

Age Effects on Injury Patterns in Pedestrian Crashes

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ABSTRACT

Approximately 600,000 fatalities occur each year as a result of pedestrians being impacted by motor vehicles (World Bank, 2008). Previous studies (Heller et al., 2009) have utilized databases such as the National Inpatient Sample (NIS) to gain a more thorough understanding of the common injury patterns that occur in real-world traffic collisions involving pedestrians in the United States. The NIS contains records on five to eight million hospital stays annually and provides a wealth of information regarding injuries to hospitalized pedestrian casualties in the U.S. Because of the large number of applicable records in the NIS and the randomized sampling procedure, the data can be used to complete analyses that are not possible with smaller databases such as the Pedestrian Crash Data Study (PCDS), which is not intended to be statistically representative of pedestrian crashes in general. The current study utilizes the NIS to evaluate the effect of age on real-world injury outcomes for hospitalized pedestrian casualties. NIS data collected between 1998 and 2007 were divided into eight age categories that correspond to children (0-4, 5-9, and 10-14 years) and adults (15-29, 30-44, 45-59, 60-79, and 80 years and older). Outcomes regarding injury frequency and injury patterns, as well as length and cost of hospital stay, were evaluated and compared among the eight age categories to determine how age affects the type, frequency, and pattern of injuries sustained in pedestrian crashes.

INTRODUCTION

Injuries to pedestrians involved in pedestrian versus motor vehicle crashes are a significant contributor to death and disability in all motorized societies. Considering fatalities only, over 50% of the worldwide road traffic casualties are pedestrians [1]. In the United States alone, approximately

69,000 or 2.9% of the 2,346,000 who were injured and 4,378 or 11.7% of the 37,261 who were killed in road traffic crashes in 2008 were pedestrians according to the National Highway Traffic Safety Administration (NHTSA) [2]. While pedestrian-motor vehicle trauma affects all age categories, the results from several epidemiological studies indicate that exposure (risk of becoming a casualty of a pedestrian crash) as well as morbidity, mortality, and type and severity of injuries sustained among pedestrian casualties are age dependent.

Several studies have compared the types and/or severity of injury between pediatric and adult or between pediatric, adult, and elderly pedestrian casualties [3,4,5,6,7]. Derlet et al. (1989) reviewed the records of the 217 pedestrian casualties treated at the University of California Davis Medical Center in Sacramento, California, during a one-year period in 1986-1987 and reported findings regarding adult and pediatric patients [3]. Kong et al. (1996) conducted a similar study utilizing a population consisting of the 273 pedestrian casualties seen at the Cedars-Sinai Medical Center in Los Angeles, California, during a three-year period from 1991-1994 [4]. The patients were grouped by age as pediatric (<16 years, n = 73), adult (16-59 years, n = 148), and elderly (≥ 59 years, n = 52). Peng and Bongard (1999) reviewed the records of 5,000 pedestrian casualties seen at thirteen level I and II trauma centers in Los Angeles County, California, during the three-year period of 1994-1996 [5]. The distribution of injury type/location was determined for the pediatric (< 15 years, n = 1,904), adult (15-65 years, n = 2,696), and elderly (>65 years, n = 400) patient categories. One of the most comprehensive and detailed epidemiological studies comparing pediatric and adult pedestrian injuries to date is the study by Demetriades et al. (2004) in which the population consisted of the 5,838 pedestrian casualties admitted to a level I trauma center in Los Angeles, California,

during a time period of 10 years and 4 months in 1993-2003 [6]. The patients were grouped by age in four categories spanning the ages ≤ 14 years ($n = 1,136$), 15-55 years ($n = 3,741$), 56-65 years ($n = 420$), and >65 years ($n = 541$).

Considering the large variation of stature and body weight within the pediatric population, a number of studies have also investigated how the types and/or severity of injury vary among age categories of pediatric pedestrian casualties [8,9,10,11]. Ashton (1979) reviewed the injuries sustained by 660 0- to 14- year-old pedestrian casualties (608 survivors treated at one hospital and 52 fatalities) in Birmingham, UK, during the five year period 1972-1976 [8]. The data were grouped according to age into three categories: 0-4, 5-9, and 10-14 years. Byard et al. (2000) conducted a retrospective review of the autopsy records and case histories of 68 child pedestrian fatalities in South Australia during the 20-year period 1977-1996 to compare injury patterns between the 0 to 1 year 11 months, 2 to 4 years 11 months, 5-9 years 11 months, and 10 to 16-years 11 months-age categories [9]. Ivarsson et al. (2006) reviewed the injury records of the 1,590 1- to 15-year-old pedestrian casualties treated at the Children's National Medical Center in Washington, DC, from June 1988 through October 2002 [11]. The patients were grouped by age in five categories spanning the ages 1-3 years ($n = 201$), 4-6 years ($n = 435$), 7-9 years ($n = 445$), 10-12 years ($n = 321$), and 13-15 years ($n = 188$).

The studies reviewed demonstrated some consistent trends in terms of age-related injury patterns in pedestrian casualties. However, many of the previous studies have focused on a limited number of patients within a confined geographic area. The current study aims to further investigate some of the trends that have been discussed in the literature by using a comprehensive database with over 5 million cases sampled annually throughout the United States. The large sample size taken from across the country allows for a more thorough investigation of injury patterns in pedestrian casualties across age categories, from birth to 80 years and older, than has been done previously. As a result, more details regarding the trends touched upon in previous studies can be explored.

METHODS

The Nationwide Inpatient Sample (NIS) is an annual survey of five to eight million inpatient hospital discharges from approximately 1,000 hospitals. This NIS is part of the Healthcare Cost and Utilization Project (HCUP), a federal-state-industry cooperative program sponsored by the Agency for Healthcare Research and Quality (AHRQ) under the U.S. Department of Health and Human Services (HHS). Comprising a 20 percent sample of all inpatient hospital discharges in the United States, the NIS is designed to allow for calculation of national estimates for inpatient stays. The NIS has grown since the program began in 1988 to include 40 states in 2007.

