D. Black patients more likely than whites to undergo surgery at low-quality hospitals in segregated regions. *Health Aff. (Millwood)* **32,** 1046–1053 (2013).

7. Haider, A. H. *et al.* Disparities in trauma care and outcomes in the United States: A systematic review and meta-analysis. *J. Trauma Acute Care Surg.* **74,** 1195–1205 (2013).

8. Maybury, R. S. *et al.* Pedestrians struck by motor vehicles further worsen race- and insurance-based disparities in trauma outcomes: The case for inner-city pedestrian injury prevention programs. *Surgery* **148,** 202–208 (2010).

9. Reimers, A. & Laflamme, L. Hip Fractures Among the Elderly: Personal and Contextual Social Factors That Matter. *J. Trauma Acute Care Surg.* **62,** 365–369 (2007).

10. Corrigan, J. D. & Bogner, J. A. Neighborhood Characteristics and Outcomes After Traumatic Brain Injury. *Arch. Phys. Med. Rehabil.* **89,** 912–921 (2008).

11. Iceland, J. & Sharp, G. White Residential Segregation in U.S. Metropolitan Areas: Conceptual Issues, Patterns, and Trends from the U.S. Census, 1980 to 2010. *Popul. Res. Policy Rev.* **32,** 663–686 (2013).

12. Bergeron, E., Lavoie, A., Moore, L., Clas, D. & Rossignol, M. Comorbidity and age are both independent predictors of length of hospitalization in trauma patients. *Can. J. Surg.* **48,** 361 (2005).

13. Moore, L. *et al.* Using information on preexisting conditions to predict mortality from traumatic injury. *Ann. Emerg. Med.* **52,** 356–364.e2 (2008).

14. Tsai, T. C., Orav, E. J. & Jha, A. K. Patient Satisfaction and Quality of Surgical Care in US Hospitals. *Ann. Surg.* **261,** 2–8 (2015).

15. Hasnain-Wynia R, Baker DW, Nerenz D & et al. Disparities in health care are driven by where minority patients seek care: Examination of the hospital quality alliance measures. *Arch. Intern. Med.* **167,** 1233–1239 (2007).

16. Vettukattil, A. S. *et al.* Do Trauma Safety-Net Hospitals Deliver Truly Safe Trauma Care? A Multilevel Analysis of the National Trauma Data Bank. *J. Trauma Acute Care Surg.* **70,** 978–984 (2011).

17. Darden, J., Rahbar, M., Jezierski, L., Li, M. & Velie, E. The Measurement of Neighborhood Socioeconomic Characteristics and Black and White Residential Segregation in

Metropolitan Detroit: Implications for the Study of Social Disparities in Health. *Ann. Assoc. Am. Geogr.* **100,** 137–158 (2010).

18. Healthcare Cost and Utilization Project (HCUP). *HCUP State Inpatient Databases (SID)*. (Agency for Healthcare Research and Quality, 2006).

19. Brown, H. & Prescott, R. *Applied mixed models in medicine*. (John Wiley & Sons, 2014).

20. Nakagawa, S., Johnson, P. C. D. & Schielzeth, H. The coefficient of determination R2 and intra-class correlation coefficient from generalized linear mixed-effects models revisited and expanded. *J. R. Soc. Interface* **14,** (2017).

Table 1. Variance decomposition statistics

	Hospital Variance	Neighborhood Variance	Residual Variance	Patient N	Hospital N	ZIP code N	Mean (SD) or %
All Injuries							
Mortality	15.4%	0.8%	83.8%	404,675	143	214	2.5%
Length of Stay	36.2%	0.2%	63.6%	397,564	143	214	6.4 (8.3)
Total Cost	37.7%	0.2%	62.2%	277,668	143	214	36,264 (55,237)
Falls							
Mortality	2.9%	0.2%	96.9%	117,931	123	213	2.2%
Length of Stay	20.5%	0.5%	79.3%	115,798	123	213	5.2 (5.1)
Total Cost	25.0%	0.1%	74.9%	78,539	109	213	29,641 (31,826)
Firearms							
Mortality	20.1%	0.8%	79.1%	6,512	60	179	5.4%
Length of Stay	11.5%	0.3%	88.2%	6,101	60	179	7.0 (10.6)
Total Cost	18.4%	0.03%	81.5%	3,163	60	179	62,215 (91,234)
Motor Vehicle							
Mortality	4.7%	1.1%	94.2%	22,755	100	211	2.3%
Length of Stay	13.1%	0.3%	86.6%	21,598	100	211	5.2 (7.9)

Total Cost	21.6%	0.6%	77.8%	12,833	100	211	49,358 (75,765)

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract **Page 1**
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found **Page 2**
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported **Pages 1 – 5**
Objectives	3	State specific objectives, including any prespecified hypotheses **Page 5**
Methods		
Study design	4	Present key elements of study design early in the paper **Pages 5 – 7**
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection **Pages 5 – 6**
Participants	6	(*a*) *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants **Pages 5 – 6**
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable **Page 6**
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group **Pages 5 – 6**
Bias	9	Describe any efforts to address potential sources of bias **Page 7**
Study size	10	Explain how the study size was arrived at **Page 8**
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why **Pages 6 – 7**
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding **Page 7**
		(*b*) Describe any methods used to examine subgroups and interactions **Page 7**
		(*c*) Explain how missing data were addressed **Page 7**
		(*d*) *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy **N/A**

		(*e*) Describe any sensitivity analyses **N/A**

Continued on next page

Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed **Page 8**
		(b) Give reasons for non-participation at each stage **N/A**
		(c) Consider use of a flow diagram **N/A**
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders **Page 8**
		(b) Indicate number of participants with missing data for each variable of interest **Table 1**
Outcome data	15*	
		Cross-sectional study—Report numbers of outcome events or summary measures **Table 1**
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included **N/A**
		(*b*) Report category boundaries when continuous variables were categorized **N/A**
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period **N/A**
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses **Page 8 & Table 1**
Discussion		
Key results	18	Summarise key results with reference to study objectives **Page 9**
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias **Page 10**
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence **Pages 9 – 10**
Generalisability	21	Discuss the generalisability (external validity) of the study results **Page 9**
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable,

for the original study on which the present article is based
N/A

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Between-hospital and between-neighborhood variance in trauma outcomes: Cross-sectional observational evidence from the Detroit metropolitan area

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-022090.R1
Article Type:	Research
Date Submitted by the Author:	15-Jun-2018
Complete List of Authors:	Sall, Lauren; St. John Hospital & Medical Center, Surgery Hayward, R. David; St. John Hospital & Medical Center, Surgery Fessler, Mary; St. John Hospital & Medical Center, Surgery Edhayan, Elango; St. John Hospital & Medical Center, Surgery
Primary Subject Heading:	Emergency medicine
Secondary Subject Heading:	Public health, Surgery
Keywords:	ACCIDENT & EMERGENCY MEDICINE, Quality in health care < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, PUBLIC HEALTH, TRAUMA MANAGEMENT

Between-hospital and between-neighborhood variance in trauma outcomes: Cross-sectional observational evidence from the Detroit metropolitan area

Lauren Sall, MD

R. David Hayward, PhD*

Mary M. Fessler, BA

Elango Edhayan, MD, FACS

St. John Hospital & Medical Center

Department of Surgery

Detroit, MI

USA

WORD COUNT: 2,912

KEY WORDS: traumatic injury; health inequalities; neighborhoods; trauma outcomes

Direct Correspondence to:
R. David Hayward, PhD
Senior Medical Researcher
Department of Surgery
St. John Hospital & Medical Center
22151 Moross Rd., PB 1, Suite. 212
Detroit, MI 48236
USA
Phone: (313) 343-3485
Email: Richard.Hayward@ascension.org

ABSTRACT

OBJECTIVES: Disparities in treatment outcomes for traumatic injury are an important concern for care providers and policy makers. Factors that may influence these disparities include differences in risk exposure based on neighborhood of residence, and differences in quality of care between hospitals in different areas. This study examines geographic disparities within a single region: the Detroit metropolitan area.

DESIGN: Data on all trauma admissions between 2006 and 2014 were obtained from the Michigan State Inpatient Database. Admissions were grouped by patient neighborhood of residence and admitting hospital. Generalized Linear Mixed Modeling procedures were used to determine the extent of shared variance based on these two levels of categorization on three outcomes. Patients with trauma due to common mechanisms (falls, firearms, and motor vehicle traffic) were examined as additional subgroups.

SETTING: 143 hospitals admitting patients for traumatic injury in the Detroit metropolitan area during the period from 2006 – 2014.

PARTICIPANTS: 404,675 adult patients admitted for treatment of traumatic injury.

OUTCOME MEASURES: In-hospital mortality, length of stay, and hospital charges.

RESULTS: Intraclass correlation coefficients indicated that there was substantial shared variance in outcomes based on hospital, but not based on neighborhood of residence. Among all injury types, hospital-level differences accounted for 15.4% of variance in mortality risk, 36.2% of variance in length of stay, and 37.7% of variance in hospital charges. Hospital variance in mortality was highest for firearm trauma (20.1%).

CONCLUSIONS: Based on these data, geographic disparities in trauma treatment outcomes were more strongly attributable to differences in access to quality hospital care than to risk

factors in the neighborhood environment. Transfer of high-risk cases, particularly firearm-related trauma, to hospitals with greater institutional experience in the relevant area may help address mortality disparities in particular.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- Data covers all hospital admissions in a major metropolitan area over a 9-year period
- Multi-level analysis allows decomposition of differences in patient outcomes shared within neighborhood of residence and hospital of treatment
- Range of outcomes including mortality, length of stay, and hospital charges
- Cannot assess mortality occurring before hospital admission
- Differences in intake patterns may increase between-hospital variance

INTRODUCTION

The persistence of disparities in patient outcomes is a serious challenge for the US health care system[1]. People with low incomes and members of racial and ethnic minority groups experience worse health outcomes across a broad spectrum, from lower birth weight[2] to greater risk of functional disability in older adulthood[3]. The causes of these disparities are complex and multifaceted, including differing levels of environmental exposure to health hazards[4], cultural differences in health behaviors[5], and unequal access to quality care[6]. Within the field of health disparities research, traumatic injury has received relatively little attention in comparison to areas such as chronic disease and infection[7]. Nevertheless, there is a significant body of evidence finding that factors including race[7,8] and socioeconomic status[9,10] may affect patients' risk of negative outcomes following trauma treatment.

