Urban/Rural Disparities in Oregon Pediatric Traumatic Brain Injury Fatality

Megan Leonhard
URBAN/RURAL DISPARITIES IN OREGON PEDIATRIC
TRAUMATIC BRAIN INJURY FATALITY

By
Megan Leonhard

A THESIS
Presented to the Department of Public Health & Preventive Medicine
And the Oregon Health & Science University School of Medicine
In partial fulfillment of the requirement for the degree of
Master of Public Health
June 2014
Department of Public Health and Preventive Medicine

School of Medicine

Oregon Health & Science University

____________________________________

CERTIFICATE OF APPROVAL

____________________________________

This is to certify that the Master’s thesis of

Megan Leonhard

has been approved

____________________________________

Mentor/Advisor: Dr. Kathleen Carlson

____________________________________

Thesis Chair: Dr. Rochelle Fu

____________________________________

Thesis Member: Dr. Dagan Wright

____________________________________

Thesis Member: Dr. David Lehrfeld
# TABLE OF CONTENTS

List of Tables and Figures ....................................................... iv

List of Abbreviations .............................................................. v

Acknowledgments ................................................................. vi

Abstract ................................................................................... vii

Background .............................................................................. 1

Methods ................................................................................. 3

Results ................................................................................... 6

Discussion ............................................................................... 9

Summary and Conclusions ........................................................ 14

References ............................................................................... 15

Appendix .................................................................................. 32
LIST OF TABLES AND FIGURES

Table 1: Annual Traumatic Brain Injury Incidence per 100,000 Oregon Children ≤19 Years of Age, by Urban/Rural Location. ..............................................19

Table 2: Characteristics of Pediatric Patients ≤19 Years of Age Admitted to Oregon Trauma Hospitals for Traumatic Brain Injury, 2009-2012, by Urban-Rural Location. .................................................................20

Table 3: Characteristics of Pediatric Patients ≤19 Years of Age Admitted to Oregon Trauma Hospitals for Traumatic Brain Injury, 2009-2012, by Mortality Outcome. .................................................................25

Table 4: Odds of Mortality by Urban/Rural Location among Oregon Children ≤19 Years of Age with Traumatic Brain Injury. ..................................................29

Figure 1: Causal Model Depicting Theorized Associations between Location of Injury and Mortality. .................................................................30

Figure 2: Patient Counts for Initial Presentation Trauma Level and Post Transfer Trauma Level and Mortality for Severe Pediatric Traumatic Brain Injuries Sustained in Oregon. .................................................................31

Table 5: Characteristics of Excluded Pediatric Patients ≤19 Years of Age Admitted to Oregon Trauma Hospitals for Traumatic Brain Injury, 2009-2012 .................................................................32

Table 6: Severity Indicators Summary Statistics for Pediatric Patients ≤19 Years of Age Admitted to Oregon Trauma Hospitals for Traumatic Brain Injury, 2009-2012 .................................................................35
**LIST OF ABBREVIATIONS**

| Abbreviation | Description |
|--------------|-------------|
| CDC          | Center for Disease Control and Prevention |
| CI           | Confidence Interval |
| E-code       | External Cause of Injury Code |
| GCS          | Glasgow Coma Scale |
| GEE          | General Estimation Equations |
| ICD-9-CM     | International Classification of Diseases, Ninth Revision, Clinical Modification |
| ISS          | Injury Severity Score |
| LOS          | Length of Stay |
| MVC          | Motor Vehicle Collision |
| NCHS         | National Center for Health Statistics |
| OHA          | Oregon Health Authority |
| OR           | Odds Ratio |
| SES          | Socioeconomic Status |
| TBI          | Traumatic Brain Injury |
| US           | United States |
ACKNOWLEDGMENTS

Thank you to my Thesis Committee members: Dr. Kathleen Carlson, Dr. Rochelle Fu, Dr. Dagan Wright, and Dr. David Lehrfeld for their guidance and support. Thank you to the Oregon Health Authority for allowing me to utilize their data and work at their facility and also to Lisa Millet for the encouragement along the way. Last, but not least, thank you to my partner, friends, and family for their patience, understanding, encouragement, and support.
ABSTRACT

BACKGROUND: Traumatic brain injury (TBI) greatly contributes to morbidity and mortality in the pediatric population. Outcomes of TBI may vary geographically. We examined potential urban/rural disparities in mortality amongst Oregon pediatric TBI patients treated in trauma hospitals.

METHODS: Oregon pediatric patients, ages 0-19, seen in trauma hospitals for TBI were identified from the Oregon Trauma Registry for years 2009-2012. Location of injury was classified using the National Center for Health Statistics (NCHS) Urban-Rural Classification Scheme. Severity of overall trauma was estimated using Injury Severity Scores (ISS) and type of TBI was categorized as blunt versus penetrating injury. Incidence rates were calculated using Census data for denominators. Associations between urban/rural injury location and mortality were assessed using multivariable logistic regression, controlling for potential confounders. Generalized estimating equations were used to help account for clustering of data within hospitals.