Within each record, the NIS contains more than 100 clinical and nonclinical data elements, including disease diagnoses, surgical procedures, and admission and discharge status. Up to fifteen diagnoses and procedures can be captured within each record using the ICD-9-CM codes. Other elements such as patient demographics (e.g., age, gender, race/ethnicity), total hospital charges, duration of hospital stay, and hospital characteristics (e.g., teaching status) are also available. Sampling information is included in the NIS, thereby allowing for computation of sampling errors in the estimates. In addition to the diagnosis codes, each record includes up to four E-codes which identify external causes of injury, such as a motor vehicle traffic accident involving collision with a pedestrian (E814).

NIS data from 1998 through 2007 were purchased from the HCUP Central Distributor via the HCUP website and imported into the statistical software SAS, version 9.2. Subsequently, data were restricted to only patients with ECODE 814.7: "motor vehicle traffic accident involving collision with pedestrian injuring pedestrian." Injured pedestrians were identified as patients with a primary diagnosis of ICD-9-CM codes 800 through 999 excluding codes corresponding to non-impact related injuries, such as poisoning, burns, environmental effects, etc. ICD-9-CM codes cannot be directly or completely mapped to Abbreviated Injury Scale (AIS) scores, and as a consequence, injury severity was not directly addressed in this study.

The identified population of pedestrian casualties was divided into eight age categories (0-4, 5-9, 10-14, 15-29, 30-44, 45-59, 60-79, and 80+ years). These age ranges were influenced in part by restricted release of age data by some state agencies that supply NIS records (for purposes of confidentiality). Several states set the age value in each record to the midpoint of its respective five-year range. For example, in some states any age in the 5-9 year range would be assigned a midpoint age of 7 years, and any age in the 30-34 year range would be assigned the midpoint age of 32 years. The same 5-year age categories, or combinations thereof, were used in this study to avoid unrepresentative age sampling. In order to track differences in pedestrian injuries in youth as closely as possible, single 5-year ranges were used. For adulthood, age categories were expanded to 15-year ranges. Age ranges of 20+ years (60-79 and 80+) were used for the elderly to capture sufficient numbers of pedestrian casualties to permit assessment of injury trends. The dataset was summarized by patient characteristics and diagnosis codes.

The ICD-9-CM codes were classified according to injury type (fracture, dislocation, blood vessel injury, soft tissue injury, open wound, superficial injury, sprain, crushing injury, or unknown injury) and body region of injury (head, face, neck, spine, chest, abdomen, upper extremity, lower extremity, or unknown). Pelvis injuries were categorized as a lower

extremity injury for this analysis. Using this restricted “injured pedestrian” data set, the twelve commonest injury diagnoses (at the 3-digit level of ICD-9-CM) were identified for each age category and combined to create a superset of the 27 commonest injury diagnoses over all ages. Additionally, several common co-diagnoses related particularly to some of the head injury diagnoses were investigated. Factors including injury type, body region, diagnosis frequency, and common co-diagnoses were investigated and trends were assessed over age. Data were explored at both the detailed (4- or 5-digit) and broad (3-digit) level of ICD-9-CM codes. Data regarding head injuries can be found across several 3-digit ICD-9-CM codes, and skull fractures, intracranial injuries, and the duration of loss of consciousness (LOC) were examined by reviewing head injury data from the 5-digit codes. The head injury codes included in this analysis were as follows: non-external head injuries including skull fractures (ICD-9-CM 800-801, 803-880), facial fractures (ICD-9-CM 802), concussion (ICD-9-CM 851), and intracranial injuries (ICD-9-CM 852-854).

Samples from the NIS database were used to determine the national estimates of the number of patients and diagnoses. The national estimates are based on given weighting variables that take into account geographic region, urban/rural location, teaching status, bed size, and controls. These estimates and the standard errors of these estimates were calculated with Statistical Analysis Software (SAS) accounting for the survey sample design of the NIS database (Tables A3A4,A5,A6a,A6b,A6c,A6d,A7,A8,A9,A10,A11,A12,A13,A14,A15,A16,A17,A18,A19).

RESULTS

There were 46,593 inpatients in the NIS from 1998 to 2007 who were identified as pedestrians that sustained traumatic injuries due to a motor vehicle interaction, approximately 0.06 percent of the total database. These sampled cases represented an estimated national sample of 231,171 patients with an estimated total of 720,429 traumatic injury diagnoses. Sixty-three percent of the hospitalized pedestrian casualties were male and 37 percent were female. In all age categories below 60 years old, males outnumbered females by 5-to-3 or greater, with males doubling females in the 0-4, 5-9, and 30-44 year-old categories and nearly doubling females in the 15-29 and 45-59-year-old categories (Figure 1). This trend disappeared in the 60-79-year-old category (1:1 ratio of men to women), and reversed in the 80+ year-old category, in which hospitalized females outnumbered males 9-to-7. This demographic shift in the hospitalized pedestrian casualty population is presumably influenced by the greater female longevity in the overall population. Most patients (83-85% in all age ranges) were admitted from the emergency department, with much of the remainder admitted via “routine” avenues, such as physician, outpatient and HMO

referrals (8-10% in all age ranges) or transfers from other hospitals (3-5% in all age ranges). Most survived the hospital stay (95% or greater for all ages under 60 years, 92% in the 60-79-year-old category, and 88% in the 80+ year-old category) (Figure 2). The average length of hospital stay for the pediatric patients (under age 15) was five days or less. The length of hospital stay increased to approximately six days for young adults (15-29 years old) and ranged between approximately eight and nine days in all age ranges of 30 years and older (Figure 3).