The local geography of cities may play an important role in forming these disparities. Cities in the US remain heavily segregated by both race and socioeconomic status, with sharp differences in the demographic makeup of neighborhoods that may be in close proximity to one another[11]. These neighborhoods may differ in terms of the risks they pose for traumatic injury. For example, socioecomically-disadvantaged neighborhoods may have higher rates of trauma from causes like assault, which may entail greater risks of poorer outcomes. More broadly, residents of marginalized neighborhoods may face greater background health challenges, leaving them more likely to suffer from multiple comorbidities that are likely to complicate recovery from traumatic injury[12,13].

A related facet of metropolitan geography potentially impacting trauma outcomes relates to hospital quality and access. Quality of care issues are an increasing concern in the realm of public policy[14]. Large cities contain numerous hospitals providing emergency trauma care, and

most trauma patients are likely to be receive treatment at facilities in close proximity to the places in which they live. Hospitals and other health care facilities serving primarily poor and marginalized local populations may face challenges with funding levels and patient demands that inhibit care quality[6,15]. Insurance issues and patient familiarity may also serve to funnel high-risk patients towards under-resourced hospitals, as patients may be more likely to opt to seek care at institutions with which they are more familiar, and which they may perceive as less costly[16].

The extent to which these two aspects of local geography within metropolitan areas– residential neighborhood and care facility – may be related to trauma outcomes has not been thoroughly assessed. In this study, we use data from all trauma patients admitted for traumatic injury to hospitals in the Detroit metropolitan area between 2006 and 2014 and apply statistical techniques to determine the extent to which three outcomes (mortality, length of hospital stay, and hospital charges) differ as a function of (a) the neighborhoods in which patients reside, and (b) the hospital providing care. The Detroit metropolitan area has some of the highest levels of residential racial and ethnic segregation in the US, as well as some of the most extreme economic inequalities[17]. As a region that has experienced a historical pattern of economic decline and rejuvenation, as well as successive waves of movement between urban and suburban neighborhoods, it serves to exemplify a number of the socioeconomic challenges facing policy makers and health care providers in numerous US cities. It has a well-developed emergency and trauma infrastructure, including three hospitals with ACS Level I trauma designation and 13 with Level II designation during the period covered by this study.

METHOD

Individual-level admissions data for this project were obtained from the Healthcare Cost and Utilization Project (HCUP), sponsored by the Agency for Health Research and Quality

(AHRQ). One element of the HCUP is the compilation of an annual database including medical details of all hospital discharges in each state, known as the State Inpatient Database (SID). Ethical approval for use of the data was granted by the Institutional Review Board of St. John Hospital and Medical Center. Because the data were derived from clinical patient records and were fully anonymous and de-identified, participant consent was not required.

Data for the present analyses come from the Michigan SID for the period of years from 2006 to 2014[18]. Patients residing in the Detroit Metropolitan Statistical Area (MSA) were identified using the US Census Bureau definition as consisting of Wayne, Lapeer, Livingston, Macomb, Oakland, and St. Clair counties. Trauma cases were identified using ICD-9 diagnostic codes present at admission (ICD-9 codes 800 – 959 were included).

Hospitals. Each record in the SID includes a unique, anonymized, identification code corresponding to the hospital to which the patient was admitted. This allows patients to be clustered according to hospital. After excluding institutions with fewer than 100 trauma admissions during the 9-year study period, there were a total of 66 hospitals represented in the data, with a median of 2,845 observations in each cluster.

Neighborhoods. Patient residence was identified by ZIP code in the SID, and in this study each ZIP code is treated as a separate neighborhood. There were a total of 214 neighborhoods represented in the data, with a median of 1,633 observations in each.

Patient outcomes. Patient outcomes include in-hospital mortality, length of stay, and total hospital charges. Mortality was derived from the case disposition code (0 = did not die, 1 = died). Length of stay is given by the number of days between admission and discharge. Total hospital charges is a dollar amount corresponding to the total amount billed to any payer for each admission.

Trauma mechanism. Trauma mechanisms are derived from ICD-9 diagnosis codes included for each admission case in the SID. The three most common specific mechanisms in this sample were examined in these analyses: falls, firearms, and motor vehicle traffic.

Injury severity. ICD-9 diagnosis codes included in the SID were used to calculate estimated injury severity scores (ISS) for all patients. This procedure was carried out using ICDPIC-R[19], an open-source program executed in the R statistical environment which computes abbreviated injury score (AIS) by body region based on ICD-9 codes, and then calculates an estimated ISS based on regional AIS, and is based on a set of procedures that have been extensively validated for this purpose[20,21].

Patient and neighborhood demographics. Individual demographics included age (in years), gender, and race (white, black, or other). Neighborhood socioeconomic status (SES) was measured using ZIP code-level poverty rate estimates published by the US Census Bureau[22]. These estimates represent a three-year rolling average (e.g., the estimates for 2014 represent data from 2012 – 2014). Because poverty rate data were not made available until 2012, whereas this study covers the period from 2006 – 2014, neighborhood SES is represented in this study as a single rate regardless of year (rather than varying across time), using data from 2014. It was not possible to include information about hospital characteristics (e.g., trauma level designation) because the Michigan SID excludes identifiers that would enable cross-referencing hospital IDs with American Hospital Association data.

Analytical approach

In this study, we use a generalized linear mixed modeling (GLMM) framework to estimate the proportion of variance in individual outcomes that is attributable to each of three levels: hospitals, neighborhoods, and individuals (i.e., residual variance after hospital and neighborhood variance has been accounted for). The GLMM method[23] is a statistical modeling technique which includes a mixture of fixed and random effects. Random effects represent shared group-level linear relationships. Individual outcome values are allowed to vary at random around a group mean, allowing for an estimate of the part of the outcome that varies between groups and that varying between individuals. In these analyses, random intercept effects are specified for both hospital and neighborhood, meaning that individual outcomes are allowed to vary at random around both a hospital mean and a neighborhood mean. The group-level design matrix is specified as cross-classified, meaning that both sets of higher-level clusters are included in the same model, with each individual belonging to both a hospital and neighborhood cluster. Because the distributions of the outcome variables are not the same, different linking functions are used in GLMM models with different outcomes. Mortality is a binary variable, and uses a binary linking function. Length of stay and total charges both have highly skewed continuous distributions, making the use of a longnormal linking function appropriate.

The proportion of variance at the group level is given by the intra-class correlation coefficient (ICC) corresponding to the level of clustering (in this case, hospital and neighborhood). For outcomes with a non-binary function (i.e., length of stay and charges), the ICC is computed by dividing the group-level variance parameter by the sum of the group and residual variance parameters. For binary GLMM (i.e., mortality), the ICC is given by dividing the group-level variance parameter by the sum of the group-level parameter and 3.29, an estimate of the theoretical variance in the binomial distribution[24]. In the results, these figures are expressed as a percentage of the total variance at each level. Cases with missing outcome data were excluded on a pairwise basis. LOS analyses exclude cases with mortality prior to admission (hence missing LOS data), but include other in-hospital mortality cases. Analyses were conducted using SAS 9.4, except for the estimation of ISS, which was carried out using ICDPIC-R in R 3.5.

Patient and Public Involvement

This study addresses patient priorities by seeking to better understand how trauma care systems may be able to reduce patient mortality rates, the length of hospitalization, and charges incurred. Data are derived from administrative records, so patients were not directly involved in the design, recruitment, or conduct of the study. Results will be accessible to the public, including to individuals who may have patients during the study period.

RESULTS

Table 1 presents descriptive statistics for the full patient sample at the individual, hospital, and neighborhood levels. There were a total of 404,675 admissions for traumatic injury during the time period included in this study, representing a total of 66 hospitals and 214 ZIP codes. The mean number of patients per hospital was 2,845 (IQR: 349 – 9,683), and the mean number per neighborhood was 1,630 (IQR: 765 – 2,879). The three largest subgroups based on mechanism were falls (N = 117,931), motor vehicle traffic (N = 22,755), and firearms (N = 6,512).

Table 1. Descriptive statistics at the individual, hospital, and neighborhood levels

	Individual (N = 404,675) Mean (SD) or %	Hospital (N = 66) Median [IQR]	Neighborhood (N = 214) Median [IQR]
N individuals		2,845 [349; 9,683]	1,630 [765; 2,879]
Age	60.4 (23.7)	62.0 [53.2, 66.6]	60.8 [57.3, 65.2]
Female	49.8%	50.6% [40.1%, 56.7%]	50.5% [46.3%, 54.2%]
Race			
White	70.0%	74.6% [40.6%, 91.0%]	70.8% [45.5%, 82.4%]

Black	26.0%	7.6% [2.2%, 19.3%]	2.3% [0.9%, 10.0%]
Other	4.0%	8.2% [3.6%, 23.2%]	17.2% [12.0%, 30.7%]
Mechanism			
Falls	44.3%	43.7% [26.9%, 54.1%]	46.7% [40.4%, 52.2%]
Firearms	2.4%	0.4% [0.04%, 1.1%]	0.6% [0.2%, 1.4%]
Motor Vehicle	8.6%	5.4% [2.8%, 12.1%]	8.4% [7.0%, 10.4%]
Severity	4.9 (5.4)	4.5 [3.5, 5.5]	5.0 [4.7, 5.2]
Mortality	2.5%	2.2% [1.6%, 3.0%]	2.4% [2.0%, 2.7%]
LOS	6.4 (8.3)	5.9 [5.2, 6.7]	6.3 [5.9, 6.7]
Charges (thousands of dollars)	36.3 (55.2)	32.5 [25.5, 41.2]	36.9 [33.7, 39.5]
Poverty Rate	17.4 (14.4)	14.5 [11.8, 19.9]	10.7 [6.5, 18.7]

Tables 2 and 3 allow for comparisons of case characteristics by neighborhood SES (defined by poverty rate quartiles) and injury severity (defined by cases with ISS up to 15 and those with ISS greater than 15). Patients from the poorest neighborhoods were substantially younger than the patient population as a whole, and were more likely to be male and black. Mortality rates, LOS, and charges were all significantly higher in poorer neighborhoods, but the magnitude of these differences in outcomes was small (e.g., 2.4% mortality in the lowest-quartile poverty neighborhoods, compared with 2.6% in the highest-poverty quartile). Both outcomes and demographics differed substantially by injury severity. Severely injured patients were much more likely to be male, and were somewhat younger and somewhat more likely to be Black. Firearm and MVT mechanisms were also much more common among the more severe injuries.

