Objectives: To determine the epidemiology of pediatric traumatic brain injury (TBI) in a midwestern state and to examine differences between metropolitan and nonmetropolitan residents.


Participants: Patients aged 0-19 years sustaining TBI in 1993 that resulted in hospitalization or death.

Interventions: None.

Main Outcome Measures: Incidence, mortality and case-fatality rates, length of hospital stay, discharge status, and Glasgow Outcome Scale score.

Results: Nine hundred seventy-seven patients met inclusion criteria. Incidence, mortality, and case-fatality rates were 73.5 per 100000, 9.3 per 100000, and 12.8 per 100, respectively. Higher median household incomes and percentages of adult high-school graduates in a patient's census block group correlated with lower incidence. Median length of stay was 2 days. Of those included in the study, 720 patients (74%) were discharged home with self-care. Three hundred fifty-seven patients met criteria for severe TBI; 346 (97%) were assigned Glasgow Outcome Scale scores, of which 161 (47%) had disabilities or died. Severe TBI was associated with nonmetropolitan residence, higher median household income, and certain injury mechanisms. Incidence was similar for metropolitan and nonmetropolitan residents. Median head-region Abbreviated Injury Score, Injury Severity Score, and mortality and case-fatality rates were higher for nonmetropolitan residents.

Conclusions: This study reports the lowest incidence of pediatric TBI that results in death or hospitalization to date. One half of severely injured patients suffered poor outcomes. A greater proportion of nonmetropolitan than metropolitan residents suffered severe TBI and had higher mortality and case-fatality rates.

PATIENTS AND METHODS

CASE ASCERTAINMENT

Minnesota Statute 144.661-665 requires Minnesota hospitals to report all admissions of patients with TBI identified from International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) codes. Some hospitals from bordering states voluntarily report cases of Minnesota residents admitted with TBI. These reports constitute the Minnesota Department of Health TBI Registry. The registry records age; sex; county of residence; county of injury; dates of injury, admission, and discharge; ICD-9-CM nature-of-injury codes; and external-cause-of-injury codes. From registry data, we identified a population of children and adolescents with TBI who met the following criteria: (1) injury assigned ICD-9-CM codes 800.00 to 801.99, 803.00 to 804.99, or 850.00 to 854.19; (2) injury resulted in hospitalization or death; (3) resident of Minnesota; (4) injury sustained during 1993; and (5) aged 0 to 19 years at time of injury. For morbidity statistics, patients injured in 1993 but hospitalized after 1993 were included. Also included were Minnesota residents who sustained a TBI outside Minnesota but were subsequently admitted to a Minnesota hospital for that injury.

Additional cases of fatal TBI involving patients meeting inclusion criteria were identified from death certificates. Death certificates from 1993 listing a qualifying ICD-9-CM code were reviewed. Those cases involving Minnesota residents aged 0 to 19 years at time of death were included in the study. All death certificate cases with an ICD-9-CM code of 873.0 to 873.9 (open wound of head) without a qualifying TBI code were reviewed and found to involve TBI.

DATA COLLECTION

Prehospital, emergency department (ED) and inpatient records for each case were abstracted by trauma registrars retrospectively to determine principal and injury-related ICD-9-CM codes and final dispositions. Final dispositions were categorized as (1) home with age-appropriate self-care; (2) home with nonskilled assistance; (3) home with skilled assistance; (4) home with outpatient rehabilitation services; (5) residential facility without skilled care; (6) residential facility with skilled care; (7) inpatient rehabilitation facility; (8) died in the field, were dead on arrival, or died in the ED; and (9) inpatient death. When patients had multiple admissions for consequences of the same injury, data from admissions subsequent to the initial hospitalization were analyzed for length of stay only.

A second abstraction of hospital charts was performed for patients with hospital stays longer than 1 day and a head-region Abbreviated Injury Score (HR-AIS) of less than 2, or who died at the hospital. Injury Severity Score (ISS) and Glasgow Outcome Scale (GOS) score were recorded. The GOS score was assigned on the basis of review of discharge summaries, discharge orders, and medical chart entries from relevant hospital staff and consultants.

DEFINITIONS AND OTHER METHODS

A severe-injury cohort of patients was defined as those who had an HR-AIS of greater than 2 or who died. In accordance with Centers for Disease Control and Prevention guidelines, all deaths occurring before inpatient admission to the hospital, including ED deaths, were defined as preadmission deaths.