RESULTS: Of 2,794 pediatric TBI patients, 46.6% were injured in large metropolitan locations, 24.8% in medium/small metropolitan locations, and 28.6% in non-metropolitan locations. Children from non-metropolitan (rural) locations had the greatest annualized incidence rate of TBI, at 107/100,000 children per year, and also tended to have higher ISS scores than those from large metropolitan areas (71/100,000 per year). Without adjustment for other factors, non-metropolitan location of injury was associated with increased odds of mortality (odds ratio [OR]=2.51; 95% CI= 1.57-4.03). This association remained significant while adjusting for age, gender, race/ethnicity, insurance status, ISS, and TBI type (OR=1.91; 95% CI=1.11-3.30).
CONCLUSION: This study identified a greater incidence rate of TBI and a higher proportion of severe injury in rural areas compared to urban areas in Oregon. Rural children treated in the trauma system for TBI were more likely to die than urban children after controlling for overall trauma severity and other factors associated with urban/rural residence. Research is needed to examine treatment and care disparities between urban and rural children. Future work should also identify interventions that can reduce risk of TBI and TBI-related mortality among children, particularly those who live in rural areas.
BACKGROUND

Traumatic brain injury (TBI) is a major cause of morbidity and mortality in the United States (US) pediatric population.\textsuperscript{1,2} TBI results in substantial health care costs and many survivors experience permanent disability.\textsuperscript{3,4} People who live in urban areas have different physical and socioeconomic environments than those who live rurally; therefore, risk factors for injury and poor outcomes of injury are likely also very different.\textsuperscript{5} These inherent differences between urban and rural location may lead to differences in the epidemiology and outcomes of TBI that have important implications for care and prevention.\textsuperscript{6} Furthermore, differences in the provision of care can lead to outcomes disparities between children in urban versus rural locations.\textsuperscript{7,8,9}

Among the few studies that include pediatric populations in the US, injury severity has consistently been reported to be higher in rural locations compared to urban locations.\textsuperscript{3,6,10} In contrast, studies examining urban/rural differences in TBI mortality have reported mixed results.\textsuperscript{6,10,11} Children in rural areas had a higher frequency of motor vehicle related mechanisms of injury than children in metropolitan locations. Furthermore, motor vehicle related mechanisms are known to be associated with increased injury severity compared to other mechanisms and suggested as a possible contributor to regional severity and mortality differences.\textsuperscript{3,6,10} Similarly, firearm-related mechanisms were also implicated as a factor associated with severity and mortality, especially in cases of suicide.\textsuperscript{3,6} Currently, TBI prevention programs tend to target risk factors determined as high priority for states as a whole.\textsuperscript{12} Knowledge of urban/rural differences in risk factors for pediatric TBI may enhance effectiveness of these and other population-level prevention programs.
Studies also indicate that there may be treatment and care disparities between urban and rural children. Pre-hospital, emergency department, and hospital care and treatment differences can lead to mortality disparities. In addition to longer transport times, rural children are more likely to receive care from emergency personnel who have basic life support training rather than advanced life support training. Furthermore, children in rural locations are more likely to present to non-trauma hospitals or Level III or IV trauma centers than children in urban locations. The hospital to which patients present can affect mortality due to care differences and the lack of specialized care. For example, Levels I and II trauma centers have pediatric and TBI-specialized surgical staff, while Levels III and IV hospitals are not required to have these resources and non-trauma hospitals rarely have these resources.

This study examined urban/rural differences in the incidence, severity, and outcomes (mortality) among Oregon pediatric TBI patients treated in trauma system hospitals using a multi-level urban/rural geographic classification scheme. This scheme was specially designed to capture health differences and is useful for identifying potential mortality disparities by location due to treatment and care disparities. Additionally, the scheme will aid in providing important information that will contribute to development of geography-specific injury prevention strategies. We hypothesized that, after accounting for potential confounding factors, mortality among children with TBI sustained in Oregon would be greater among those in rural locations compared to those in urban locations.
METHODS

Study population

This retrospective analysis was based on data from the Oregon Trauma Registry maintained by the Oregon Health Authority (OHA). The study was approved by the OHA Institutional Review Board with ceded oversight from Oregon Health & Science University. The registry was queried from 2009-2012 for pediatric TBI patients ages 0-19 years identified using International Classification of Diseases -9th Revision-Clinical Modification (ICD-9-CM) diagnosis codes specified in the Barell Injury Diagnosis Matrix.20 We included ICD-9-CM 959.01 indicating a head injury not otherwise specified to prevent under-estimation of TBI as recommended by the US Centers for Disease Control and Prevention (CDC).20,21,22 Patients who had transfers indicated but without final mortality outcomes available within the Oregon Trauma System were included in incidence calculations but excluded from subsequent analysis. Demographic data obtained from the registry included age, gender, race/ethnicity, insurance status, zip code/county of injury location, and zip code/county of residence. High agreement between location of injury and location of residence has been previously reported.6 To capture TBI cases occurring in Oregon, regardless of state of residence, we included patients who had an in-state location of injury but excluded patients with an out-of-state location of injury.

Measures

County of injury location information was used to assign urban/rural categories using the National Center for Health Statistics (NCHS) urban-rural classification scheme.18 To accommodate the relatively small number of outcome events, the scale was collapsed into three categories: large metropolitan, medium/small metropolitan, and non-
Patients were assigned 2013 NCHS designations. For the purposes of this analysis, non-metropolitan designations were considered rural. Mortality information was obtained directly from the Trauma Registry database. For those with multiple records due to transfer, the record from the final Oregon Trauma Registry hospital was used to assess mortality outcome.

Race/ethnicity categories were categorized as white, non-white, and missing/unknown. Insurance categories were categorized as insured, including those with private insurance, public insurance, car insurance or workers compensation; uninsured, including those who self-paid or received charity; and missing/unknown. Public insurance included Medicare/Medicaid and other government insurance. The CDC reports that those ages 0-4 and 15-19 years are at the greatest risk for TBI. Thus, we categorized age as 0-4, 5-14, and 15-19 years.