As would be expected, mortality was substantially higher among those with more severe injuries, as were median LOS and charges.

Table 2. Individual descriptive statistics by poverty quartile

	1st Quartile (< 6.5%) N = 103,004	2nd Quartile (6.5% - 10.8%) N = 79,738	3rd Quartile (10.8% - 18.7%) N = 90,554	4th Quartile (> 18.7%) N = 134,257	*p*-value[a]
Age, mean [95% CI]	63.9 [63.7, 64.0]	65.1 [64.9, 65.2]	62.3 [62.1, 62.4]	53.8 [53.6, 53.9]	< .001
Female	53.0%	54.0%	52.0%	43.4%	< .001
Race					< .001
White	86.9%	93.5%	83.1%	38.5%	
Black	9.5%	3.3%	13.7%	56.3%	
Other	3.6%	3.2%	3.2%	5.2%	
Mechanism					< .001
Falls	49.8%	51.7%	47.3%	35.4%	
Firearms	1.0%	0.4%	1.0%	5.1%	
Motor Vehicle	8.0%	7.6%	8.1%	9.6%	
Severity (ISS), mean [95% CI]	5.0 [4.9, 5.0]	4.9 [4.9, 4.9]	4.7 [4.7, 4.7]	4.9 [4.9, 5.0]	< .001
Mortality	2.4%	2.5%	2.4%	2.6%	.002
LOS, median [IQR]	4.0 [2.0, 7.0]	4.0 [2.0, 7.0]	4.0 [2.0, 7.0]	4.0 [2.0, 8.0]	< .001
Charges (thousands of dollars), median [IQR]	22.2 [13.0, 37.8]	22.7 [13.2, 38.9]	22.3 [13.0, 38.0]	23.3 [13.3, 41.7]	< .001

NOTES: ISS Injury Severity Score, LOS Length of Stay
[a] *p*-values for 1-way ANOVA (age, ISS), Kruskall-Wallis (LOS, cost), or chi-square (female, race, mechanism, mortality)

Table 3. Individual descriptive statistics by injury severity group

	Less Severe Injuries ISS <= 15 (N = 380,218)	More Severe Injuries ISS > 15 (N = 25,997)	*p*-value[a]
Age, mean [95% CI]	60.6 [60.6, 60.7]	57.0 [56.7, 57.3]	< .001
Female	50.8%	35.8%	
Race			< .001
White	70.4%	64.0%	
Black	25.7%	31.1%	
Other	3.9%	4.9%	
Mechanism			< .001

Falls	44.4%	41.7%	
Firearms	2.0%	8.1%	
Motor Vehicle	7.4%	24.2%	
Mortality	2.1%	8.2%	< .001
LOS	4.0 [2.0, 7.0]	6.0 [3.0, 11.0]	< .001
Charges (thousands of dollars), median [IQR]	22.0 [12.8, 37.5]	37.2 [19.6, 80.2]	< .001
Neighborhood poverty rate, median [IQR]	12.4 [6.5, 26.5]	13.2 [6.5, 32.3]	< .001

NOTES: ISS Injury Severity Score, LOS Length of Stay
[a] *p*-values for 1-way ANOVA (age), Kruskall-Wallis (LOS, cost), or chi-square (female, race, mechanism, mortality)

Table 4 presents the variance decomposition results for the full and stratified samples, along with the number of patients included in each model. All patients were included in analyses of mortality. Sample sizes for analyses of length of stay were somewhat smaller, likely reflecting patients who were transported to a hospital but died before admission (1.8% of the full sample was lost at this stage). Total charge data were available for only a subset of patients, due to under-reporting of this variable by hospitals (31.4% of the total sample was lost at this stage). Supplemental analyses (not shown) indicated that patients with missing charge data were substantially more likely to be black, male, and live in high-poverty neighborhoods. A substantial proportion of this missing data may be due to hospitals waiving or not reporting charges for uninsured patients with means to pay, and thus directly confounded with the aims of the study. Charge results should therefore be interpreted with some caution.

Table 4. Variance decomposition statistics

	Hospital Variance	Neighborhood Variance	Residual Variance	Patient N	Hospital N	ZIP code N

	(ICC)	(ICC)	(ICC)			
All Injuries						
Mortality	15.4%	0.8%	83.8%	404,675	66	214
Length of Stay	36.2%	0.2%	63.6%	397,564	66	214
Total Charges	37.7%	0.2%	62.2%	276,478	66	214
Less Severe Injuries (ISS <= 15)						
Mortality	12.3%	0.4%	87.3%	378,788	66	214
Length of Stay	15.8%	0.2%	84.0%	370,933	66	214
Total Charges	33.0%	0.1%	66.9%	258,744	66	214
More Severe Injuries (ISS > 15)						
Mortality	4.8%	0.4%	94.8%	25,887	64	212
Length of Stay	21.3%	1.3%	77.3%	25,150	64	212
Total Charges	17.7%	0.8%	81.4%	17,734	64	212
All Falls						
Mortality	2.9%	0.2%	96.9%	117,454	65	213
Length of Stay	20.5%	0.5%	79.3%	115,334	65	213
Total Charges	25.0%	0.1%	74.9%	78,166	65	213
All Firearms						
Mortality	20.1%	0.8%	79.1%	6,498	52	178
Length of Stay	11.5%	0.3%	88.2%	6,089	52	178
Total Charges	18.4%	0.03%	81.5%	3,151	52	178
All Motor Vehicle						
Mortality	4.7%	1.1%	94.2%	22,604	65	211

Length of Stay	13.1%	0.3%	86.6%	21,457	65	211
Total Charges	21.6%	0.6%	77.8%	12,725	65	211

NOTES: ICC Intraclass Correlation Coefficient

There was significant variance at the hospital level across outcomes and trauma mechanism, although the extent of this variance ranged from 2.9% for mortality due to falls to 37.7% for total charges across all injury mechanisms. Neighborhood variance was minimal across outcomes and mechanism as well, with the highest estimate being 1.1% for motor vehicle traffic mortality. The extent of variance at the hospital levels was somewhat reduced but still substantial in the analyses stratified by both injury severity and by trauma mechanism. Hence, clustering of risk types did not appear to fully explain inter-hospital differences.

DISCUSSION

The persistence of disparities in health outcomes is an important concern for public policy makers and for hospital administrators. These results reflect a growing literature finding substantial between-hospital differences in outcomes for injured patients, related to hospital factors including patient volume[25], trauma level designation[26], and treatment efficiency[27]. This analysis addresses two important issues. First, the extent of disparity in outcomes from trauma treatment has received relatively little attention, with most research focusing primarily on treatment of acute and chronic disease. Second, a longstanding question has been the relative importance of placement of care facilities versus neighborhood risk factors and individual differences in creating patterns of geographic health inequality – i.e., do marginalized neighborhoods suffer because they have access to hospitals that have worse outcomes; because they exhibit environmental risk factors like exposure to greater violence, more toxic substances, and generally unsanitary and stressful conditions; or because their populations have other underlying risk factors, like higher rates of chronic disease and lower levels of insurance coverage, unrelated to specific neighborhood conditions.

With respect to the first question, these results suggest that there are substantial disparities in trauma outcomes related to factors outside of the facts of the trauma case and individual differences in trauma patients. Ideally, these individual factors (represented here as part of the residual variance) should account for all of the variance in outcomes – patient outcomes should be equal across hospitals and across neighborhoods. Regarding the second question, these data indicate that identifiable inequalities account for between 3% and 36% of outcomes, depending on the outcome and trauma type examined. They also suggest that most of these disparities in trauma outcomes appear to be due to hospital-level disparities, with the independent influence of neighborhood being comparatively trivial. This lends support to the view that geographic disparities in trauma outcomes (at least within the specific context of the Detroit metropolitan area) seem to be mainly due to differences in care provided by facilities available in these areas.

Comparative analyses based on neighborhood poverty levels and injury severity illustrates some potentially confounding factors. For example, patients living in high-poverty neighborhoods tend are at higher risk for negative outcomes in some regards – particularly in terms of incidence of firearm injuries – but they are also substantially younger on average, and thus may suffer from fewer risks related to comorbid conditions, which tend to increase with age. Hospital-level disparities in outcomes remained after stratifying the analyses by injury severity and by mechanism of injury. This suggests that these differences between hospitals are not solely based on different background case characteristics. Although there are clearly disparities in terms of risk for different types of injury based on geographic location, these differences in caseload do not appear to fully explain differences in hospital outcomes. Nevertheless, it remains likely that different patient populations with different risk profiles play an important role in some fraction of the inter-hospital variability seen here. Although it is beyond the scope of a single study to identify all of these factors, it remains an important area for focus in future research.

These findings suggest that, at least in the case of trauma outcomes, policy should focus on reducing disparities in treatment quality between hospitals in order to reduce community-level disparities in outcomes. More broadly, it suggests that factors influencing geographic disparities in trauma outcomes may arise at the point of treatment, rather than being the result of different levels of risk derived from the neighborhood environment, at least when considered within a single metropolitan area. Disparities in treatment quality may have a number of causes, including differences in investment, differences in resource allocation, and differences in institutional experience with treating trauma. In addition to addressing funding and investment disparities, ways of addressing these differences might include transferring high risk cases to hospitals with more extensive institutional experience in the relevant field.