A child’s residence was determined to be metropolitan or nonmetropolitan using the method previously described by Goldsmith et al.2 Median household income and the percentage of high school graduates living in a child’s area of residence were determined by geocoding the child’s home address within the census block group of which it was a part,3 and then using 1990 US census data.4

Data obtained from the Minnesota Center for Health Statistics and the US Census Bureau were combined with registry data to calculate incidence and frequency distributions with respect to age, socioeconomic status, and metropolitan vs nonmetropolitan residency. Incidence and mortality rates were derived after applying capture-recapture analysis to data from the registry and death certificates. Capture-recapture analysis makes it possible to estimate the total number of subjects from the overlap of those subjects captured by one data set (eg, the TBI registry) and those captured by another (eg, the death certificates). Its use has recently been applied to epidemiology and public health research.5-7

For determination of mortality rates, 1 child who was injured in 1993 but died in 1994 was excluded. Information entered into the registry or death certificates was collected through December 31, 1996. This study was reviewed by the Minnesota Department of Health Institutional Review Board and determined to be exempt from the need for formal approval.

STATISTICAL ANALYSIS

Statistical methods for metropolitan and nonmetropolitan comparisons included the following: z tests for rates, assuming events follow a Poisson distribution; Wilcoxon nonparametric tests for length of stay, HR-AIS, ISS, and GOS score; and continuity-corrected χ² analysis for mechanism differences for selected age groups. We performed multivariate analyses of variables associated with severity and outcome using backward stepwise logistic regression and statistical analyses with commercially available software (SAS PROC LOGISTIC and SAS 6.12, respectively; SAS Institute Inc, Cary, NC).

INCIDENCE

By including the additional 6 deaths estimated by capture-recapture analysis, we determined an overall incidence of 73.5 per 100,000 (983/13,376,669). Incidence peaks in infancy (<1 year of age), early childhood (ages 6 and 7 years), and adolescence (ages 13-19 years) were observed. At each of these years of age, incidence of TBI exceeded 39. We noted a higher incidence for male than for female patients. The rate of TBI decreased as median household income and percentage of high school graduates in the census block increased.
MECHANISM OF INJURY

Table 1 summarizes the leading causes of TBI for each age group.

SEVERE-INJURY COHORT

Three hundred fifty-seven patients met our criteria for severe injury. Children who did not meet our criteria for the severe-injury cohort (n=620) had a hospital length of stay of less than 2 days and were discharged home with age-appropriate self-care, or had an HR-AIS of less than 3. Seventy-five patients in the severe-injury cohort were identified from death certificates only; these cases lacked all in-hospital data elements, including HR-AIS and ISS. Of the patients in the severe-injury cohort with a known HR-AIS, 126 (45%) had a score of 3; 67 (24%), a score of 4; 81 (29%), a score of 5; 3 (1%), a score of 6; and 3 (1%), a score of 9 (eg, unknown).

RISK FACTORS FOR SEVERE INJURY

Table 2 summarizes the results of multivariate analyses identifying factors associated with severe TBI.

OUTCOMES

Of the 974 patients for whom the final discharge status was known, 120 (12%) died, 720 (74%) were discharged home for age-appropriate self-care, and 134 (14%) were discharged to a residential or inpatient facility or home to receive assistance or care from others. The median length of hospital stay was 2 days.

For the 346 patients in the severe-injury cohort for whom the GOS score was known, outcomes in terms of GOS were as follows: good recovery, 185 (53%); moderate disability, 29 (8%); severe disability, 10 (3%); vegetative state, 2 (1%); and death, 120 (35%).

METROPOLITAN RESIDENCE VS NONMETROPOLITAN RESIDENCE

Table 3 summarizes differences in pediatric TBI between metropolitan and nonmetropolitan residents. In 1993, census and Minnesota Center for Health Statistics data indicate that 876,728 and 460,941 persons aged 0 to 19 years were living in metropolitan and nonmetropolitan Minnesota, respectively. Reapplication of capture-recapture analysis to both populations estimated no additional deaths (95% CI, 0–1) among metropolitan residents and 9 additional deaths (95% CI, 0–19) among nonmetropolitan residents.

Fifty-seven deaths occurred in residents of metropolitan areas compared with 62 in residents of nonmetropolitan areas. For 854 patients for whom county of injury was known, 691 (81%) were injured in their county of residence. No differences were observed between the 2 groups with respect to age or sex.

MECHANISM OF INJURY

Residents of nonmetropolitan areas had a significantly higher incidence of TBI related to motor-vehicle occupancy during a crash (P = .002) and significantly higher mortality rates for this category of TBI (P < .001).