Injury-related information included variables such as mechanism of injury and intent of injury (based on ICD-9-CM external cause of injury codes, or E-codes), Injury Severity Score (ISS), Glasgow Coma Scale (GCS), and TBI-type. Mechanism of injury was categorized as fall, struck by/against, motor vehicle collision (MVC), firearm, other/specified classifiable, other/specified not elsewhere classifiable, unspecified, and other. Injury intent was defined as unintentional, suicide attempt, assault, and undetermined/other. Injury Severity Score (ISS) is a system used to assess injuries of six body regions (Head, Face, Chest, Abdomen, Extremities, and External) for patients with multiple injuries. ISS scores range from 0 to 75, with higher scores indicating greater severity. We categorized ISS as done in past research: mild (<8), moderate (9-15), and severe (>15). However, due to small cell sizes, mild and moderate ISS categories were combined for analysis. The Glasgow Coma Scale measures the level of
consciousness in head-injured patients. GCS scores were categorized as mild/moderate (scores= 9-15) versus severe injuries (3-8). TBI-type was defined as either blunt or penetrating.

Transfer status to another trauma facility was coded as a dichotomous variable (yes/no). Hospital trauma system level was reported as a categorical variable corresponding to the four levels: Level I, II, III, and IV. Time from initial location of injury scene to the trauma center was classified in minute increments: <30, 30-60, and 60 plus.

**Statistical Analysis**

We used Census data for years 2009-2012 to calculate annual TBI incidence by urban-rural location. We examined differences in demographic and injury variables by urban/rural location of injury using χ² tests. To account for clustering within individual hospitals, we used generalized estimating equations (GEEs) in all logistic regression analyses. Univariate logistic regression analysis was performed to investigate the association between urban/rural location and mortality. We performed multivariable logistic regression to assess the association between urban/rural location and mortality while controlling for potentially confounding variables. An *a priori* causal model (Figure 1) and directed acyclic graphs were used to determine the most parsimonious set of available covariates to include in analyses. These covariates included age, sex, race/ethnicity, insurance status, injury severity, and TBI-type. We explored multiple indicators of injury severity (Appendix Table 6) and determined that ISS would serve as the best proxy of severity for this analysis due to the low percentage of missing values (1.4%) compared to other potential variables and its common use in TBI literature. We computed the adjusted odds ratios (ORs) and 95% confidence intervals (CIs) of mortality
for non-metropolitan and small/medium metropolitan areas compared with large metropolitan areas. We were unable to examine potential effect modification of the association between urban-rural location and mortality by transfer status or ISS due to small cell counts.

**Posthoc Analyses**

We were interested in exploring potential explanations for any observed differences in mortality by geographic location. Therefore, we further examined transfer information for children with severe traumatic injuries who initially presented to Level III and Level IV trauma centers. Triage criteria indicate that patients with severe TBI are to either be directly taken to the highest level of trauma care or be stabilized then transferred to the highest level trauma center.\(^{17,30}\) We also examined transportation times from the injury scene to initial care by location. We entered transfer and transportation time into our final multivariable regression model to determine if these factors could account for mortality differences.

All analyses were performed using Stata/SE 13.1.\(^{31}\)

**RESULTS**

**TBI Incidence**

There were 3,169 children ages 0-19 years treated for TBI in the Oregon Trauma system from 2009-2012. The average incidence of pediatric TBI in Oregon over the four year period was 87 per 100,000 children. The incidence rates of TBI among those with non-metropolitan locations of injury were greater than those of the large and medium/small metropolitan areas for all years examined (Table 2).
Patient Characteristics

After excluding patients without a reported location of injury (n=247) and patients for whom final disposition could not be assessed (n=128), the study population for assessing association between injury location and mortality included 2,794 patients. Race/ethnicity and gender were not statistically different between included and excluded children (Appendix Table 5). However, excluded children were more likely to be older, have injuries classified as severe, have a missing GCS score, and have an unknown/missing insurance status. Excluded children were also less likely to present to either a Level I or II trauma hospital. There were 1,303 patients injured in a large metropolitan location (46.6%), 692 in a medium/small metropolitan location (24.8%), and 799 in a non-metropolitan location (28.6%). There were 1,879 males (67.3%). Overall 2,007 patients were categorized as white (71.8%), 575 as non-white (20.6%), and 212 as unknown or missing race (7.6%). The causes of injury included MVC (32.7%), fall (33.6%), struck by/against (12.3%), firearms (0.5%) and other (20.9%).

The characteristics of children and their injuries varied by injury location. Children sustaining TBI in rural locations were more likely to be White and between the ages of 15-19 compared to children in large-metropolitan locations. Furthermore, rural children were more likely to be uninsured or classified as having unknown/missing insurance. Motor-vehicle collisions were the most common mechanism of injury among rural children (37%), while falls were the most common mechanism among urban children (39%). Over the four year period examined, a slightly higher percentage of injuries in rural locations were unintentional compared to those in large metropolitan areas, although the difference was statistically insignificant (95% vs. 92%).
Severity of injuries was also different by location (Table 2). Of the children with a rural location of injury 34% sustained severe traumatic injuries compared to 24% of children from large metropolitan locations. Children from rural locations had a higher percentage of missing GCS scores (18%) compared to children from large metropolitan areas (7.7%). Of the children with a recorded GCS score, there was no difference in the proportion of severe TBIs by location; 3.6% in rural locations were categorized as severe compared to 3.2% in large metropolitan locations.

**Mortality**

We observed a significant difference between location of injury and mortality outcome, with crude mortality of 1.8% for large-metropolitan location of injury, 2.3% for small/medium metropolitan location of injury, and 4.5% for non-metropolitan location of injury (Table 3). Patients injured in non-metropolitan (rural) locations were 2.5 times more likely to die compared to those in large metropolitan locations (OR=2.51; 95% CI=1.56-4.03) (Table 4). In contrast, there was no statistical difference in risk of mortality for patients injured in small/medium metropolitan locations compared to those in large metropolitan locations (OR=1.28; 95% CI=0.58-2.80). When controlling for potential confounders (age, race/ethnicity, gender, insurance, ISS, and TBI-type), the estimated adjusted odds of mortality among children injured in a non-metropolitan location, compared to those in large metropolitan locations, was 1.91 (95% CI=1.11-3.30).