Limitations of this study include the inherent inability to differentiate hospital-level variance that may be caused by differences in the patient population served at different institutions. For example, some institutions may admit a larger volume of more serious traumas, which may have less favorable outcomes. It is plausible that neighborhood disparities would be larger if these cases were included. Additionally, our data did not include information on pre-hospital mortality, which has been identified in previous research as a critical phase for trauma management[28]. Since there is the potential for significant inequalities in pre-hospital care, for example due to geographical differences in response times, this is an important element of the trauma care system to address in future research on disparities. Other shortcomings include a lack of hospital-level data, including trauma level designation, due to limitations on the Michigan SID data aimed at preserving institutional anonymity. Charge data must be interpreted with some caution, because charges billed do not necessarily reflect hospital costs, and can vary between regions based on a variety of factors unrelated to care[29]. Finally, alternative ways of identifying neighborhood clusters other than ZIP code (e.g., census tracts, or homogeneous ZIP code groups) might yield more information regarding neighborhood variation. Future research should seek to create and validate better methods of defining neighborhoods.

As policy-makers look for ways to reduce both disparities in trauma outcomes and the cost of providing care for traumatic injury, it is important to have a clear picture of the extent to which they differ as a function of local geography. This study represents a step towards addressing that question, indicating that differences between hospitals may play an important role in determining the extent of these differences.

CONFLICT OF INTEREST STATEMENT:

The authors have no conflicting interests to declare.

AUTHOR CONTRIBUTIONS

LS, RH, and MF drafted the manuscript. RH conducted the statistical analyses. LS and EE developed the research questions. All authors reviewed and revised the manuscript.

DATA STATEMENT

Data from the State Inpatient Database (SID for the state of Michigan for the years 2006 – 2014 were obtained from the Agency for Health Research and Quality's (AHRQ) Healthcare Cost and Utilization Project (HCUP). These data are available for purchase from AHRQ at http://www.hcup-us.ahrq.gov/

FUNDING

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

References

1. Adler, N. E. & Rehkopf, D. H. U.S. Disparities in Health: Descriptions, Causes, and Mechanisms. *Annu. Rev. Public Health* **29,** 235–252 (2008).
2. Howell, E. A., Hebert, P., Chatterjee, S., Kleinman, L. C. & Chassin, M. R. Black/white differences in very low birth weight neonatal mortality rates among New York City hospitals. *Pediatrics* **121,** e407–e415 (2008).
3. Freedman, V. A., Martin, L. G. & Schoeni, R. F. Recent trends in disability and functioning among older adults in the united states: A systematic review. *J. Am. Med. Assoc.* **288,** 3137–3146 (2002).
4. Juarez, P. D. *et al.* The public health exposome: a population-based, exposure science approach to health disparities research. *Int. J. Environ. Res. Public. Health* **11,** 12866–12895 (2014).
5. Jackson, J. S., Knight, K. M. & Rafferty, J. A. Race and Unhealthy Behaviors: Chronic Stress, the HPA Axis, and Physical and Mental Health Disparities Over the Life Course. *Am. J. Public Health* **100,** 933–939 (2010).
6. Dimick, J., Ruhter, J., Sarrazin, M. V. & Birkmeyer, J. D. Black patients more likely than whites to undergo surgery at low-quality hospitals in segregated regions. *Health Aff. (Millwood)* **32,** 1046–1053 (2013).
7. Haider, A. H. *et al.* Disparities in trauma care and outcomes in the United States: A systematic review and meta-analysis. *J. Trauma Acute Care Surg.* **74,** 1195–1205 (2013).
8. Maybury, R. S. *et al.* Pedestrians struck by motor vehicles further worsen race- and insurance-based disparities in trauma outcomes: The case for inner-city pedestrian injury prevention programs. *Surgery* **148,** 202–208 (2010).

9. Reimers, A. & Laflamme, L. Hip Fractures Among the Elderly: Personal and Contextual Social Factors That Matter. *J. Trauma Acute Care Surg.* **62,** 365–369 (2007).

10. Corrigan, J. D. & Bogner, J. A. Neighborhood Characteristics and Outcomes After Traumatic Brain Injury. *Arch. Phys. Med. Rehabil.* **89,** 912–921 (2008).

11. Iceland, J. & Sharp, G. White Residential Segregation in U.S. Metropolitan Areas: Conceptual Issues, Patterns, and Trends from the U.S. Census, 1980 to 2010. *Popul. Res. Policy Rev.* **32,** 663–686 (2013).

12. Bergeron, E., Lavoie, A., Moore, L., Clas, D. & Rossignol, M. Comorbidity and age are both independent predictors of length of hospitalization in trauma patients. *Can. J. Surg.* **48,** 361 (2005).

13. Moore, L. *et al.* Using information on preexisting conditions to predict mortality from traumatic injury. *Ann. Emerg. Med.* **52,** 356–364.e2 (2008).

14. Tsai, T. C., Orav, E. J. & Jha, A. K. Patient Satisfaction and Quality of Surgical Care in US Hospitals. *Ann. Surg.* **261,** 2–8 (2015).

15. Hasnain-Wynia, R., Baker, Nerenz, D. & et al. Disparities in health care are driven by where minority patients seek care: Examination of the hospital quality alliance measures. *Arch. Intern. Med.* **167,** 1233–1239 (2007).

16. Vettukattil, A. S. *et al.* Do Trauma Safety-Net Hospitals Deliver Truly Safe Trauma Care? A Multilevel Analysis of the National Trauma Data Bank. *J. Trauma Acute Care Surg.* **70,** 978–984 (2011).

17. Darden, J., Rahbar, M., Jezierski, L., Li, M. & Velie, E. The Measurement of Neighborhood Socioeconomic Characteristics and Black and White Residential Segregation in

Metropolitan Detroit: Implications for the Study of Social Disparities in Health. *Ann. Assoc. Am. Geogr.* **100,** 137–158 (2010).

18. Healthcare Cost and Utilization Project (HCUP). *HCUP State Inpatient Databases (SID)*. (Agency for Healthcare Research and Quality, 2006).

19. Clark, D. E., Black, A. W., Skavdahl, D. H. & Hallagan, L. D. Open-access programs for injury categorization using ICD-9 or ICD-10. *Inj. Epidemiol.* **5,** 11 (2018).

20. Sears, J. M., Blanar, L. & Bowman, S. M. Predicting work-related disability and medical cost outcomes: A comparison of injury severity scoring methods. *Injury* **45,** 16–22 (2014).

21. Greene, N. H., Kernic, M. A., Vavilala, M. S. & Rivara, F. P. Validation of ICDPIC software injury severity scores using a large regional trauma registry. *Inj. Prev.* **21,** 325 (2015).

22. U. S. Census Bureau. *American FactFinder*. (2014).

23. Brown, H. & Prescott, R. *Applied mixed models in medicine*. (John Wiley & Sons, 2014).

24. Nakagawa, S., Johnson, P. C. D. & Schielzeth, H. The coefficient of determination R2 and intra-class correlation coefficient from generalized linear mixed-effects models revisited and expanded. *J. R. Soc. Interface* **14,** (2017).

25. Nathens AB, Jurkovich GJ, Maier RV & et al. Relationship between trauma center volume and outcomes. *JAMA* **285,** 1164–1171 (2001).

26. Demetriades, D. *et al.* The effect of trauma center designation and trauma volume on outcome in specific severe injuries. *Ann. Surg.* **242,** 512–519 (2005).

27. Novack, V., Jotkowitz, A., Etzion, O. & Porath, A. Does delay in surgery after hip fracture lead to worse outcomes? A multicenter survey. *Int. J. Qual. Health Care* **19,** 170–176 (2007).

28. Kleber, C. *et al.* Overall Distribution of Trauma-related Deaths in Berlin 2010: Advancement or Stagnation of German Trauma Management? *World J. Surg.* **36,** 2125–2130 (2012).

29. Wakeam, E. *et al.* Variation in the cost of 5 common operations in the United States. *Surgery* **162,** 592–604 (2017).

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract **Page 1**
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found **Page 2**
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported **Pages 1 – 5**
Objectives	3	State specific objectives, including any prespecified hypotheses **Page 5**
Methods		
Study design	4	Present key elements of study design early in the paper **Pages 5 – 7**
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection **Pages 5 – 6**
Participants	6	(*a*) *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants **Pages 5 – 6**
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable **Page 6**
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group **Pages 5 – 6**
Bias	9	Describe any efforts to address potential sources of bias **Page 7**
Study size	10	Explain how the study size was arrived at **Page 8**
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why **Pages 6 – 7**
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding **Page 7**
		(*b*) Describe any methods used to examine subgroups and interactions **Page 7**
		(*c*) Explain how missing data were addressed **Page 7**
		(*d*) *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy **N/A**

		(*e*) Describe any sensitivity analyses **N/A**

Continued on next page

Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed **Page 8**
		(b) Give reasons for non-participation at each stage **N/A**
		(c) Consider use of a flow diagram **N/A**
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders **Page 8**
		(b) Indicate number of participants with missing data for each variable of interest **Table 1**
Outcome data	15*	
		Cross-sectional study—Report numbers of outcome events or summary measures **Table 1**
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included **N/A**
		(*b*) Report category boundaries when continuous variables were categorized **N/A**
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period **N/A**
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses **Page 8 & Table 1**
Discussion		
Key results	18	Summarise key results with reference to study objectives **Page 9**
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias **Page 10**
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence **Pages 9 – 10**
Generalisability	21	Discuss the generalisability (external validity) of the study results **Page 9**
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable,

for the original study on which the present article is based
N/A

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

BMJ Open

Between-hospital and between-neighborhood variance in trauma outcomes: Cross-sectional observational evidence from the Detroit metropolitan area

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-022090.R2
Article Type:	Research
Date Submitted by the Author:	09-Oct-2018
Complete List of Authors:	Sall, Lauren; St. John Hospital & Medical Center, Surgery Hayward, R. David; St. John Hospital & Medical Center, Surgery Fessler, Mary; St. John Hospital & Medical Center, Surgery Edhayan, Elango; St. John Hospital & Medical Center, Surgery
Primary Subject Heading:	Emergency medicine
Secondary Subject Heading:	Public health, Surgery
Keywords:	ACCIDENT & EMERGENCY MEDICINE, Quality in health care < HEALTH SERVICES ADMINISTRATION & MANAGEMENT, PUBLIC HEALTH, TRAUMA MANAGEMENT

Between-hospital and between-neighborhood variance in trauma outcomes: Cross-sectional observational evidence from the Detroit metropolitan area

Lauren Sall, MD

R. David Hayward, PhD*

Mary M. Fessler, BA

Elango Edhayan, MD, FACS

St. John Hospital & Medical Center

Department of Surgery

Detroit, MI

USA

WORD COUNT: 2,912

KEY WORDS: traumatic injury; health inequalities; neighborhoods; trauma outcomes

Direct Correspondence to:
R. David Hayward, PhD
Senior Medical Researcher
Department of Surgery
St. John Hospital & Medical Center
22151 Moross Rd., PB 1, Suite. 212
Detroit, MI 48236
USA
Phone: (313) 343-3485
Email: Richard.Hayward@ascension.org

ABSTRACT

OBJECTIVES: Disparities in treatment outcomes for traumatic injury are an important concern for care providers and policy makers. Factors that may influence these disparities include differences in risk exposure based on neighborhood of residence, and differences in quality of care between hospitals in different areas. This study examines geographic disparities within a single region: the Detroit metropolitan area.