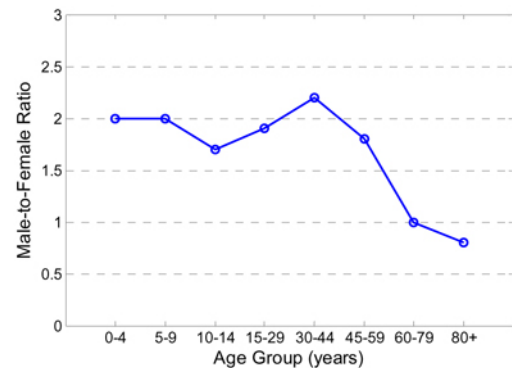


Figure 1. The ratio of male to female pedestrian patients in the NIS over age.

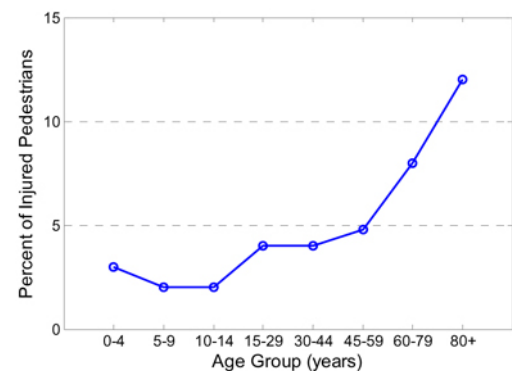


Figure 2. Fatalities during hospitalization among injured pedestrians over age.

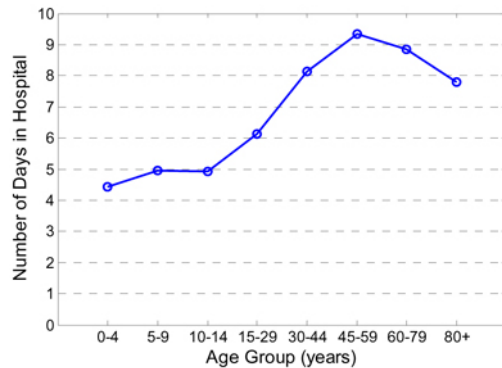


Figure 3. Length of hospital stay for injured pedestrians over age.

Of all the diagnoses for the hospitalized pedestrians, fractures were the commonest type of injury. Fractures accounted for 46 percent of all diagnoses for the pedestrian population (Figure 4), and were the commonest type of injury in every age category over 5-years-old. With increasing age, fractures comprised an increasing fraction of all injuries, from 29 percent in the youngest children to more than half (52 to 53%) for all hospitalized pedestrians 45 and older. Superficial injuries, which were the commonest injury diagnoses in the youngest children (33%), decreased with age and comprised less than 15 percent of injuries in populations 30 and older. Soft tissue injury diagnoses decreased monotonically with age (from 22% in 0-4-year-old category to 15% in the 80+ -year-old category). Sprains and dislocations were not common injuries in any age range, but did exhibit age-related trends from less than 0.5 percent in children under 10 to nearly 2 percent for dislocations and more than 2 percent for sprains for nearly all adults (15 to 79 years) except those over 80.

<figure 4 here>

The commonest body region injured in the hospitalized population of pedestrian casualties was the lower extremity, accounting for 34 percent of all diagnoses (Figure 5). This was true for adult ages, though lower extremity injuries did increase monotonically over age from 24 percent in the 0-4-year-old category to 38 percent in the 80+ year-old category. Head/face/neck injuries were the commonest body region injured in the pediatric age categories and decreased over age from 37 percent in the 0-4-year-old category to 27 percent in the 80+ year-old category. Similarly, upper extremity injuries increased throughout childhood (from 9% in the 0-4-year-old category to 13% by 10-14-year-old category), plateaued during adulthood (12-13%), and increased again in old age (14% in the 60-79-year-old category and 15% for those 80+ year-old category). In contrast, injuries to the head, neck, and face decreased throughout childhood into adulthood and then represented roughly constant proportions relative to other body regions throughout the rest of life (30 years and older).

Torso injuries, including chest injuries, were highest for the youngest children (23% for 0-4- year-old category) and adults in the 30-59-year-old category (22%).

<figure 5 here>

For each of the eight age ranges, the twelve commonest three-digit injury diagnoses in the NIS (in terms of number of pedestrians) were identified and combined to form a superset of the 27 commonest injuries over all ages. These diagnoses and their frequencies over age, shown in Figures 6a,6b,6c,6d, were selected for more detailed analysis.

<figure 6a. here>

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Several age-related trends stood out among the commonest pedestrian injury diagnoses. Among the commonest types of head injury, the frequency of brain injuries generally increased with age, while the frequency of basilar skull fractures decreased (Figure 6a). Within the torso region, the frequency of fractures (ribs, vertebrae and pelvis) increased with age, whereas the frequency of heart/lung injuries demonstrated the opposite trend. (Figure 6b). Among the commonest extremity injuries, the frequency of upper arm and forearm fractures increased with age, as did lower leg (tibia, fibula and ankle) and femoral neck fractures (Figure 6c). Most of the fracture diagnoses for which the frequency increased with age exhibited their steepest frequency rise during childhood, peaked at some point during adulthood, and in some cases, diminished slightly among the oldest pedestrians. One exception was femoral neck fractures, for which the frequency increased throughout adulthood, most steeply in old age. Other femur fractures peaked in the 5-9-year-old category (21%) and then decreased into adulthood (8% by 15-29) and throughout life. Many superficial injuries decreased with age, many monotonically (Figure 6d). Others showed little change over age. Only leg contusions (and contusions not classified elsewhere or not specified, also included in ICD-9-CM code 924) showed a trend increasing with age.

BREAKDOWN OF INJURY DIAGNOSES

Head Injuries

Information regarding head injuries is included across several 3-digit ICD-9-CM codes. For this reason, the occurrence of skull fractures, intracranial injuries, and the duration of loss of consciousness were examined by simultaneously

reviewing the data from the 5-digit codes of the head injuries. The head injury codes included in this analysis were internal head injuries including skull fractures (800-801, 803-80), facial fractures (802), intracranial injuries (852-854), and concussion (851). The percentage of head injury diagnoses out of all injury diagnoses was similar between all age categories.