**Posthoc Analyses**

We found that those injured in rural locations were more likely to initially present to Levels III and IV trauma centers than those injured in large metropolitan areas. Furthermore, 38.7% of patients presenting to Levels III and IV trauma centers had
injuries classified as severe, compared to 29.4% of patients presenting to Levels I and II trauma centers. There were 481 total transfer patients but only 353 for which final mortality status could be determined. Of the 786 severely injured patients, 170 initially presented to Levels III and IV trauma centers of which 69.4% were transferred (Figure 2). Those with large metropolitan locations of injury were transferred 91% of the time, those in small/medium metropolitan areas were transferred 51% of the time and those with non-metropolitan locations of injury were transferred 75% of the time. There was a 16% difference in survival between those transferred and not-transferred (93% and 77% respectively). Of the patients who were not transferred and who died, nine expired in the emergency department and none were dead on arrival.

Entering transportation time into the final multivariable model attenuated the odds ratio, but did not account for the entire mortality difference between children with large metropolitan locations of injury and non-metropolitan locations of injury (OR=1.90; 95% CI=1.08-3.33). Entering transfer status into the model elevated the odds of mortality for children with non-metropolitan locations of injury versus large metropolitan locations of injury (OR=2.09; 95% CI=1.12-3.92).

DISCUSSION

This is the first study to use the NCHS Urban/Rural Classification Scheme to examine potential urban-rural disparities in TBI-related incidence, severity, and mortality among children using trauma system care. We found that there was a greater incidence rate of trauma system care for TBI among children in rural areas compared to large metropolitan areas. Our results indicated that rural children treated in the trauma system for TBI were more likely to die than urban children while controlling for injury severity
and other factors associated with urban/rural residence. A greater proportion of children in non-metropolitan areas sustained severe overall trauma, as indicated by the ISS, when compared to those with TBI from large metropolitan locations. Frequencies of primary mechanism tended to differ between urban and rural locations, although intent of injury did not significantly differ between locations.

Our findings suggest that there are systematic differences in care and/or treatment leading to increased mortality in children sustaining TBIs in rural locations. Currently, longer transport times are thought to be associated with the increased risk of injury mortality in rural areas. Studies have reported decreased chances of survival with transportation times from injury scene to initial care over 30 minutes. A larger proportion of children injured in rural locations in our study population experienced transportation times greater than 30 minutes (20% versus 14.6% for large metropolitan locations). Treatment received during prehospital transportation may also contribute to mortality disparities. Rural locations are more likely to have volunteer emergency medical technicians (EMTs) with less experience due to low retention of workers. Additionally, rural areas have fewer trained advanced life support responders (such as paramedics) compared to large metropolitan locations. Basic life support trained responders do not have the training necessary to intubate patients or provide intravenous medications or fluids. Future research should focus on identifying disparities in prehospital treatment by urban versus rural location and assessing how these disparities influence mortality outcomes.

Our finding that roughly 70% of severely injured patients were transferred from Levels III or IV trauma centers in conjunction with a lower percentage of survival for non-transfers, suggests disparities in TBI treatment at the hospital level. Rural children
are more likely to present to non-trauma hospitals or lower levels of trauma care. These facilities generally lack pediatric surgeons as well as neurotrauma specialists. Studies should assess the relationship between triage compliance and TBI mortality as well as potential associations with other long-term outcomes such as disability.

Our findings are consistent with previous reports of differences in incidence and outcome of TBI based on location. Gabella et al. (1997) reported rates of 97.8 per 100,000 for most urban groups and 172.1 per 100,000 for most rural groups in Colorado. Although our study suggested a similar trend in relative incidence, the incidence rates for our study are lower due to our focus on the pediatric population. Our overall average incidence of 87 per 100,000 children is similar to that reported by Reid et al. (2001) in their study of pediatric TBI in Minnesota (73.5 per 100,000 children). Gabella et al. also reported increased TBI-related mortality in rural locations compared to urban locations. Chapital et al. (2007) found no statistically significant differences in TBI mortality rates for all ages between urban and rural locations, although findings did suggest a higher rate in the rural population. Further research focusing on the pediatric population should use meaningful urban-rural classification schemes, such as the NCHS Classification Scheme which is designed to identify health differences.

Similar to previous studies, falls and MVCs accounted for the highest proportions of TBI mechanisms in our population. Our findings are consistent with previous reports that MVC is more commonly the primary mechanism of injury among those in non-metropolitan locations. MVC has been shown to be significantly associated with greater TBI severity while falls were not. This may partially explain the observed increased injury severity for children with rural locations of TBI. Transport times were also longer for children with TBI sustained in a rural location. Research into rural
location-specific injury prevention strategies for MVCs and severity-reduction strategies for injuries sustained by MVCs should be conducted to guide development of prevention plans targeted towards rural children.

This retrospective analysis has several limitations. Due to the relatively small number of outcome events (mortality) in conjunction with a high number of missing variables for GCS scores, we used ISS to measure overall severity of children’s injuries. Although ISS does not directly measure TBI severity, severe head injuries will be accounted for in the ISS score. Consequently, patients with severe levels of TBI should have a high ISS translating to a severe injury classification for our study. Also related to low cell counts, we were unable to assess effect modification of the association between urban/rural location of injury and mortality by either ISS or transfer status. We had wanted to assess a larger time period, but registry data quality issues and reporting differences between years prevented utilization of data prior to 2009. Our findings suggest that improvements could be made to the Oregon Trauma Registry to facilitate TBI-related research and development of prevention strategies. Future studies should be conducted in larger populations with more complete reporting to help disentangle associations between urban-rural location, TBI and overall injury severity, transfer status, and risk of mortality.