DESIGN: Data on all trauma admissions between 2006 and 2014 were obtained from the Michigan State Inpatient Database. Admissions were grouped by patient neighborhood of residence and admitting hospital. Generalized Linear Mixed Modeling procedures were used to determine the extent of shared variance based on these two levels of categorization on three outcomes. Patients with trauma due to common mechanisms (falls, firearms, and motor vehicle traffic) were examined as additional subgroups.

SETTING: 66 hospitals admitting patients for traumatic injury in the Detroit metropolitan area during the period from 2006 – 2014.

PARTICIPANTS: 404,675 adult patients admitted for treatment of traumatic injury.

OUTCOME MEASURES: In-hospital mortality, length of stay, and hospital charges.

RESULTS: Intraclass correlation coefficients indicated that there was substantial shared variance in outcomes based on hospital, but not based on neighborhood of residence. Among all injury types, hospital-level differences accounted for 12.5% of variance in mortality risk, 28.5% of variance in length of stay, and 32.2% of variance in hospital charges. Adjusting results for patient age, injury severity, mechanism, and comorbidities did not result in significant reduction in the estimated variance at the hospital level.

CONCLUSIONS: Based on these data, geographic disparities in trauma treatment outcomes were more strongly attributable to differences in access to quality hospital care than to risk factors in the neighborhood environment. Transfer of high-risk cases to hospitals with greater institutional experience in the relevant area may help address mortality disparities in particular.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- Data covers all hospital admissions in a major metropolitan area over a 9-year period
- Multi-level analysis allows decomposition of differences in patient outcomes shared within neighborhood of residence and hospital of treatment
- Range of outcomes including mortality, length of stay, and hospital charges
- Cannot assess mortality occurring before hospital admission
- Differences in intake patterns may increase between-hospital variance

INTRODUCTION

The persistence of disparities in patient outcomes is a serious challenge for the US health care system[1]. People with low incomes and members of racial and ethnic minority groups experience worse health outcomes across a broad spectrum, from lower birth weight[2] to greater risk of functional disability in older adulthood[3]. The causes of these disparities are complex and multifaceted, including differing levels of environmental exposure to health hazards[4], cultural differences in health behaviors[5], and unequal access to quality care[6]. Within the field of health disparities research, traumatic injury has received relatively little attention in comparison to areas such as chronic disease and infection[7]. Nevertheless, there is a significant body of evidence finding that factors including race[7,8] and socioeconomic status[9,10] may affect patients' risk of negative outcomes following trauma treatment.

The local geography of cities may play an important role in forming these disparities. Cities in the US remain heavily segregated by both race and socioeconomic status, with sharp differences in the demographic makeup of neighborhoods that may be in close proximity to one another[11]. These neighborhoods may differ in terms of the risks they pose for traumatic injury. For example, socioecomically-disadvantaged neighborhoods may have higher rates of trauma from causes like assault, which may entail greater risks of poorer outcomes. More broadly, residents of marginalized neighborhoods may face greater background health challenges, leaving them more likely to suffer from multiple comorbidities that are likely to complicate recovery from traumatic injury[12,13].

A related facet of metropolitan geography potentially impacting trauma outcomes relates to hospital quality and access. Quality of care issues are an increasing concern in the realm of public policy[14]. Large cities contain numerous hospitals providing emergency trauma care, and

most trauma patients are likely to be receive treatment at facilities in close proximity to the places in which they live. Hospitals and other health care facilities serving primarily poor and marginalized local populations may face challenges with funding levels and patient demands that inhibit care quality[6,15]. Insurance issues and patient familiarity may also serve to funnel high-risk patients towards under-resourced hospitals, as patients may be more likely to opt to seek care at institutions with which they are more familiar, and which they may perceive as less costly[16].

The extent to which these two aspects of local geography within metropolitan areas– residential neighborhood and care facility – may be related to trauma outcomes has not been thoroughly assessed. In this study, we use data from all trauma patients admitted for traumatic injury to hospitals in the Detroit metropolitan area between 2006 and 2014 and apply statistical techniques to determine the extent to which three outcomes (mortality, length of hospital stay, and hospital charges) differ as a function of (a) the neighborhoods in which patients reside, and (b) the hospital providing care. The Detroit metropolitan area has some of the highest levels of residential racial and ethnic segregation in the US, as well as some of the most extreme economic inequalities[17]. As a region that has experienced a historical pattern of economic decline and rejuvenation, as well as successive waves of movement between urban and suburban neighborhoods, it serves to exemplify a number of the socioeconomic challenges facing policy makers and health care providers in numerous US cities. It has a well-developed emergency and trauma infrastructure, including three hospitals with ACS Level I trauma designation and 13 with Level II designation during the period covered by this study.

METHOD

Individual-level admissions data for this project were obtained from the Healthcare Cost and Utilization Project (HCUP), sponsored by the Agency for Health Research and Quality

(AHRQ). One element of the HCUP is the compilation of an annual database including medical details of all hospital discharges in each state, known as the State Inpatient Database (SID). Ethical approval for use of the data was granted by the Institutional Review Board of St. John Hospital and Medical Center. Because the data were derived from clinical patient records and were fully anonymous and de-identified, participant consent was not required.

Data for the present analyses come from the Michigan SID for the period of years from 2006 to 2014[18]. Patients residing in the Detroit Metropolitan Statistical Area (MSA) were identified using the US Census Bureau definition as consisting of Wayne, Lapeer, Livingston, Macomb, Oakland, and St. Clair counties. Trauma cases were identified using ICD-9 diagnostic codes present at admission (ICD-9 codes 800 – 959 were included; no exclusions were made for codes indicating late effects of trauma or superficial injuries).

Hospitals. Each record in the SID includes a unique, anonymized, identification code corresponding to the hospital to which the patient was admitted. This allows patients to be clustered according to hospital. After excluding institutions with fewer than 100 trauma admissions during the 9-year study period, there were a total of 66 hospitals represented in the data, with a median of 2,845 observations in each cluster.

Neighborhoods. Patient residence was identified by ZIP code in the SID, and in this study each ZIP code is treated as a separate neighborhood. There were a total of 214 neighborhoods represented in the data, with a median of 1,633 observations in each.

Patient outcomes. Patient outcomes include in-hospital mortality, length of stay, and total hospital charges. Mortality was derived from the case disposition code (0 = did not die, 1 = died). Length of stay is given by the number of days between admission and discharge. Total hospital charges is a dollar amount corresponding to the total amount billed to any payer for each admission.

Patient comorbidities. The SID database includes data on a range of comorbid conditions (i.e., medical conditions existing prior to the present hospitalization episode). Examples include asthma, substance abuse, and obesity. The total number of comorbidities noted in each patient's record was computed to serve as an index of underlying patient health for the purposes of these analyses.

Trauma mechanism. Trauma mechanisms are derived from ICD-9 diagnosis codes included for each admission case in the SID. The three most common specific mechanisms in this sample were examined in these analyses: falls, firearms, and motor vehicle traffic.

Injury severity. ICD-9 diagnosis codes included in the SID were used to calculate estimated injury severity scores (ISS) for all patients. This procedure was carried out using ICDPIC-R[19], an open-source program executed in the R statistical environment which computes abbreviated injury score (AIS) by body region based on ICD-9 codes, and then calculates an estimated ISS based on regional AIS, and is based on a set of procedures that have been extensively validated for this purpose[20,21].

Patient and neighborhood demographics. Individual demographics included age (in years), gender, and race (white, black, or other). Neighborhood socioeconomic status (SES) was measured using ZIP code-level poverty rate estimates published by the US Census Bureau[22]. These estimates represent a three-year rolling average (e.g., the estimates for 2014 represent data from 2012 – 2014). Because poverty rate data were not made available until 2012, whereas this study covers the period from 2006 – 2014, neighborhood SES is represented in this study as a single rate regardless of year (rather than varying across time), using data from 2014. It was not possible to include information about hospital characteristics (e.g., trauma level designation) because the Michigan SID excludes identifiers that would enable cross-referencing hospital IDs with American Hospital Association data.

Analytical approach

In this study, we use a generalized linear mixed modeling (GLMM) framework to estimate the proportion of variance in individual outcomes that is attributable to each of three levels: hospitals, neighborhoods, and individuals (i.e., residual variance after hospital and neighborhood variance has been accounted for). The GLMM method[23] is a statistical modeling technique which includes a mixture of fixed and random effects. Random effects represent shared group-level linear relationships. Individual outcome values are allowed to vary at random around a group mean, allowing for an estimate of the part of the outcome that varies between groups and that varying between individuals. In these analyses, random intercept effects are specified for both hospital and neighborhood, meaning that individual outcomes are allowed to vary at random around both a hospital mean and a neighborhood mean. The group-level design matrix is specified as cross-classified, meaning that both sets of higher-level clusters are included in the same model, with each individual belonging to both a hospital and neighborhood cluster. Because the distributions of the outcome variables are not the same, different linking functions are used in GLMM models with different outcomes. Mortality is a binary variable, and uses a binary linking function. Length of stay and total charges both have highly skewed continuous distributions, making the use of a longnormal linking function appropriate.