SEVERE-INJURY COHORT

The HR-AIS, ISS, and GOS score were assigned only to patients in the severe-injury cohort (Table 3). Patients missing HR-AIS and ISS (n=80) and those not missing the scores (n=277) did not differ significantly with regard to metropolitan vs nonmetropolitan residency (P = .11).

OUTCOMES

Residents of metropolitan and nonmetropolitan areas did not significantly differ with regard to median length of stay. Of 193 severely injured metropolitan residents, 110 (57%) had a good recovery as defined by GOS; of 153 severely injured nonmetropolitan residents, 75 (49%) had a good recovery (P = .07).

COMMENT

Although many previous studies of TBI have examined general populations, this is one of the few population-based studies to gather data on the characteristics of TBI in a defined pediatric population. By using a uniform data system case definition rather than a clinical case definition, our study conforms to Centers for Disease Control and Prevention guidelines. By including data on patients with fatal TBI who never presented to a hospital, our data may more accurately depict the full societal bur-
MORTALITY AND CASE-FATALITY RATES

The mortality rate in this population (9.3/100,000) compares favorably with those of previous studies of pediatric populations. Dunn et al29 used a method similar to ours in a 1994 study of 7 states and reported a higher mortality rate (11.6/100,000). Capture-recapture analysis was not used to estimate missing cases. Comparison with other studies is problematic because of methodological differences and unreported mortality rates. Lower rates of motor-vehicle crashes and of driving under the influence of alcohol and improvements in roadways and motor vehicles by 1993 may account for some reduction in mortality. Injury severity, and therefore mortality, may have been reduced by the increased use of seat belts and infant and child car seats, improved crash characteristics of motor vehicles, and improved prehospital medical care.33

Few previous population-based studies report case-fatality rates for children. However, our postadmission case fatality rate (4.6%) is higher than that reported by Kraus et al30 (2.5%) for a population younger than 15 years. This difference may reflect a trend toward outpatient management of mild TBI.33

Table 1. Leading Causes of TBI by Age Group*

<table>
<thead>
<tr>
<th>Cause, Rank</th>
<th>Age Group, y</th>
<th>&lt;1</th>
<th>1-4</th>
<th>5-9</th>
<th>10-14</th>
<th>15-19</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Cause Fall (U)</td>
<td>46 (61)</td>
<td>71 (53)</td>
<td>49 (27)</td>
<td>43 (22)</td>
<td>200 (51)</td>
</tr>
<tr>
<td>2</td>
<td>Cause Battering (A)</td>
<td>14 (19)</td>
<td>26 (19)</td>
<td>32 (17)</td>
<td>32 (17)</td>
<td>45 (11)</td>
</tr>
<tr>
<td>3</td>
<td>Cause Unspecified (UD)</td>
<td>5 (7)</td>
<td>11 (8)</td>
<td>26 (14)</td>
<td>23 (12)</td>
<td>24 (6)</td>
</tr>
<tr>
<td>All other causes, No. (%)</td>
<td>10 (13)</td>
<td>26 (19)</td>
<td>76 (42)</td>
<td>95 (49)</td>
<td>123 (31)</td>
<td></td>
</tr>
<tr>
<td>Total, No. (%)</td>
<td>75 (100)</td>
<td>134 (100)</td>
<td>183 (100)</td>
<td>193 (100)</td>
<td>392 (100)</td>
<td></td>
</tr>
</tbody>
</table>

* TBI indicates traumatic brain injury; U, unintentional; A, assault; MV, motor vehicle; and UD, undetermined. Causes are ranked by frequency.

Table 2. Factors Associated With Severe TBI*

<table>
<thead>
<tr>
<th>Factor</th>
<th>Odds Ratio (95% Confidence Interval)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firearm</td>
<td>88.5 (11.7-667.0)</td>
</tr>
<tr>
<td>Battering</td>
<td>8.6 (3.1-23.9)</td>
</tr>
<tr>
<td>All-terrain vehicle</td>
<td>8.0 (1.6-40.7)</td>
</tr>
<tr>
<td>Motor vehicle crash</td>
<td>2.5 (1.8-3.4)</td>
</tr>
<tr>
<td>Struck by objects or persons</td>
<td>2.2 (1.4-3.6)</td>
</tr>
<tr>
<td>Falls and all other mechanisms (comparison)</td>
<td>...</td>
</tr>
<tr>
<td>Nonmetropolitan residence</td>
<td>2.2 (1.6-3.0)</td>
</tr>
<tr>
<td>Metropolitan residence (comparison)</td>
<td>...</td>
</tr>
<tr>
<td>Median household income†</td>
<td>1.16 (1.03-1.30)</td>
</tr>
</tbody>
</table>

* TBI indicates traumatic brain injury. Excludes 26 children whose area of residence was not geocoded (n = 951). R² = 0.16. † For an increase of $10,000.