Another limitation is the potential for selection bias if there were systematic underreporting or overreporting by region. Cases that did not have an Oregon location of injury or where the location of injury was missing were excluded from location-specific incidence calculations and multivariable analysis. We found that those we excluded were more likely to be older, have injuries classified as severe, have a missing GCS score, and have an unknown/missing insurance status and were less likely to present to either a
Level I or II trauma hospital. These characteristics are consistent with characteristics of children in our analysis population with non-metropolitan and small/medium metropolitan locations of injury. Since children who had injuries classified as severe, who had missing GCS scores, and who presented to Level III or IV trauma centers had higher crude mortality in the analysis population, we could be missing deaths at a higher rate in the non-metropolitan and small/medium metropolitan locations in the excluded population. This would lead to falsely attenuated reported adjusted odds of mortality for non-metropolitan and small/medium metropolitan locations. If location was less likely to be reported for rural areas, this could lead to an under sampling of rural TBI cases causing an under-reporting primarily of rural TBI incidence. The registry does not capture pre-hospital mortality cases or patients admitted to non-trauma centers. In our population, transportation times were longer for rural locations of injury which could lead to higher rates of death prior to presentation at the emergency department. Rural patients may also be admitted to non-trauma centers at a higher rate and die prior to transfer. Studies among rural hospitals across Oregon and Washington have shown that over 10% of patients in non-trauma centers die in non-trauma center emergency departments awaiting transfer to trauma centers. Thus, mortality cases in rural areas could be excluded at a greater rate than urban mortality cases, potentially resulting in falsely attenuated odds of mortality for those in rural areas. Future studies should use methods to enumerate children with TBI who may have died prior to receipt of care in the Trauma System.
SUMMARY AND CONCLUSIONS

Despite these limitations, our study found mortality disparities as well as difference in the epidemiology of TBI by urban vs. rural location. Children in rural areas had higher TBI incidence rates as well as greater odds of dying from their injuries. Our results suggest that disparities in treatment and care lead to a greater burden of TBI mortality among rural children, after adjusting for severity of injury. Further examination of specific treatment and care disparities are needed amongst pediatric patients who sustain TBIs. Low overall transfer rates as well as differences in the proportion transferred by location of injury for pediatric patients with severe TBI to higher trauma level hospitals suggests that further examination of triage and transfer criteria compliance in Oregon may be warranted. Additionally, differences in mechanisms and severity of injury suggest that location-specific TBI prevention programs may be warranted.
REFERENCES

1. Hartman M, Watson RS, Linde-Zwirble W, Clermont G, Lave J, Weissfeld L, Kochanek P, Angus D. Pediatric traumatic brain injury is inconsistently regionalized in the United States. *Pediatrics*. 2008 Jul;122(1):e172-80.

2. Halldorsson JG, Flekkoy KM, Gudmundsson KR, Arnløksson GB, Arnarson EO. Urban-rural differences in pediatric traumatic brain injuries: A prospective nationwide study. *Neuropsychiatr Dis Treat*. 2007 December; 3(6): 935–941.

3. Reid SR, Roesler JS, Gaichas AM, Tsai AK. The epidemiology of pediatric traumatic brain injury in Minnesota. *Arch Pediatr Adolesc Med*. 2001 Jul;155(7):784-9.

4. Howard I, Joseph JG, Natale JE. Pediatric traumatic brain injury: do racial/ethnic disparities exist in brain injury severity, mortality, or medical disposition? *Etnh Dis*. 2005 Autumn;15(4 Suppl 5):S5-51-6.

5. Kim K, Ozegovic D, Voaklander DC. Differences in incidence of injury between rural and urban children in Canada and the USA: a systematic review. *Inj Prev*. 2012 Aug;18(4):264-71.

6. Gabella B, Hoffman RE, Marine WW, Stallones L. Urban and rural traumatic brain injuries in Colorado. *Ann Epidemiol*.1997;7(3):207–12.

7. Grossman DC, Kim A, Macdonald SC, Klein P, Copass MK, Ronald V. Urban-rural differences in prehospital care of major trauma. *J Trauma*. 1997;42(4):723-729.

8. Mullins RJ, Hedges JR, Rowland DJ, et al. Survival of seriously injured patients first treated in rural hospitals. *J Trauma*. 2002;25:1019-102.

9. Esposito TJ, Sanddal ND, Hansen JD, Reynolds S. Analysis of preventable trauma deaths and inappropriate trauma care in rural areas. *J Trauma*. 1995;39(5):955-962.

10. Chapital AD, Harrigan RC, Davis J, Easa D, Withy K, Yu M, Takanishi DM Jr. Traumatic brain injury: Outcomes from rural and urban locations over a 5-year period (Part 1). *Hawaii Med J*. 2007 Dec;66(12):318-21.
11. Adekoya N, Majumder R. Fatal traumatic brain injury, West Virginia, 1989–1998. *Public Health Rep.* 2004;119(5):486–92.

12. Thurman DJ, Alverson C, Browne D, Dunn KA, Guerrero J, Johnson R, . . . Frazier L. *Traumatic Brain Injuries in the United States: A Report to Congress.* Center for Disease Control and Prevention. 1999.

13. Messek WJ, Rutledge R, Meyer AA, The association of advanced life support training and decreased per capita trauma rates: an analysis of 12,417 trauma deaths. *J Trauma.* 1992; 33:850-855.

14. Rutledge R, Smith CY, Azizkhan RG. A population-based multivariable analysis of the association of county demographic and medical system factors with per capita pediatric trauma death rates in North Carolina. *Ann Surg.* 1994; 219:205-210.

15. Newgard CD, McConnell KJ, Hedges JR, Mullins RJ. The benefit of higher level of care transfer of injured patients from nontertiary hospital emergency departments. *J Trauma.* 2007;63:965-971.