The vast majority of head injury diagnoses (>94%) across all age categories were specified as “closed”. The diagnosis of skull/facial fracture varied between the age categories diagnosed with a head injury (Figure 7). Of all the head injury diagnoses, skull/facial fracture made up 59% of the diagnoses in the 0-4-year-old age category and decreased to 48% for 10-14-year-olds. This percentage remained steady (50%–51%) in adulthood and then decreased to 41% in the oldest patients. In contrast, the incidence of intracranial injury (ICI) diagnoses increased with age. Of the head injury diagnoses, 16% were ICI in the 0-4-year-old age category and increased to 42% in the oldest age category. Skull/facial fractures occurred at a rate of approximately 4-to-1 compared to ICI diagnoses in the 0-4-year-old head injured patients. This ratio decreased with age and the incidences of skull/facial fracture and ICI were approximately equivalent in the oldest patients.

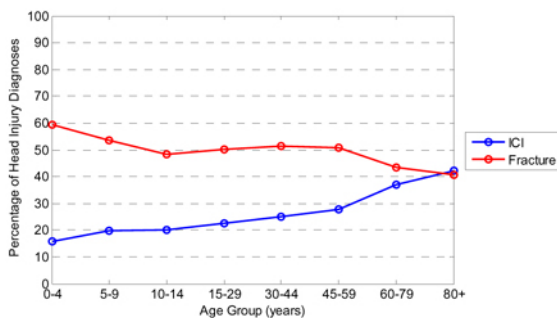


Figure 7. The occurrence of skull fractures and intracranial injury (ICI) within the head injury diagnoses.

The diagnoses of skull fracture and/or ICI were examined across age categories (Figure 8). Skull fracture without associated ICI generally decreased with age through childhood and early adulthood and then remained steady in the older age categories, decreasing from 22% in the 0-4-year-olds to 5% by age 30 to 44. Skull fractures with ICI also decreased with age, ranging from 25% in the 0-4-year-old age category to 14% in the 80+ year-old age category. The occurrence of intracranial injury with no skull fracture increased with age. Sixteen percent of the head injury diagnoses were ICI with no skull fracture in the 0-4-year-old age category, rising to 25% and 42% for the 30-44 and 80+ year-old age categories, respectively. Head injury diagnoses with no skull fracture and no ICI increased from 25% in the 0-4-year-old age category to 32% in the 10-14-year-old age

category. This percentage decreased to 24% and 17% in the 45-59 and 80+ year-old age categories, respectively.

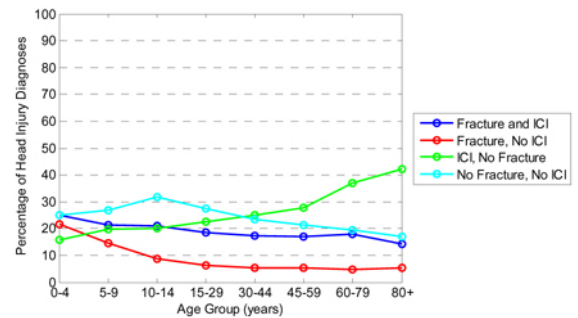


Figure 8. Skull fracture and/or intracranial injury (ICI) diagnoses for the various age categories.

Among the skull fracture diagnoses, the location of the fractures changed with age (Figure 9). The skull base was the commonest fracture location in the 0-9-year-olds while the face was the commonest location in the 15-80-year-olds. The diagnosis of basilar skull fractures declined only slightly with age (ranging from 31% to 43%). Vault fractures decreased from 29% in the 0-4-year-old category to 8% in the 33-44-year-old category and stayed steady in the adult patient population (8%–9%). Facial fractures increased from 21% in the 0-4-year-old category to 56% in the 30-44-year-old age category. The diagnosis of multiple skull fractures accounted for less than 2% of the skull fracture diagnoses in all age categories.

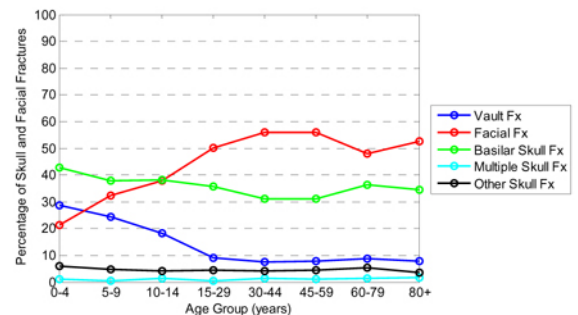


Figure 9. The distribution of skull fracture location for the various age categories. (Fx = fracture)

The distribution of ICI classification was approximately constant across all age categories (Figure 10). The majority of the ICI were hemorrhages (65-72%).

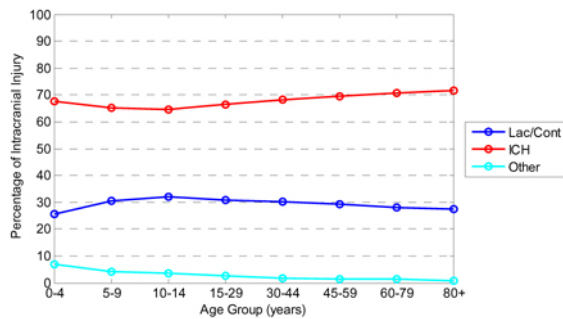


Figure 10. Distribution of ICI diagnoses for the various age categories. (Lac = laceration, Cont = contusion, ICH = intracranial hemorrhage)

A loss of consciousness (LOC) occurred in the majority of head injury diagnoses for which LOC status was available (Figure 11). The occurrence of LOC was lowest in the youngest children (43%), increased to 57% in the 10-14-year-old age category, and then remained generally steady through adulthood (approximately 50%). The diagnoses with unspecified LOC were less than 20-35% for all age categories with head injuries.