The proportion of variance at the group level is given by the intra-class correlation coefficient (ICC) corresponding to the level of clustering (in this case, hospital and neighborhood). For outcomes with a non-binary function (i.e., length of stay and charges), the

ICC is computed by dividing the group-level variance parameter by the sum of the group and residual variance parameters. For binary GLMM (i.e., mortality), the ICC is given by dividing the group-level variance parameter by the sum of the group-level parameter and 3.29, an estimate of the theoretical variance in the binomial distribution[24]. In the results, these figures are expressed as a percentage of the total variance at each level. Cases with missing outcome data were excluded on a pairwise basis. LOS and charge analyses exclude cases with in-hospital mortality.

For each analysis, two GLMM models are computed. The first model includes random effects only, and provides an estimate of the total variance at each level, ignoring differences in outcomes arising due to systematic between-group differences in patient demographics and injury characteristics. The second model includes add fixed effects to control for some of these differences in casemix, including patient age, number of comorbidities, ISS, and mechanism of injury. By comparing the confidence intervals of the ICC estimates, it is possible to evaluate whether or not a significant proportion of the shared variance at each random effects level can be attributed to the factors controlled for as fixed effects. Analyses were conducted using SAS 9.4, except for the estimation of ISS, which was carried out using ICDPIC-R in R 3.5.

Patient and Public Involvement

This study addresses patient priorities by seeking to better understand how trauma care systems may be able to reduce patient mortality rates, the length of hospitalization, and charges incurred. Data are derived from administrative records, so patients were not directly involved in the design, recruitment, or conduct of the study. Results will be accessible to the public, including to individuals who may have patients during the study period.

RESULTS

Table 1 presents descriptive statistics for the full patient sample at the individual, hospital, and neighborhood levels. There were a total of 404,675 admissions for traumatic injury during the time period included in this study, representing a total of 66 hospitals and 214 ZIP codes. The mean number of patients per hospital was 2,845 (IQR: 349 – 9,683), and the mean number per neighborhood was 1,630 (IQR: 765 – 2,879). The three largest subgroups based on mechanism were falls (N = 117,931), motor vehicle traffic (N = 22,755), and firearms (N = 6,512).

Table 1. Descriptive statistics at the individual, hospital, and neighborhood levels

	Individual (N = 404,675) Mean (SD) or %	Hospital (N = 66) Median [IQR]	Neighborhood (N = 214) Median [IQR]
N individuals		2,845 [349; 9,683]	1,630 [765; 2,879]
Age	60.4 (23.7)	62.0 [53.2, 66.6]	60.8 [57.3, 65.2]
Female	49.8%	50.6% [40.1%, 56.7%]	50.5% [46.3%, 54.2%]
Race			
White	70.0%	74.6% [40.6%, 91.0%]	70.8% [45.5%, 82.4%]
Black	26.0%	7.6% [2.2%, 19.3%]	2.3% [0.9%, 10.0%]
Other	4.0%	8.2% [3.6%, 23.2%]	17.2% [12.0%, 30.7%]
Mechanism			
Falls	44.3%	43.7% [26.9%, 54.1%]	46.7% [40.4%, 52.2%]
Firearms	2.4%	0.4% [0.04%, 1.1%]	0.6% [0.2%, 1.4%]
Motor Vehicle	8.6%	5.4% [2.8%, 12.1%]	8.4% [7.0%, 10.4%]
Severity	4.9 (5.4)	4.5 [3.5, 5.5]	5.0 [4.7, 5.2]
Comorbidities	2.7 (2.0)	2.8 [2.0, 3.1]	2.7 [2.5, 2.8]
Mortality	2.5%	2.2% [1.6%, 3.0%]	2.4% [2.0, 2.7%]
LOS	6.4 (8.3)	5.9	6.3

		[5.2, 6.7]	[5.9, 6.7]
Charges (thousands of dollars)	36.3 (55.2)	32.5 [25.5, 41.2]	36.9 [33.7, 39.5]
Poverty Rate	17.4 (14.4)	14.5 [11.8, 19.9]	10.7 [6.5, 18.7]

Tables 2 and 3 allow for comparisons of case characteristics by neighborhood SES (defined by poverty rate quartiles) and injury severity (defined by cases with ISS up to 15 and those with ISS greater than 15). Patients from the poorest neighborhoods were substantially younger than the patient population as a whole, and were more likely to be male and black. Mortality rates, LOS, and charges were all significantly higher in poorer neighborhoods, but the magnitude of these differences in outcomes was small (e.g., 2.4% mortality in the lowest-quartile poverty neighborhoods, compared with 2.6% in the highest-poverty quartile). Both outcomes and demographics differed substantially by injury severity. Severely injured patients were much more likely to be male, and were somewhat younger and somewhat more likely to be Black. Firearm and MVT mechanisms were also much more common among the more severe injuries. As would be expected, mortality was substantially higher among those with more severe injuries, as were median LOS and charges.

Table 2. Individual descriptive statistics by poverty quartile

	1st Quartile (< 6.5%) N = 103,004	2nd Quartile (6.5% - 10.8%) N = 79,738	3rd Quartile (10.8% - 18.7%) N = 90,554	4th Quartile (> 18.7%) N = 134,257	*p*-value[a]
Age, mean [95% CI]	63.9 [63.7, 64.0]	65.1 [64.9, 65.2]	62.3 [62.1, 62.4]	53.8 [53.6, 53.9]	< .001
Female	53.0%	54.0%	52.0%	43.4%	< .001
Race					< .001
White	86.9%	93.5%	83.1%	38.5%	
Black	9.5%	3.3%	13.7%	56.3%	
Other	3.6%	3.2%	3.2%	5.2%	
Mechanism					< .001
Falls	49.8%	51.7%	47.3%	35.4%	

Firearms	1.0%	0.4%	1.0%	5.1%	
Motor Vehicle	8.0%	7.6%	8.1%	9.6%	
Severity (ISS), mean [95% CI]	5.0 [4.9, 5.0]	4.9 [4.9, 4.9]	4.7 [4.7, 4.7]	4.9 [4.9, 5.0]	< .001
Comorbidities, mean [95% CI]	2.7 [2.7, 2.7]	2.8 [2.8, 2.8]	2.9 [2.8, 2.9]	2.7 [2.7, 2.7]	< .001
Mortality	2.4%	2.5%	2.4%	2.6%	.002
LOS, median [IQR]	4.0 [2.0, 7.0]	4.0 [2.0, 7.0]	4.0 [2.0, 7.0]	4.0 [2.0, 8.0]	< .001
Charges (thousands of dollars), median [IQR]	22.2 [13.0, 37.8]	22.7 [13.2, 38.9]	22.3 [13.0, 38.0]	23.3 [13.3, 41.7]	< .001

NOTES: ISS Injury Severity Score, LOS Length of Stay
[a] *p*-values for 1-way ANOVA (age, ISS), Kruskall-Wallis (LOS, cost), or chi-square (female, race, mechanism, mortality)

Table 3. Individual descriptive statistics by injury severity group

	Less Severe Injuries ISS <= 15 (N = 380,218)	More Severe Injuries ISS > 15 (N = 25,997)	*p*-value[a]
Age, mean [95% CI]	60.6 [60.6, 60.7]	57.0 [56.7, 57.3]	< .001
Female	50.8%	35.8%	
Race			< .001
White	70.4%	64.0%	
Black	25.7%	31.1%	
Other	3.9%	4.9%	
Mechanism			< .001
Falls	44.4%	41.7%	
Firearms	2.0%	8.1%	
Motor Vehicle	7.4%	24.2%	
Comorbidities, mean [95% CI]	2.8 [2.7, 2.8]	2.5 [2.5, 2.5]	< .001
Mortality	2.1%	8.2%	< .001
LOS	4.0 [2.0, 7.0]	6.0 [3.0, 11.0]	< .001
Charges (thousands of dollars), median [IQR]	22.0 [12.8, 37.5]	37.2 [19.6, 80.2]	< .001
Neighborhood poverty rate, median [IQR]	12.4 [6.5, 26.5]	13.2 [6.5, 32.3]	< .001

NOTES: ISS Injury Severity Score, LOS Length of Stay

[a] *p*-values for 1-way ANOVA (age), Kruskall-Wallis (LOS, cost), or chi-square (female, race, mechanism, mortality)

Table 4 presents the ICC results for the full and stratified samples, along with the number of patients included in each model. All patients were included in analyses of mortality. Sample sizes for analyses of length of stay were somewhat smaller, likely reflecting patients who were transported to a hospital but died before admission (1.8% of the full sample was lost at this stage). Total charge data were available for only a subset of patients, due to under-reporting of this variable by hospitals (31.4% of the total sample was lost at this stage). Supplemental analyses (not shown) indicated that patients with missing charge data were substantially more likely to be black, male, and live in high-poverty neighborhoods. A substantial proportion of this missing data may be due to hospitals waiving or not reporting charges for uninsured patients with means to pay, and thus directly confounded with the aims of the study. Charge results should therefore be interpreted with some caution.

Table 4. Variance decomposition statistics, all cases

	Hospital ICC [95% CI]	Neighborhood ICC [95% CI]	Residual ICC [95% CI]	Patient N
Mortality, unadjusted	12.5% [7.4, 17.0]	0.4% [0.2, 0.6]	87.1% [82.4, 92.3]	404,675
Mortality, adjusted for case mix	9.3% [5.5, 12.8]	0.2% [0.05, 0.4]	90.5% [86.9, 94.4]	397,170
Length of Stay, unadjusted	28.5% [20.6, 35.0]	0.3% [0.2, 0.4]	71.2% [64.7, 79.1]	386,886
Length of Stay, adjusted for case mix	23.9% [16.9, 29.8]	0.2% [0.1, 0.2]	76.0% [70.0, 82.9]	379,881
Total Charges, unadjusted	32.2% [21.7, 40.5]	0.2% [0.1, 0.3]	67.5% [59.3, 78.1]	269,816
Total Charges, adjusted for case mix	22.7% [16.5, 28.2]	0.3% [0.2, 0.4]	77.0% [71.5, 83.3]	266,861

NOTES: ICC Intraclass Correlation Coefficient; unadjusted models include random effects only, adjusted models include fixed effects for patient age, Injury Severity Scale (ISS), mechanism of injury, and number of patient comorbidities; Hospital N = 66; ZIP code N =

214

There was significant variance at the hospital level for all outcomes. The extent of the hospital-level variance was significantly higher for LOS and total charges than for mortality. In each case, the magnitude of the ICC estimate was lower in the case mix adjusted model than in the unadjusted model, but none of these differences were statistically significant (i.e., between-hospital differences in the factors controlled in the adjusted model did not account for a significant proportion of the between-hospital disparities in outcomes). Although neighborhood ICC was statistically significant in all of the models presented in Table 4, the magnitude of the variance explained at this level was not clinically meaningful (less than 0.5% in all models).