16. Oregon Trauma Registry Report 2010-2011. (June 2014). Oregon Health Authority, Public Health Division. May 2012. Retrieved from http://public.health.oregon.gov/providerpartnerresources/emstraumystems/traumystems/documents/reports/otr-report.pdf.

17. Sugerman DE, Xu L, Pearson WS, Fual M. Patients with severe traumatic brain injury transferred to a Level I or II trauma center: United States, 2007 to 2009. *J Trauma Acute Care Surg.* 2012; 73(6):1491-99.

18. Ingram DD, Franco SJ. NCHS urban-rural classification scheme for counties. *Vital Health Stat 2.* 2012 Jan;(154):1-65.

19. Oregon Trauma Registry. (June 2014). Oregon Health Authority. 2002-2012. Retrieved from https://public.health.oregon.gov/providerpartnerresources/emstraumystems/traumystems/pages/registry.aspx.
20. Barell V, Aharonson-Daniel L, Fingerhut LA, Mackenzie EJ, Ziv A, Boyko V, Abargel A, Avitzour M, Heruti R. An introduction to the Barell body region by nature of injury diagnosis matrix. *Inj Prev* 2002;8:91-96.

21. CDC. Recommended framework for presenting injury mortality data. MMWR 46 (RR-14) Centers for Disease Control and Prevention. Available from: [http://www.cdc.gov/mmwr/preview/mmwrhtml/00049162.htm](http://www.cdc.gov/mmwr/preview/mmwrhtml/00049162.htm). 1997. ICD–9 modified to be consistent with ICD–10 External Cause of Injury

22. Bazarian JJ, Veazie P, Mookerjee S, Lerner EB. Accuracy of Mild Traumatic Brain Injury Case Ascertainment Using ICD-9 Codes. *Acad EmergMed*. 13(1): 31-38.

23. Ingram DD, Franco SJ. 2013 NCHS urban–rural classification scheme for counties. National Center for Health Statistics. *Vital Health Stat*. 2014;2(166).

24. Howard I, Joseph JG, Natale JE. Pediatric traumatic brain injury: do racial/ethnic disparities exist in brain injury severity, mortality, or medical disposition? *Ethn Dis*. 2005 Autumn;15(4 Suppl 5):S5-51-6.

25. Stevenson M., Segui-Gomez M., Lescohier I., Di Scala C., McDonald-Smith G. An overview of the injury severity score and the new injury severity score. *Injury Prevention*. 2001;7 (1): 10-13.

26. Copes WS, Champion HR, Sacco WJ, Lawnick MM, Keast SL, Bain LW. The Injury Severity Score revisited. *J Trauma*. 1988 Jan;28(1):69-77.

27. United States Census Bureau. Oregon Populations by FIPS. 2002-2012.

28. Hardin JW ; Hilbe JM . *Generalized Linear Models and Extensions*, 2nd Edition Stata Press, College Station, TX . 2007.

29. Greenland S, Pearl J, Robins M. Causal Diagrams for Epidemiological Research. *Epidemiology*. 1999 10: 37-48.

30. Tiesman H, Young T, Torner JC, et al. Effects of a rural trauma system on traumatic brain injuries. *J Neurotrauma*. 2007;24:1189–97.
31. StataCorp. 2013. *Stata Statistical Software: Release 13*. College Station, TX: StataCorp LP.
Table 1. Annual Traumatic Brain Injury Incidence per 100,000 Oregon Children ≤19 Years of Age, by Urban/Rural Location

| Injury Location            | 2009 | 2010 | 2011 | 2012 | Total |
|----------------------------|------|------|------|------|-------|
| Large metropolitan         | 75   | 73   | 71   | 68   | 71    |
| Small/medium metropolitan  | 66   | 64   | 59   | 48   | 59    |
| Non-metropolitan           | 111  | 108  | 110  | 101  | 107   |
| Missing Location           | 17   | 10   | 8    | 13   | 12    |
| Combined incidence         | 96   | 87   | 83   | 80   | 87    |
Table 2. Characteristics of Pediatric Patients ≤19 Years of Age Admitted to Oregon Trauma Hospitals for Traumatic Brain Injury, 2009-2012, by Urban-Rural Location