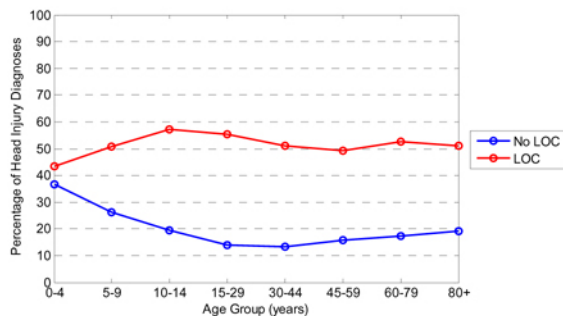


Figure 11. The occurrence of loss of consciousness (LOC) among the head injury diagnoses.

The duration of LOC in the head injured patients was separated into two categories: 0 to 1 hour and greater than 1 hour. In all age categories, the majority of those with a documented LOC durations regained consciousness within an hour (Figure 12). The fraction of head injured patients who experienced LOC for more than an hour increased from 9% in the 0-4-year-old category to 13% in the 30-44-year-old category. The fraction of head injured patients who experienced LOC for up to one hour decreased over those same age categories from 56% to 30%. For a substantial number of head injury diagnoses in each age category, the LOC duration status was reported as being not available (22%–30%).

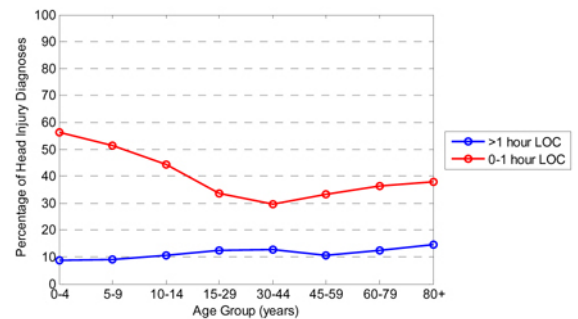


Figure 12. The duration of loss of consciousness (LOC) within the head injury diagnoses.

Torso Injuries

Vertebral column fractures without spinal cord injury (ICD-9-CM code 805) were infrequent among the pediatric patients (2% in the 0-4 and 5-9 year categories), increased among adults (13% of 30-44 and 45-59-year-old categories), and decreased again among the elderly (to 10% in the 80+ year-old category) (Figure 6b). The distribution of vertebral fracture location also changed with age (Figure 13). Vertebral fractures in pediatric patients tended to be mostly cervical (46% of all vertebral fractures in the 0-4-year-old category) and sacrococcygeal into early adolescence (45% of all vertebral fractures in the 10-14-year-old category). Both cervical and sacrococcygeal fractures decreased proportionally into adulthood (to 17% of vertebral fractures by 15-29-year-old for cervical fractures and to 25% of vertebral fractures by 30-44-year-old for sacrococcygeal fractures), as lumbar fractures increased (from 0% in the 0-4-year-old category to 35% of vertebral fractures in the 15-29-year-old category). In the elderly patients, cervical, lumbar and sacrococcygeal fractures converged to similar proportions (25-30% of all vertebral fractures). Thoracic fractures were the least frequent vertebral fractures in all age ranges over the age of 10 years, reaching a maximum proportion of 18 percent in the 80+ year-old categories.

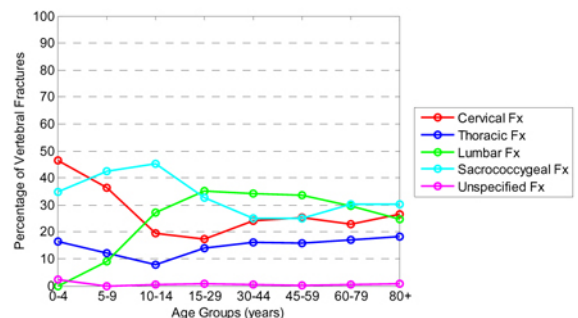


Figure 13. Distribution of vertebral fractures (without spinal cord injury) throughout the spine. (Fx = fracture)

Specified pedestrian chest injuries, not including superficial injuries, were examined using a hybrid category that combined the most frequent chest-related ICD-9-CM diagnosis codes, namely 860 (traumatic pneumothorax and hemothorax), 861 (injury to the heart and lung), and ribcage fractures from 807 (rib and sternum fractures) and 805 (thoracic vertebra fractures). Lung injuries accounted for approximately half of chest injuries up to 14 years of age after which their contribution to chest injuries decreased (Figure 14). Inversely, ribcage fractures accounted for only one in five chest injuries in pediatric patients but increased throughout adolescence and adulthood, ultimately comprising more than 60 percent of chest injuries in the 60-79 and 80+ year-old categories. As a fraction of chest injuries, traumatic pneumothorax and hemothorax gradually declined with age. Heart injuries comprised approximately one percent of chest injuries in most age ranges except in the 10-14 and 60-79-year-old categories where it comprised approximately 2 percent and in the 80+ year-old category where it made up approximately 3 percent.

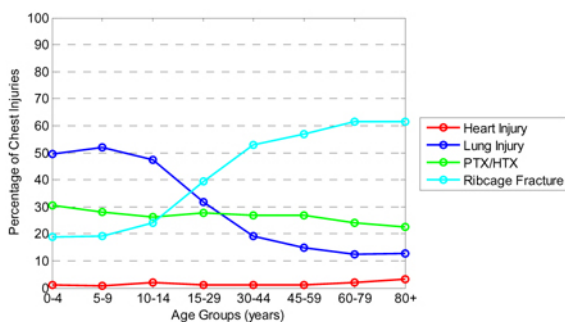


Figure 14. Relative distribution of the commonest chest injuries. (PTX = pneumothorax, HTX = hemothorax)

Pelvis and Lower Extremity

The incidence of pelvis fracture increased monotonically with age (7% in 0-4-year-olds to 19% in those 80 years and older) (Figure 6b). The relative distribution of pelvis fracture types changed across the age categories as well (Figure 15). Fracture of the pubis, the commonest pelvis fracture, constituted almost 60 percent of all pelvis fractures in 5-9-year-olds and over 50 percent in the 80+ year-old category. Sacrococcygeal and acetabular fractures increased proportionally during childhood and adolescence. Other specified pelvis fractures (such as fracture of the ilium and ischium or multiple fractures with disruption of the pelvic ring) were the commonest pelvis fracture in the youngest children (46% of all pelvis fractures in 0-4-year-olds) but the relative prevalence decreased steeply throughout childhood and adolescence.