Table 5. Variance decomposition statistics by injury severity

	Hospital ICC [95% CI]	Neighborhood ICC [95% CI]	Residual ICC [95% CI]	Patient N
Less Severe Injuries (ISS <= 15)[a]				
Mortality, unadjusted	12.3% [7.2, 16.8]	0.4% [0.1, 0.6]	87.3% [82.7, 92.6]	378,788
Mortality, adjusted for casemix	9.5% [5.6, 13.1]	0.1% [-0.1, 0.3]	90.4% [86.7, 94.4]	371,287
Length of Stay, unadjusted	16.6% [11.3, 21.3]	0.2% [0.1, 0.2]	83.2% [78.4, 88.5]	363,469
Length of Stay, adjusted for casemix	13.4% [9.0, 17.4]	0.1% [0.06, 0.1]	86.5% [82.5, 90.9]	356,467
Total Charges, unadjusted	33.4% [22.6, 41.6]	0.1% [0.08, 0.2]	66.5% [58.2, 77.3]	253,507
Total Charges, adjusted for casemix	30.3% [20.3, 38.2]	0.3% [0.2, 0.4]	69.4% [61.5, 79.5]	250,555
More Severe Injuries (ISS > 15)[b]				
Mortality, unadjusted	4.8% [1.2, 8.0]	0.4% [-0.2, 1.1]	94.8% [90.9, 99.0]	25,887
Mortality, adjusted for casemix	4.3% [0.9, 7.4]	0.6% [-0.1, 1.3]	95.1% [91.3, 99.3]	25,883
Length of Stay, unadjusted	19.7% [12.0, 26.4]	1.5% [0.9, 2.2]	78.9% [72.0, 86.8]	23,417
Length of Stay, adjusted for casemix	17.0% [9.9, 23.3]	0.1% [0.06, 1.6]	81.9% [75.5, 89.3]	23,414

Total Charges, unadjusted	17.2% [9.5, 24.1]	0.1% [0.04, 1.6]	81.8% [74.8, 89.8]	16,309
Total Charges, adjusted for casemix	13.5% [7.2, 19.2]	0.5% [0.1, 0.8]	86.0% [80.2, 92.5]	16,306

NOTES: ICC Intraclass Correlation Coefficient; unadjusted models include random effects only, adjusted models include fixed effects for patient age, Injury Severity Scale (ISS), mechanism of injury, and number of patient comorbidities
[a] Hospital N = 66; ZIP Code N = 214
[b] Hospital N = 64; ZIP Code N = 212

Tables 5 and 6 present the stratified analyses by injury severity (Table 5) and mechanism of trauma (Table 6). There was significant variance at the hospital level across outcomes and trauma mechanism, although the extent of this variance ranged from 2.9% for mortality due to falls to 33.4% for total charges among less severe injuries. Again, there were no cases in which the unadjusted and case mix adjusted models differed significantly in the estimation of hospital ICC. Neighborhood variance was minimal across outcomes and mechanism as well, with the highest estimate being 1.6% for motor vehicle traffic mortality (after case mix adjustment).

Table 6. Variance decomposition statistics by selected injury mechanisms

	Hospital ICC [95% CI]	Neighborhood ICC [95% CI]	Residual ICC [95% CI]	Patient N
Falls[a]				
Mortality, unadjusted	2.9% [1.0, 4.7]	0.2% [-0.2, 0.7]	96.9% [94.6, 99.3]	117,454
Mortality, adjusted for casemix	2.4% [2.4, 2.4]	0.0% [0.0, 0.0]	97.6% [97.6, 97.6]	117,454
Length of Stay, unadjusted	19.3% [11.2, 26.2]	0.2% [0.1, 0.3]	80.5% [73.6, 88.7]	112,954
Length of Stay, adjusted for casemix	13.5% [7.3, 18.9]	0.1% [0.06, 0.2]	86.4% [80.9, 92.6]	112,915
Total Charges, unadjusted	22.5% [10.9, 31.7]	0.09% [0.02, 0.2]	77.4 [67.2, 89.1]	76,409
Total Charges, adjusted for casemix	24.0% [11.1, 33.8]	0.04% [-0.006, 0.1]	75.9 [66.1, 88.8]	76,385
Firearms[b]				
Mortality, unadjusted	20.2% [15.9, 32.9]	0.8% [-2.9, 4.2]	79.1% [64.5, 101.9]	6,498
Mortality, adjusted for casemix	16.4% [-0.6, 28.5]	1.5 % [-2.2, 4.9]	82.1% [68.1, 103.3]	6,498

Length of Stay, unadjusted	20.3% [6.7, 30.4]	0.0% [0.0, 0.0]	79.7% [69.6, 93.3]	2,970
Length of Stay, adjusted for casemix	12.6% [4.9, 19.7]	0.2% [-0.2, 0.8]	87.1% [79.8, 95.2]	5,857
Total Charges, unadjusted	12.2% [5.0, 18.8]	0.2% [-0.2, 0.6]	87.6% [80.8, 95.1]	5,858
Total Charges, adjusted for casemix	21.3% [5.8, 33.6]	0.07% [-0.4, 0.8]	78.6% [66.2, 94.7]	2,970
Motor Vehicle[c]				
Mortality, unadjusted	4.7% [-0.8, 9.7]	1.1% [-1.1, 3.4]	94.2% [87.3, 101.9]	22,604
Mortality, adjusted for casemix	2.7% [-0.4, 5.7]	1.6% [-1.0, 4.2]	95.6% [90.4, 101.5]	22,604
Length of Stay, unadjusted	13.0% [6.0, 19.2]	0.3% [0.1, 0.6]	86.7% [80.3, 93.8]	21,082
Length of Stay, adjusted for casemix	14.5% [7.0, 21.2]	0.2% [-0.002, 0.4]	85.3% [78.6, 93.0]	21,057
Total Charges, unadjusted	19.6% [10.0, 27.7]	0.6% [0.2, 1.2]	79.8% [71.5, 89.7]	12,430
Total Charges, adjusted for casemix	18.3% [8.9, 26.4]	0.5% [0.2, 1.0]	81.1% [73.0, 90.8]	12,418

NOTES: ICC Intraclass Correlation Coefficient; unadjusted models include random effects only, adjusted models include fixed effects for patient age, Injury Severity Scale (ISS), mechanism of injury, and number of patient comorbidities
[a] Hospital N = 65; ZIP Code N = 213
[b] Hospital N = 52; ZIP Code N = 178
[c] Hospital N = 65; ZIP Code N = 211

Sensitivity analyses were conducted to evaluate whether the decision to exclude cases with in-hospital mortality from the LOS and total charges. No significant differences were detected in any ICC statistics between analyses conducted with and without these cases.

DISCUSSION

The persistence of disparities in health outcomes is an important concern for public policy makers and for hospital administrators. These results reflect a growing literature finding substantial between-hospital differences in outcomes for injured patients, related to hospital factors including patient volume[25], trauma level designation[26], and treatment efficiency[27]. This analysis addresses two important issues. First, the extent of disparity in outcomes from trauma treatment has received relatively little attention, with most research focusing primarily on treatment of acute and chronic disease. Second, a longstanding question has been the relative importance of placement of care facilities versus neighborhood risk factors and individual differences in creating patterns of geographic health inequality – i.e., do marginalized neighborhoods suffer because they have access to hospitals that have worse outcomes; because they exhibit environmental risk factors like exposure to greater violence, more toxic substances, and generally unsanitary and stressful conditions; or because their populations have other underlying risk factors, like higher rates of chronic disease and lower levels of insurance coverage, unrelated to specific neighborhood conditions.

With respect to the first question, these results suggest that there are substantial disparities in trauma outcomes related to factors outside of the facts of the trauma case and individual differences in trauma patients. Ideally, these individual factors (represented here as part of the residual variance) should account for all of the variance in outcomes – patient outcomes should be equal across hospitals and across neighborhoods. Regarding the second question, these data indicate that identifiable inequalities account for between 2% and 33% of outcomes, depending on the outcome and trauma type examined. They also suggest that most of these disparities in trauma outcomes appear to be due to hospital-level disparities, with the independent influence of neighborhood being comparatively trivial. This lends support to the view that geographic disparities in trauma outcomes (at least within the specific context of the Detroit metropolitan area) seem to be mainly due to differences in care provided by facilities available in these areas.

Comparative analyses based on neighborhood poverty levels and injury severity illustrates some potentially confounding factors. For example, patients living in high-poverty neighborhoods are at higher risk for negative outcomes in some regards – particularly in terms of incidence of firearm injuries – but they are also substantially younger on average, and thus may suffer from fewer risks related to comorbid conditions, which tend to increase with age. Hospital-level disparities in outcomes remained after stratifying the analyses by injury severity and by mechanism of injury, as well as after controlling for some individual and case-level risk factors (including age, injury severity, and comorbidity). This suggests that the differences between hospitals are not solely based on different background case characteristics. Although there are clearly disparities in terms of risk for different types of injury based on geographic location, these differences in case mix do not appear to fully explain differences in hospital outcomes. Nevertheless, it remains likely that different patient populations with different risk profiles play an important role in some fraction of the inter-hospital variability seen here. Although it is beyond the scope of a single study to identify all of these factors, it remains an important area for focus in future research.

These findings suggest that, at least in the case of trauma outcomes, policy should focus on reducing disparities in treatment quality between hospitals in order to reduce community-level disparities in outcomes. More broadly, it suggests that factors influencing geographic disparities in trauma outcomes may arise at the point of treatment, rather than being the result of different levels of risk derived from the neighborhood environment, at least when considered within a single metropolitan area. Disparities in treatment quality may have a number of causes, including differences in investment, differences in resource allocation, and differences in institutional experience with treating trauma. In addition to addressing funding and investment disparities, ways of addressing these differences might include transferring high risk cases to hospitals with more extensive institutional experience in the relevant field.