|                              | Large metropolitan (n=1,303) | Small/Medium Metropolitan (n=799) | Non-metropolitan (n=692) | Total (n=2,794) | p   |
|------------------------------|------------------------------|----------------------------------|--------------------------|----------------|-----|
| Injury Severity Score        |                              |                                  |                          |                |     |
| ≤15 (mild/moderate)          | 984 (50)                     | 477 (24)                         | 507 (26)                 | 1,968          | <0.0001 |
| >15 (severe)                 | 316 (40)                     | 198 (25)                         | 272 (35)                 | 786            |     |
| Missing                      | 3 (8)                        | 17 (42)                          | 20 (50)                  | 40             |     |
| Glasgow Coma Scale           |                              |                                  |                          |                |     |
| 9-15 (mild/moderate)         | 1,161 (51)                   | 496 (22)                         | 626 (27)                 | 2,283          | <0.0001 |
| Category          | Count | SD | Count | SD | Count | SD | Count |
|-------------------|-------|----|-------|----|-------|----|-------|
| 3-8 (severe)      | 42    |    | 34    |    | 29    |    | 105   |
| Missing           | 100   |    | 162   |    | 144   |    | 406   |
| Gender            |       |    |       |    |       |    | 0.97  |
| Male              | 879   |    | 463   |    | 537   |    | 1,879 |
| Female            | 424   |    | 229   |    | 262   |    | 915   |
| Age (years)       |       |    |       |    |       |    | 0.02  |
| 0-4               | 325   |    | 163   |    | 149   |    | 637   |
| 5-14              | 380   |    | 203   |    | 240   |    | 823   |
| 15-19             | 598   |    | 326   |    | 410   |    | 1,334 |
| Race/ethnicity    |       |    |       |    |       |    | <0.0001 |
| White             | 891   |    | 538   |    | 578   |    | 2,007 |
| Category                        | Count (n) | Percent | 2 Standard Deviation | 3 Standard Deviation | 4 Standard Deviation | 5 Standard Deviation |
|--------------------------------|-----------|---------|----------------------|----------------------|----------------------|----------------------|
| Non-white                      | 348       | (60)    | 136                  | (24)                 | 91                   | (16)                 |
| Missing/unknown                | 64        | (30)    | 18                   | (9)                  | 130                  | (61)                 |
| **Insurance Status**           |           |         |                      |                      | <0.0001              |                      |
| Insured                        | 1,197     | (50)    | 579                  | (24)                 | 611                  | (26)                 |
| Uninsured                      | 84        | (43)    | 52                   | (26)                 | 62                   | (31)                 |
| Other/unknown/missing          | 22        | (11)    | 61                   | (29)                 | 126                  | (60)                 |
| **Transfer Status**            |           |         |                      |                      | <0.0001              |                      |
| Yes                            | 23        | (7)     | 129                  | (37)                 | 195                  | (56)                 |
| No                             | 1,280     | (52)    | 563                  | (23)                 | 604                  | (25)                 |
| **Mechanism of Injury**        |           |         |                      |                      | <0.0001              |                      |
| Fall                           | 509       | (54)    | 204                  | (22)                 | 227                  | (24)                 |

22
| Category                             | Value | Percent | Value | Percent | Value | Percent | Value | Percent | Value | Percent | Value | Percent |
|-------------------------------------|-------|---------|-------|---------|-------|---------|-------|---------|-------|---------|-------|---------|
| Motor vehicle collision             | 367   | (40)    | 250   | (27)    | 298   | (33)    | 915   |         |       |         |       |         |
| Struck by/against                   | 188   | (55)    | 80    | (23)    | 75    | (22)    | 343   |         |       |         |       |         |
| Firearm                             | 7     | (54)    | 3     | (23)    | 3     | (23)    | 13    |         |       |         |       |         |
| Other, specified classifiable       | 15    | (31)    | 18    | (38)    | 15    | (31)    | 48    |         |       |         |       |         |
| Other, specified NEC                | 8     | (80)    | 0     | (0)     | 2     | (20)    | 10    |         |       |         |       |         |
| Unspecified                         | 19    | (51)    | 10    | (27)    | 8     | (22)    | 37    |         |       |         |       |         |
| Other                               | 190   | (39)    | 127   | (26)    | 171   | (35)    | 488   |         |       |         |       |         |
| Hospital Level                      |       |         |       |         |       |         |       |         | <0.0001|         |       |         |
| I                                   | 1,251 | (85)    | 76    | (5)     | 149   | (10)    | 1,476 |         |       |         |       |         |
| II                                  | 5     | (1)     | 401   | (65)    | 211   | (34)    | 617   |         |       |         |       |         |
| III                                 | 1     | (0)     | 129   | (34)    | 249   | (66)    | 379   |         |       |         |       |         |
|   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|
| IV | 46 | (14) | 86 | (27) | 190 | (59) | 322 |
Table 3. Characteristics of Pediatric Patients ≤19 Years of Age Admitted to Oregon Trauma Hospitals for Traumatic Brain Injury, 2009-2012, by Mortality Outcome

|                  | Lived (n=2,718) | Died (n=76) | Total (n=2,794) | p      |
|------------------|-----------------|-------------|-----------------|--------|
|                  | n (% )          | n (%)       |                 |        |
| NCHS Urban/Rural Classification |                  |             |                 | 0.001  |
| Large metropolitan | 1,279 (98)      | 24 (2)      | 1,303           |        |
| Medium/small metropolitan | 676 (98)      | 16 (2)      | 692             |        |
| Non-metropolitan  | 763 (95)        | 36 (5)      | 799             |        |
| Injury Severity Score |                  |             |                 | <0.0001|
| ≤15 (mild/moderate) | 1,960 (100)     | 8 (0)       | 1,968           |        |
| >15 (severe)      | 720 (92)        | 66 (8)      | 786             |        |
| Missing           | 38 (95)         | 2 (5)       | 40              |        |
| Glasgow Coma Scale |                  |             |                 | <0.0001|
| 9-15 (mild/moderate) | 2,280 (100)     | 3 (0)       | 2,283           |        |
| 3-8 (severe)      | 82 (78)         | 23 (22)     | 105             |        |
| Missing           | 356 (88)        | 50 (12)     | 406             |        |
| Category                | Count | Percent | Mean Age | Standard Deviation | Total Count |
|-------------------------|-------|---------|----------|--------------------|-------------|
| **Gender**              |       |         |          |                    |             |
| Male                    | 1,827 | (97)    | 52       | (3)                | 1,879       |
| Female                  | 891   | (97)    | 24       | (3)                | 915         |
| **Age (years)**         |       |         |          |                    |             |
| 0-4                     | 612   | (96)    | 25       | (4)                | 637         |
| 5-14                    | 811   | (99)    | 12       | (1)                | 823         |
| 15-19                   | 1,295 | (97)    | 39       | (3)                | 1,334       |
| **Race/ethnicity**      |       |         |          |                    |             |
| White                   | 1,956 | (97)    | 51       | (3)                | 2,007       |
| Non-white               | 562   | (98)    | 13       | (2)                | 575         |
| Missing/unknown         | 200   | (94)    | 12       | (6)                | 212         |
| **Insurance Status**    |       |         |          |                    |             |
| Insured                 | 2,332 | (97)    | 55       | (3)                | 2,387       |
| Uninsured               | 185   | (96)    | 13       | (4)                | 198         |
| Other/unknown/missing   | 201   | (97)    | 8        | (3)                | 209         |
| **Transfer Status**     |       |         |          |                    |             |
| Yes                     | 334   | (96)    | 13       | (4)                | 347         |
| Mechanism of Injury                                      | N   | (%)  | Count | SD  | Count |
|----------------------------------------------------------|-----|------|-------|-----|-------|
| No                                                       | 2,384 | (97) | 63    | (3) | 2,447 |
| Fall                                                     | 928  | (99) | 12    | (1) | 940   |
| Motor vehicle collision                                  | 879  | (96) | 36    | (4) | 915   |
| Struck by/against                                        | 341  | (99) | 2     | (1) | 343   |
| Firearm                                                  | 6    | (46) | 7     | (54)| 13    |
| Other, specified classifiable                            | 41   | (85) | 7     | (15)| 48    |
| Other, specified NEC                                     | 8    | (80) | 2     | (20)| 10    |
| Unspecified                                              | 35   | (95) | 2     | (5) | 37    |
| Other                                                    | 480  | (98) | 8     | (2) | 488   |
| Hospital Level                                           |      |      |       |     |       |
| I                                                        | 1,447 | (98) | 29    | (2) | 1,476 |
| II                                                       | 596  | (97) | 21    | (3) | 617   |
| III                                                      | 363  | (96) | 16    | (4) | 379   |
| IV                                                       | 312  | (97) | 10    | (3) | 322   |
| Injury Type                                              |      |      |       |     |       |
| Blunt                                                    | 2,695 | (98) | 69    | (2) | 2,764 |