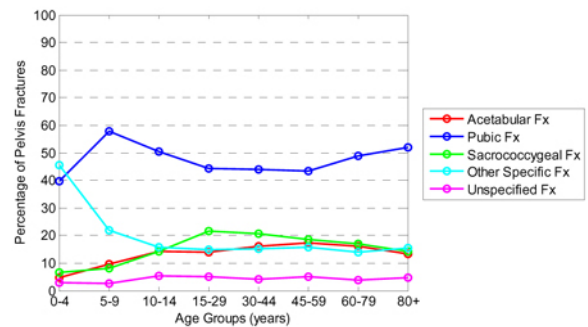


Figure 15. Relative distribution of specific pelvis fractures (fx).

Fracture distribution in the greater hip region was examined as the relative proportions among pelvis fractures (ICD-9-CM code 808 and the sacrococcygeal components of 805), femoral neck fractures (code 820), and femur fractures (code 821) (Figure 16). The proportion of hip region fractures that involved the femoral shaft and distal femur was largest during childhood but subsequently decreased throughout age. Inversely, the proportion made up by pelvis fractures increased throughout most of life. Femoral head fractures accounted for less than 10 percent of fractures in the hip region through the 45-59-year-old category, but the proportion increased during old age to 30 percent in the 80+ year-old category.

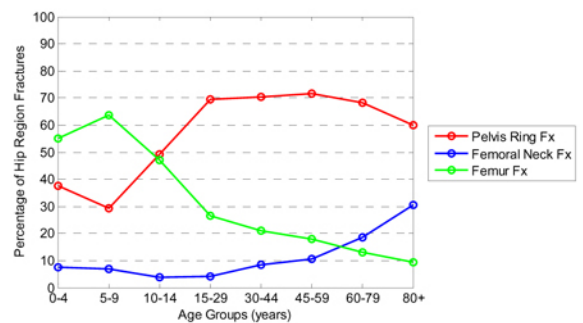


Figure 16. Relative distribution of fractures (fx) in the hip region.

The incidence of tibia and fibula fractures increased four-fold from infancy through adulthood (Figure 6c), and also showed a clear shift in location within the lower leg (Figure 17). In the 0-4-year-old category, tibia/fibula shaft fractures accounted for 65 percent of tibia/fibula fractures. This percentage declined monotonically through all age ranges to 19 percent in the 80+ year-old category. Inversely, fractures of the proximal tibia/fibula accounted for only 10 percent of tibia/fibula fractures in the youngest children but increased monotonically to 68 percent in the oldest pedestrians. Unspecified tibia/fibula fractures were highest in childhood and decreased with age.

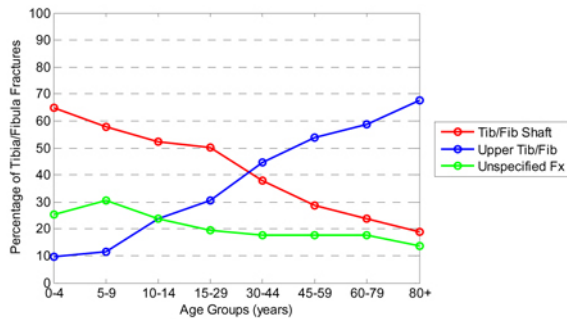


Figure 17. Relative distribution of tibia/fibula (tib/fib) fracture (fx) locations.

Like proximal and shaft fractures of the tibia/fibula (ICD-9-CM code 823), the incidence of ankle fracture (code 824) also increased during childhood ranging from 4 percent of the youngest patients to 11 percent of the patients in the 10-14-year-old category (Figure 6c). Throughout adolescence and adulthood, the incidence of ankle fracture ranged between 9 and 12 percent. The distribution of ankle fracture type also varied throughout life with the proportions being medial, lateral, bi- and tri-malleolar fractures all increasing throughout life (Figure 18). Ankle fractures that did not fit one of these types dominated the ankle fracture category through most age ranges, but was particularly dominant in children. In the 0-4-year-old category, unspecified fractures accounted for 91 percent of all ankle fractures. This proportion declined to 42 percent by the 15-29-year-old category.

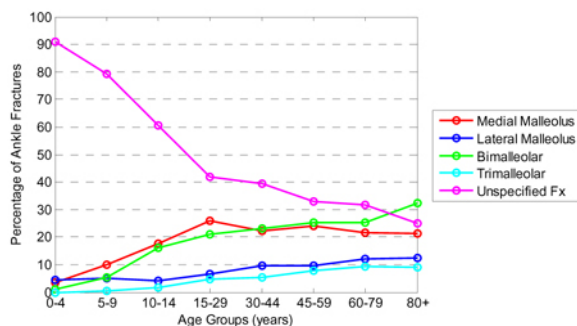


Figure 18. Relative distribution of ankle fractures (fx).

Viewed broadly, the clearest trends in the distribution of pelvis and lower extremity fractures were a lifetime increase in the fraction of pelvis fractures, a lifetime decrease in femur distal and shaft fractures, a relative increase in tibia/fibula fractures before dropping off in older pedestrians, and proportionally increasing fractures of the femoral neck (Figure 19).