Limitations of this study include the inherent inability to fully differentiate hospital-level variance that may be caused by differences in the patient population served at different institutions. Although the adjusted models partially account for some the most plausible of these factors, including injury severity and mechanism, as well as patient age and comorbidities, it is not possible to control for all factors that may contribute to disparities in case mix between hospitals. Additionally, our data did not include information on pre-hospital mortality, which has been identified in previous research as a critical phase for trauma management[28]. Since there is the potential for significant inequalities in pre-hospital care, for example due to geographical differences in response times, this is an important element of the trauma care system to address in future research on disparities. Although sensitivity analyses indicated that loss of cases with mortality did not significantly affect the results of the LOS and charge analyses, the problem of dealing with right-censored data remains a limitation. Other shortcomings include a lack of hospital-level data, including trauma level designation, due to limitations on the Michigan SID data aimed at preserving institutional anonymity. Charge data must be interpreted with some caution, because charges billed do not necessarily reflect hospital costs, and can vary between regions based on a variety of factors unrelated to care[29]. Finally, the use of ZIP code as a proxy for neighborhood (although necessary in this case because of a lack of alternate geographic identifiers in the data) presents limitations, because ZIP codes reflect administrative divisions that do not necessarily reflect the realities of the social geography in which they are situated; they may divide or combine genuine neighborhoods, limiting their usefulness as indicators of residential conditions. Alternative ways of identifying neighborhood clusters other than ZIP code (e.g., census tracts, or homogeneous ZIP code groups) might yield more accurate information regarding neighborhood variation. Future research should seek to create and validate better methods of defining neighborhoods.

As policy-makers look for ways to reduce both disparities in trauma outcomes and the cost of providing care for traumatic injury, it is important to have a clear picture of the extent to which they differ as a function of local geography. This study represents a step towards addressing that question, indicating that differences between hospitals may play an important role in determining the extent of these differences.

CONFLICT OF INTEREST STATEMENT:

The authors have no conflicting interests to declare.

AUTHOR CONTRIBUTIONS

LS, RH, and MF drafted the manuscript. RH conducted the statistical analyses. LS and EE developed the research questions. All authors reviewed and revised the manuscript.

DATA STATEMENT

Data from the State Inpatient Database (SID for the state of Michigan for the years 2006 – 2014 were obtained from the Agency for Health Research and Quality's (AHRQ) Healthcare Cost and Utilization Project (HCUP). These data are available for purchase from AHRQ at http://www.hcup-us.ahrq.gov/

FUNDING

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

References

1. Adler, N. E. & Rehkopf, D. H. U.S. Disparities in Health: Descriptions, Causes, and Mechanisms. *Annu. Rev. Public Health* **29,** 235–252 (2008).
2. Howell, E. A., Hebert, P., Chatterjee, S., Kleinman, L. C. & Chassin, M. R. Black/white differences in very low birth weight neonatal mortality rates among New York City hospitals. *Pediatrics* **121,** e407–e415 (2008).
3. Freedman, V. A., Martin, L. G. & Schoeni, R. F. Recent trends in disability and functioning among older adults in the united states: A systematic review. *J. Am. Med. Assoc.* **288,** 3137–3146 (2002).
4. Juarez, P. D. *et al.* The public health exposome: a population-based, exposure science approach to health disparities research. *Int. J. Environ. Res. Public. Health* **11,** 12866–12895 (2014).
5. Jackson, J. S., Knight, K. M. & Rafferty, J. A. Race and Unhealthy Behaviors: Chronic Stress, the HPA Axis, and Physical and Mental Health Disparities Over the Life Course. *Am. J. Public Health* **100,** 933–939 (2010).
6. Dimick, J., Ruhter, J., Sarrazin, M. V. & Birkmeyer, J. D. Black patients more likely than whites to undergo surgery at low-quality hospitals in segregated regions. *Health Aff. (Millwood)* **32,** 1046–1053 (2013).
7. Haider, A. H. *et al.* Disparities in trauma care and outcomes in the United States: A systematic review and meta-analysis. *J. Trauma Acute Care Surg.* **74,** 1195–1205 (2013).
8. Maybury, R. S. *et al.* Pedestrians struck by motor vehicles further worsen race- and insurance-based disparities in trauma outcomes: The case for inner-city pedestrian injury prevention programs. *Surgery* **148,** 202–208 (2010).

9. Reimers, A. & Laflamme, L. Hip Fractures Among the Elderly: Personal and Contextual Social Factors That Matter. *J. Trauma Acute Care Surg.* **62,** 365–369 (2007).

10. Corrigan, J. D. & Bogner, J. A. Neighborhood Characteristics and Outcomes After Traumatic Brain Injury. *Arch. Phys. Med. Rehabil.* **89,** 912–921 (2008).

11. Iceland, J. & Sharp, G. White Residential Segregation in U.S. Metropolitan Areas: Conceptual Issues, Patterns, and Trends from the U.S. Census, 1980 to 2010. *Popul. Res. Policy Rev.* **32,** 663–686 (2013).

12. Bergeron, E., Lavoie, A., Moore, L., Clas, D. & Rossignol, M. Comorbidity and age are both independent predictors of length of hospitalization in trauma patients. *Can. J. Surg.* **48,** 361 (2005).

13. Moore, L. *et al.* Using information on preexisting conditions to predict mortality from traumatic injury. *Ann. Emerg. Med.* **52,** 356–364.e2 (2008).

14. Tsai, T. C., Orav, E. J. & Jha, A. K. Patient Satisfaction and Quality of Surgical Care in US Hospitals. *Ann. Surg.* **261,** 2–8 (2015).

15. Hasnain-Wynia, R., Baker, Nerenz, D. & et al. Disparities in health care are driven by where minority patients seek care: Examination of the hospital quality alliance measures. *Arch. Intern. Med.* **167,** 1233–1239 (2007).

16. Vettukattil, A. S. *et al.* Do Trauma Safety-Net Hospitals Deliver Truly Safe Trauma Care? A Multilevel Analysis of the National Trauma Data Bank. *J. Trauma Acute Care Surg.* **70,** 978–984 (2011).

17. Darden, J., Rahbar, M., Jezierski, L., Li, M. & Velie, E. The Measurement of Neighborhood Socioeconomic Characteristics and Black and White Residential Segregation in

Metropolitan Detroit: Implications for the Study of Social Disparities in Health. *Ann. Assoc. Am. Geogr.* **100,** 137–158 (2010).

18. Healthcare Cost and Utilization Project (HCUP). *HCUP State Inpatient Databases (SID)*. (Agency for Healthcare Research and Quality, 2006).

19. Clark, D. E., Black, A. W., Skavdahl, D. H. & Hallagan, L. D. Open-access programs for injury categorization using ICD-9 or ICD-10. *Inj. Epidemiol.* **5,** 11 (2018).

20. Sears, J. M., Blanar, L. & Bowman, S. M. Predicting work-related disability and medical cost outcomes: A comparison of injury severity scoring methods. *Injury* **45,** 16–22 (2014).

21. Greene, N. H., Kernic, M. A., Vavilala, M. S. & Rivara, F. P. Validation of ICDPIC software injury severity scores using a large regional trauma registry. *Inj. Prev.* **21,** 325 (2015).

22. U. S. Census Bureau. *American FactFinder*. (2014).

23. Brown, H. & Prescott, R. *Applied mixed models in medicine*. (John Wiley & Sons, 2014).

24. Nakagawa, S., Johnson, P. C. D. & Schielzeth, H. The coefficient of determination R2 and intra-class correlation coefficient from generalized linear mixed-effects models revisited and expanded. *J. R. Soc. Interface* **14,** (2017).

25. Nathens AB, Jurkovich GJ, Maier RV & et al. Relationship between trauma center volume and outcomes. *JAMA* **285,** 1164–1171 (2001).

26. Demetriades, D. *et al.* The effect of trauma center designation and trauma volume on outcome in specific severe injuries. *Ann. Surg.* **242,** 512–519 (2005).

27. Novack, V., Jotkowitz, A., Etzion, O. & Porath, A. Does delay in surgery after hip fracture lead to worse outcomes? A multicenter survey. *Int. J. Qual. Health Care* **19,** 170–176 (2007).

28. Kleber, C. *et al.* Overall Distribution of Trauma-related Deaths in Berlin 2010: Advancement or Stagnation of German Trauma Management? *World J. Surg.* **36,** 2125–2130 (2012).

29. Wakeam, E. *et al.* Variation in the cost of 5 common operations in the United States. *Surgery* **162,** 592–604 (2017).

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract **Page 1**
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found **Page 2**
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported **Pages 1 – 5**
Objectives	3	State specific objectives, including any prespecified hypotheses **Page 5**
Methods		
Study design	4	Present key elements of study design early in the paper **Pages 5 – 7**
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection **Pages 5 – 6**
Participants	6	(*a*) *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants **Pages 5 – 6**
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable **Page 6**
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group **Pages 5 – 6**
Bias	9	Describe any efforts to address potential sources of bias **Page 7**
Study size	10	Explain how the study size was arrived at **Page 8**
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why **Pages 6 – 7**
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding **Page 7**
		(*b*) Describe any methods used to examine subgroups and interactions **Page 7**
		(*c*) Explain how missing data were addressed **Page 7**
		(*d*) *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy **N/A**

(*e*) Describe any sensitivity analyses

N/A

Continued on next page

Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed **Page 8**
		(b) Give reasons for non-participation at each stage **N/A**
		(c) Consider use of a flow diagram **N/A**
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders **Page 8**
		(b) Indicate number of participants with missing data for each variable of interest **Table 1**
Outcome data	15*	
		Cross-sectional study—Report numbers of outcome events or summary measures **Table 1**
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included **N/A**
		(*b*) Report category boundaries when continuous variables were categorized **N/A**
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period **N/A**
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses **Page 8 & Table 1**
Discussion		
Key results	18	Summarise key results with reference to study objectives **Page 9**
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias **Page 10**
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence **Pages 9 – 10**
Generalisability	21	Discuss the generalisability (external validity) of the study results **Page 9**
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable,

for the original study on which the present article is based
N/A

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.