Mechanism of Injury: <0.0001

Hospital Level: 0.053

Injury Type: <0.0001
|       |       |       |       |       |
|-------|-------|-------|-------|-------|
| Penetrating | 13  | (65) | 7    | (35) | 20   |
| Missing  | 10   | (100)| 0    | (0)  | 10   |
### Table 4. Odds of Mortality by Urban/Rural Location among Oregon Children ≤19 Years of Age with Traumatic Brain Injury

| NCHS Classification         | Bivariate Association | Multivariate Association* |
|----------------------------|-----------------------|---------------------------|
|                            | OR        | 95% CI    | OR        | 95% CI    |
| Large metropolitan         | 1.0       | Ref       | 1.0       | Ref       |
| Small/medium metropolitan  | 1.28      | (0.58, 2.80) | 1.17      | (0.50, 2.70) |
| Non-metropolitan            | 2.51      | (1.58, 4.03) | 1.91      | (1.11, 3.30) |

*Model includes age, gender, race/ethnicity, insurance, ISS, and injury type (blunt vs. penetrating)
Figure 3. Causal Model Depicting Theorized Associations between Location of Injury and Mortality
Figure 4. Patient Counts for Initial Presentation Trauma Level and Post Transfer Trauma Level and Mortality for Severe Pediatric Traumatic Brain Injuries Sustained in Oregon

Severe Pediatric TBI Cases Sustained in Oregon: N=786

- Level I: N=413
- Level II: N=203
- Level III: N=109
- Level IV: N=61

- Transferred: N=118
  - Lived: N=110
  - Died: N=8

- Not Transferred: N=52
  - Lived: N=40
  - Died: N=12
APPENDIX

Table 5. Characteristics of Excluded Pediatric Patients ≤19 Years of Age Admitted to Oregon Trauma Hospitals for Traumatic Brain Injury, 2009-2012*

|                        | Total  |
|------------------------|--------|
|                        | (n=375) |
| **p**                  | 0.002  |
| Injury Severity Score  |        |
| ≤15 (mild/moderate)    | 231    |
| >15 (severe)           | 138    |
| Missing                | 6      |
| Glasgow Coma Scale     | <0.001 |
| 9-15 (mild/moderate)   | 228    |
| 3-8 (severe)           | 19     |
| Missing                | 68     |
| Gender                 | 0.08   |
| Male                   | 269    |
| Female                 | 106    |
| Age (years) | Count |
|------------|-------|
| 0-4        | 96    |
| 5-14       | 127   |
| 15-19      | 152   |

| Race/ethnicity | Count |
|----------------|-------|
| White          | 272   |
| Non-white      | 68    |
| Missing/unknown| 35    |

| Insurance Status | Count |
|------------------|-------|
| Insured          | 280   |
| Uninsured        | 31    |
| Other/unknown/missing | 46 |

| Hospital Level | Count |
|----------------|-------|
| I              | 159   |
| II             | 54    |
| III            | 75    |
| IV             | 90    |
*Includes patients excluded for missing location of injury (n=247) and patients excluded due to inability to determine final mortality outcome (n=128).

** Results of comparison to study population
Table 6. Severity Indicator Summary Statistics for Pediatric Patients ≤19 Years of Age Admitted to Oregon Trauma Hospitals for Traumatic Brain Injury, 2009-2012

| Indicator of Severity                  | % missing | Range  | Mean   | SD    | Median |
|---------------------------------------|-----------|--------|--------|-------|--------|
| ISS                                   | 1.4       | 1-59   | 11.0   | 8.7   | 9      |
| GCS                                   | 14.5      | 3-15   | 14.1   | 2.3   | 15     |
| Systolic Blood Pressure               | 4.4       | 0-246  | 125.5  | 22.3  | 126    |
| Diastolic Blood Pressure              | 4.5       | 0-220  | 74.1   | 17.0  | 74     |
| Pulse rate                            | 1.6       | 0-226  | 102.4  | 30.0  | 98     |
| Respiratory rate                      | 10.3      | 0-98   | 21.5   | 22.3  | 20     |