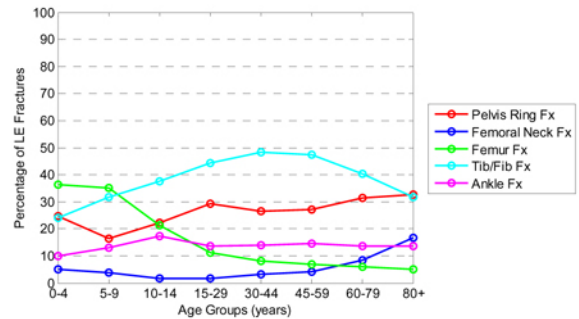


Figure 19. Relative distribution of pelvis and lower extremity fractures. (Fx = fracture, tib/fib = tibia/fibula)

PEDESTRIAN INJURY PATTERNS

The commonest ICD-9-CM codes across the age categories were evaluated to determine the most prevalent co-diagnoses for that code. A co-diagnosis was only shown if at least one age category prevalence was fifteen percent or greater. The percentages represented in Figures 20,21,22,23,24,25 may not add up to 100% because each bar does not represent a breakdown of each injury under consideration; instead, each color that comprises a bar represents the percentage of pedestrians who sustain the injury listed on the y-axis and who are also diagnosed with the injury corresponding to that color.

Head Injury

The percentage of patients diagnosed with a concussion (ICD-9-CM 850) who also were diagnosed with a superficial head injury decreases with age until approximately age thirty, after which the percentage remains relatively constant (Figure 20). The percentage of those with a concussion who had an open head wound increases with age through childhood and remains relatively constant through adulthood. Rib fractures, tibia/fibula fractures, and pelvis fractures are more common in adults with concussion than in children with concussion.

<figure 20 here>

Torso and Upper Extremity Injury

Among patients who sustained vertebral fracture (ICD-9-CM code 805), femur fractures and heart/lung injuries were more common in children than in adults (Figure 21). Over a quarter of patients with a vertebral fracture also sustained pelvis fracture, and this was exhibited across all eight age categories.

<figure 21 here>

Younger patients diagnosed with pneumothorax and/or hemothorax (ICD-9-CM code 860) were more likely to also have heart/lung or liver injury than older patients with pneumothorax and/or hemothorax (Figure 22). Conversely,

there was a higher frequency of rib and vertebral fractures in pneumothorax and/or hemothorax patients aged 30 and older.

<figure 22 here>

Pelvis and Lower Extremity Injury

Children were more likely to have a heart/lung injury associated with a pelvis fracture (ICD-9-CM code 808) than were adults (Figure 23). However, the same group of adults was more likely to sustain vertebral and rib fractures. Femur fractures associated with pelvis fracture decreased with age after age five.

<figure 23 here>

The incidences of tibia/fibula fracture, pelvis fracture, vertebra fracture, and rib fracture were higher in adults than in children who sustained a femur fracture (ICD-9-CM code 821) (Figure 24). There was also a greater prevalence of superficial face injuries in children than in adults with femur fracture. The incidence of pelvis fracture associated with tibia/fibula fractures (ICD-9-CM code 823) increased with age (Figure 25).

<figure 24 here>

<figure 25 here>

DISCUSSION

The current study investigated how injury types, affected body regions, and injury patterns related to a pedestrian crash vary as a function of age. In the broadest terms, two potential age-related factors are at play. First, from birth through adolescence, age is closely correlated with stature. Some investigators have pointed out that stature influences which part of a pedestrian's leg is impacted by a bumper, with children demonstrating a higher relative incidence of femur fracture and adults a higher relative incidence of tibia and fibula fractures [4,11]. Similarly, investigators have pointed out that children, due to their shorter stature, are struck more often directly at the head, thorax, and abdomen than adults, who are more frequently struck at the lower extremity [5,11]. The current study found trends similar to those reported elsewhere supporting stature as a predictor of injury pattern.

In addition to influencing where a pedestrian's body is struck initially, stature will also affect how a pedestrian's body continues to interact with a vehicle after impact. Numerous investigators have proposed a pedestrian-to-vehicle interaction in which the lower extremities are initially struck by the front of the vehicle followed by the pedestrian "wrapping around" the front of the vehicle and striking the head on structures such as the hood, windshield, and A-pillar. Previous NIS-based work found injury patterns in adult pedestrians to support this model [12]. Adding age -and by

corollary stature- allows further examination of how "wrap around" affects injury patterns in parts of the body above the initial impact zone.

A second potential age-related influence on pedestrian injury patterns is changing mechanical characteristics of anatomical structures and mechanical strength of body tissues throughout life. Pediatric bones, for example, are not only more elastic and compliant at a tissue level due to incomplete ossification, but are less rigidly interconnected at the skeletal level. Pediatric fracture patterns are also different from adult fracture patterns due to the presence of epiphyseal zones throughout maturation. In the elderly, degenerative processes contribute not only to embrittlement and loss of bone strength, but also to limited range of joint motion and even joint fusion which decreases the body's flexibility. Similarly, soft tissue properties change mechanically with aging. The current study found several trends in injury patterns that could be attributed to age related biomechanical changes. These effects are discussed below.

HEAD

Similar to the current study, Ivarsson et al. (2006) and Ashton (1979) found that the two most frequently injured body regions in all pediatric age categories were the head and lower extremities (Figure 5) [8,11]. The incidence of skull fracture and intracranial injuries varied between pediatric and adult age categories. The percentage of injury diagnoses that were head injuries was similar between all age categories. However, the prevalence of skull fracture diagnoses decreased with age while the occurrence of an intracranial injury (ICI) increased with age (Figure 7). Children were more likely to sustain a skull fracture than an adult pedestrian. These findings could be explained by the increasing skull and cranial bone stiffness during early childhood. Epidural hemorrhages (EDHs) are closely associated with skull fracture while subdural hemorrhages (SDH) and subarachnoid hemorrhages (SAH) could also result from rapid acceleration of the head [13-14]. Because the type of intracranial hemorrhage (SAH, SDH, or EDH) is not specified in the ICD-9-CM skull fracture diagnosis codes, the mechanism of the intracranial hemorrhage (ICH) is difficult to determine. The impact severity and orientation of the crash are unknown in these cases and therefore are confounding variables in the analysis of these data.