Table 3. Metropolitan and Nonmetropolitan Comparisons*

<table>
<thead>
<tr>
<th>Metropolitan (n = 635 [65%])</th>
<th>Nonmetropolitan (n = 342 [35%])</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incidence rate, per 100,000</td>
<td>72.4</td>
<td>76.1</td>
</tr>
<tr>
<td>Mortality rate, per 100,000</td>
<td>6.5</td>
<td>15.4</td>
</tr>
<tr>
<td>Population case fatality rate, %</td>
<td>9.0</td>
<td>20.2</td>
</tr>
<tr>
<td>Postadmission case fatality rate, %</td>
<td>3.2</td>
<td>7.0</td>
</tr>
<tr>
<td>Length of stay, d</td>
<td>Median</td>
<td>2</td>
</tr>
<tr>
<td>25th and 75th percentiles</td>
<td>1, 4</td>
<td>1, 5</td>
</tr>
<tr>
<td>HR-AIS head region‡</td>
<td>Median</td>
<td>3</td>
</tr>
<tr>
<td>25th and 75th percentiles</td>
<td>3, 5</td>
<td>3, 5</td>
</tr>
<tr>
<td>ISS total†</td>
<td>Median</td>
<td>17.5</td>
</tr>
<tr>
<td>25th and 75th percentiles</td>
<td>10, 26</td>
<td>16, 30</td>
</tr>
<tr>
<td>GOS</td>
<td>Median</td>
<td>Good recovery</td>
</tr>
<tr>
<td>25th and 75th percentiles</td>
<td>Good recovery, death</td>
<td>Good recovery, death</td>
</tr>
</tbody>
</table>

* HR-AIS indicates Abbreviated Injury Score, head region; ISS, Injury Severity Score; and GOS, Glasgow Outcome Scale. † Determined by χ² test, assuming Poisson distribution.

INCIDENCE

The rate of pediatric TBI reported in this study (73.5/100,000) is notably lower than previously reported rates. Previous studies have documented rates ranging from 90 per 100,000 to 300 per 100,000, with an average of 180 per 100,000. Dunn et al reported an incidence of 90 per 100,000 for the group aged 0 to 19 years. Kraus et al, in a study of patients younger than 15 years, reported an incidence of 185 per 100,000. This difference cannot entirely be attributed to differences in methods. The reasons for our lower incidence may parallel those that may explain our lower mortality rate. If injury frequency and severity were reduced by these means, fewer victims injured as a result of motor-vehicle occupancy during a crash may have required hospitalization. In addition, the growth of managed care may reduce the number of injuries treated as an inpatient.
care and the wide availability of computed tomography to rule out significant injury may have increased the propensity for acute care physicians to treat children with TBI as outpatients.33

A small portion of the difference may be attributable to incomplete reporting by certain hospitals. Previously, reported rates of TBI for all age groups are lower in western counties of Minnesota.33 Children injured in these areas may be treated in facilities located in a neighboring state. Reporting compliance by these facilities is variable. However, the population of western Minnesota is not large enough to account for the entire difference between our rate and that of Dunn et al.29

Unfortunately, in 1993, no standard procedure for assessing the sensitivity of injury registries existed. Because we had no second, independent data set (eg, hospital discharge data) with which to compare nonfatal cases from the registry, capture-recapture methods could not be applied to give an estimate of missing cases. To the extent that underreporting occurred, our study is limited. If underreporting occurred in a nonrandom manner, bias may have been introduced. We were unable to evaluate the positive predictive value of case reports.

MECHANISMS

As in previous reports, falls and mechanisms involving motor vehicles account for most injuries.10-26,29-32 Injuries involving motor vehicles were statistically associated with severe injury, whereas falls were not. Because injuries involving motor vehicles are among the most frequent and most severe, efforts to prevent pediatric TBI must continue to make motor vehicle safety a priority.

RISK FACTORS FOR SEVERE INJURY

Not surprisingly, injury mechanisms involving firearms, child abuse, all-terrain vehicles, and motor vehicles were correlated with severe injury. These mechanisms have been the subject of considerable prevention and intervention activities, such as those promoting trigger locks, crisis nurseries, regulation of all-terrain vehicles, and graduated driver’s licensing for minors. Clearly, continued activities are needed in these areas.

The associations of nonmetropolitan residence and higher median household income with severe TBI are not easily explained. Nonmetropolitan residency has been associated with greater motor vehicle travel at higher speeds and on roads with multiple access points.30 Greater exposure may result in more crashes and severe TBI. Although higher median household incomes are associated with decreasing incidences of TBI,37 we have noted a greater proportion of severe injury. Perhaps children in these groups have greater access to higher-risk mechanisms, such as motor vehicles at younger ages, all-terrain vehicles, and recreational sports. Unfortunately, our data set does not describe exposures (eg, vehicle miles traveled) relative to various injury mechanisms.

OUTCOME

As in previous reports, most hospitalized patients were discharged home with age-appropriate self-care after a brief hospital stay.14,17,18 For the analysis of functional outcome, we excluded nonsevere cases of TBI. The outcome of these injuries, at least as determined using the GOS, is typically good. Nearly half of our severe-injury cohort, however, had less than good outcomes as defined when using the GOS. In addition, subtle but important functional problems may not be detected using the GOS. Although we cannot quantify it, the personal and societal cost of pediatric TBI is clearly high.

Our study design necessitated assigning GOS scores retrospectively based on the functional status of each child at hospital discharge. To the extent that this diverges from the standard application of the GOS, this is a potential limitation of our study.

METROPOLITAN VS NONMETROPOLITAN RESIDENCE

Little is known about the differences in epidemiology of TBI for residents of metropolitan vs nonmetropolitan areas, particularly for pediatric populations.

For a general population, Fife et al17 has previously reported an increased incidence of TBI in areas with greater population density. In contrast, Gabella et al37 has reported lower incidence of TBI requiring hospitalization and fatal TBI in urban areas, compared with rural areas. We found little difference in the incidence of TBI requiring hospitalization and fatal TBI in a pediatric population in metropolitan and nonmetropolitan areas. Metropolitan vs nonmetropolitan residence may have little impact on the incidence of TBI in childhood.

We found, however, a striking disparity between mortality rates for residents of metropolitan and nonmetropolitan areas. This is consistent with the analysis by Gabella et al37 of TBI requiring hospitalization and fatal TBI in urban and rural areas for a general population. Previous studies have noted higher rural mortality rates for all childhood injuries and have implicated motor-vehicle crashes as an important factor.38,39 Our findings support this by noting a higher mortality rate related to motor-vehicle occupancy during a crash for residents of nonmetropolitan areas. Because of insufficient data regarding severity of brain injury for preadmission deaths, we were unable to determine whether the discrepancy between metropolitan and nonmetropolitan mortality rates would remain after controlling for severity.

Higher mortality rates for residents of nonmetropolitan areas may result from greater injury severity. Residents of nonmetropolitan areas in our severe-injury cohort had significantly higher HR-AIS, perhaps as a result of more forceful injury mechanisms (ie, motor vehicle occupancy during a crash).

Although injury severity was greater for residents of nonmetropolitan areas, we did not detect a statistically significant difference in outcomes between residents of metropolitan and those of nonmetropolitan areas. This may reflect insensitivity on the part of the GOS in describing outcomes.
A possible limitation of this study is its classification of patients into metropolitan and nonmetropolitan populations based on residence. Our findings are relevant regardless of whether TBI is influenced by the injury environment or by the characteristics of individuals living in a particular environment. Eighty-one percent of our patients were injured in their county of residence. This is comparable to data reported by Gabella et al, who found that 89% of patients who died and 92% of patients who survived were injured in their county of residence. We agree, then, that county of residence serves as a reasonable proxy for county of injury.

CONCLUSIONS

To our knowledge, this study reports the lowest incidence of pediatric TBI that results in death or hospitalization to date. A greater proportion of pediatric residents of nonmetropolitan areas sustained severe injuries, and pediatric residents of nonmetropolitan areas had higher mortality rates than their metropolitan counterparts, presumably due in large part to motor vehicle crashes. No differences in outcomes were observed between nonmetropolitan and metropolitan residents.

Accepted for publication February 10, 2001.

This study was supported with grants MCH-274001-01-0 and MCH-274002 from the Emergency Medical Services for Children Program of Minnesota, Minneapolis.

Preliminary findings from this study were presented at the American Academy of Pediatrics Annual Meeting, San Francisco, Calif, October 19, 1998.

We thank James M. Kaufmann, PhD, for editing earlier versions of this article.

Corresponding author and reprint requests: Samuel R. Reid, MD, Pediatric Emergency Medicine, Children's Hospitals and Clinics, 345 N Smith Ave, St Paul, MN 55102 (e-mail: krinamdsam@aol.com).

REFERENCES

4. SEDAC [database online], Palisades, NY: Socioeconomic Data and Applications Center; 1997.