Among the skull and facial fracture diagnoses, the location of fracture changed for the various age categories (Figure 9). The skull base was the commonest location in the younger children while the face was the commonest fracture location in the adults. Vault fractures were the least common type of skull/facial fracture in older children and adults. The anthropometry of the head changes from infancy to adulthood. The facial portion of the head relative to the cranium is approximately 1-to-8 and the face becomes larger

compared to the cranium with age [16]. A possible explanation for the decreased incidence of facial fractures in the younger children is the smaller face proportion relative to the whole head.

Demetriades et al. (2004) reported that the incidence of severe head injury increased with age (7%–24%) in the fatal pedestrian crashes [6]. Kong et al. (1996) also showed a slightly lower incidence of head injury among the pediatric pedestrian casualties (32% vs. adult = 34% and elderly = 40%) [4]. In contrast, Derlet et al. (1989) reported that pediatric patients (≤ 15 years) had a higher incidence of head injury than the fatally injured adult pedestrians (57% vs. 48%) [3]. Similar to the results of Derlet et al., the current study of inpatient admissions shows a lower incidence of head injury (14% vs. 11%) and head/face/neck injury (36% v. 28%) in the pediatric population (0-14 yo) [3]. Demetriades et al. (2004) also showed that the incidence of SDH (1.1-8.1%), SAH (2.6-11.8%), and brain contusion (4.1-9.8%) increased with age in injured pedestrians while the incidence of EDH (0.5-1.1%) did not [6]. The latter finding supports the theory that EDH is infrequent in elderly head injury patients due to the firm attachment between the dura and skull in the elderly population [6]. With ICD-9-CM codes, ICH and brain contusions/lacerations can be examined, however, SDH, EDH, and brain contusions cannot be analyzed separately. Similar to the findings reported by Demetriades et al., the incidence of ICH and brain contusions/lacerations increased with age until adulthood (Figure 7) [6].

Ivarsson et al. (2006) found that frequency of casualties with at least one AIS 2+ and AIS3+ head injury was roughly 50% and 15%, respectively, in the 4-15-year-old age category and 60% and 19%, respectively, in the 1-3-year-old category [11]. In NIS, the percentage of pediatric pedestrians (0-15 years old) with skull fracture or intracranial injury did not increase or decrease with age (approximately 32% across the 0-4, 5-9, and 10-14-year-old age categories). Peng and Bongard (1999) found that intracranial injuries were the commonest non-external injury among the pediatric, adult, and elderly casualties (49, 29, and 33% respectively) [5]. The commonest non-external injury in the current NIS data was fracture to the tibia and/or fibula. The number of pedestrians with intracranial injuries increased with age and only accounted for 2-6% of the diagnoses.

CHEST AND SPINE

Previous investigators have reported that the incidence of pedestrian chest injury increases with age. Derlet et al. found that fewer pediatric (<15 years old) than adult pedestrian patients had chest injuries (8% vs. 23%) [3]. Kong et al. found a higher incidence of chest injury in elderly (19%) than in pediatric (3%) or adult (7%) pedestrian casualties [4]. Demetriades et al. found severe chest injuries (AIS > 3) in

only 0.6 percent of pediatric patients but in greater numbers for adult and elderly patients (2.7% for ages 15-55, 4.3% for ages 56-65, and 8.8% over age 65) [6]. The current study identified similar broad trends, but also found variability within these broad age categories by subdividing them into eight smaller age ranges. If adults were averaged into a large category from 15-59 years old, they had a lower fraction of chest injuries (7.7%) than the elderly (8.3% for 60+). Averaged over a broader age range (0-14), chest injuries accounted for 6.7% of the injuries in pediatric patients.

ICD-9-CM diagnoses for the commonest types of internal chest trauma among pedestrians actually decreased with age. Heart and lung injuries (ICD-9-CM code 861), for example, affected 13 percent of 0-4 year-old pedestrians but the proportion decreased monotonically throughout age to 4 percent of those 80 and older (Figure 6b). The incidence of other chest injuries, such as ribcage fracture (code 807) and traumatic pneumo/hemothorax (code 860) decreased with age during childhood, then increased through adulthood, and then decreased again in the elderly (Figure 6b and Table A2). Specific injuries within the chest region also showed clear changes in their distribution with age. Ribcage fractures increased threefold as a fraction of all chest injuries over lifespan while lung injury decreased more than fourfold as a percentage of all chest injuries from the youngest children to the elderly (Figure 14). Pneumo- and hemothorax, which can be linked causally to lung injury or rib fracture, showed only a slight decrease over age. Not surprisingly, on a patient-by-patient basis, pneumo- and/or hemothorax was more frequently co-diagnosed with lung injury in children and adolescents but was co-diagnosed with ribcage fractures more frequently in adult and elderly pedestrians. These results suggest that chest trauma to younger pedestrians more frequently injures the lungs without fracturing the more compliant pediatric ribcage, while the more fragile elderly ribcage fractures more readily absent lung injury. Demetriades et al. similarly attributed the relatively high incidence of hemopneumothorax in their oldest pedestrian category (> 65 years) to rib cage fragility.

The current study found that vertebral fractures increased from childhood into adulthood but decreased again among the elderly (Figure 6b). This differed from the finding of Demetriades et al. (2004) who reported that the incidence of spinal injury increased monotonically with age (0.4-8.5%) [6]. This may be the result of different category definitions between spinal injury in the study by Demetriades et al. and vertebral fracture (ICD-9-CM code 805) in the current study [6]. Code 805 is also limited to vertebral fracture without spinal cord injury, but as previously reported by Heller et al., 2009, hospitalized pedestrians with vertebral fractures but no spinal cord injury (code 805) outnumbered pedestrians with vertebral fracture and spinal cord injury (code 806) nearly 20-to-1 [12]. Therefore, this factor does not explain the differences between the current study and Demetriades et al.