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Injury patterns among pedestrians using assistive mobility devices

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ABSTRACT

Introduction: As the population ages, growing numbers of individuals are turning to assisted mobility devices (AMDs) to maintain independence. These devices often place users in a seated position. Like ambulatory pedestrians, pedestrians seated in an AMD are at risk for involvement in an automobile versus pedestrian crash. The purpose of this study is to compare the injury pattern and comorbidities of standing pedestrians struck by an automobile versus those of seated pedestrians.

Methods: The Arizona State Trauma Registry was queried for pedestrians struck by an automobile between 2010 and 2015. Using ICD 9 and 10 codes as well as other available documentation, seated pedestrians were identified and matched based on age and gender to standing pedestrians. Presence of co-morbidities, injury pattern, Injury Severity Score (ISS), hospital length of stay (LOS), and mortality were compared between the two groups.

Results: There were 70 seated pedestrians identified, matched to 140 standing pedestrians. Co-morbidities were present in 89% of seated pedestrians vs 66% of standing pedestrians ($p = 0.002$). Functional dependence was more prevalent in the seated pedestrians (21% vs 1%, $p = 0.004$). There were not significant differences in the proportion of AIS injuries by body region. However, within the thoracic region, seated pedestrians were more likely to suffer pulmonary contusions: 14% vs 4%, $p = 0.05$.

Conclusions: The injury pattern for seated pedestrians differs slightly from that of standing pedestrians struck by an automobile. However, seated pedestrians are more likely to have co-morbid conditions that may complicate care. These findings are important when caring for the injured pedestrian and performing injury prevention outreach.

Introduction

Pedestrians struck by light motor vehicles, hereafter referred to as automobiles, represent a large and diverse segment of the trauma patient population. The kinematics of these collisions have been previously described as a fulcrum effect, whereby the automobile strikes the pedestrian in the lower extremities, causing the lower portion of the body to move at the same rate of speed as the automobile while the stationary upper body rotates downward, striking the hood and windshield of the car [1] (Fig. 1). Conventional wisdom holds that this results in a relatively predictable and lethal injury pattern known as the fatal triad [2]. This includes high likelihood of lower extremity injuries at the level of the automobile's bumper, followed by pelvis and head injuries as the patient's body strikes the hood and windshield of the automobile due to the fulcrum effect [2,3]. An additional injury pattern known as the ipsilateral dyad has also been described, consisting of lower extremity fractures with either an upper extremity fracture or a pelvic fracture, and has also been associated with increased risk of mortality in the pedestrian trauma patient [4,5].

Lower extremity injuries may be observed in greater than 80% of pedestrians struck by an automobile, while injuries to the torso and head are observed in approximately 30% and 40% respectively of those same individuals [6]. However, this injury pattern assumes a standing pedestrian and a standard size passenger car. Light trucks and sport utility vehicles (SUVs), with their higher bumpers, change the point of impact and therefore the injury distribution. Patients struck by light trucks and SUVs have a relatively higher frequency of torso injuries and fewer extremity injuries [7].

Just as the height of the bumper may influence injury pattern, patient position would be expected to change the characteristics of injuries in pedestrians struck by an automobile. As a significant portion of the population continues to age, we have witnessed both an increased prevalence of elderly patients being treated in trauma centers and a shift towards mechanisms of injury associated with the elderly, such as ground-level falls [8]. According to the 2016 American Community Survey 5 year estimates, 7.1% of the Arizona

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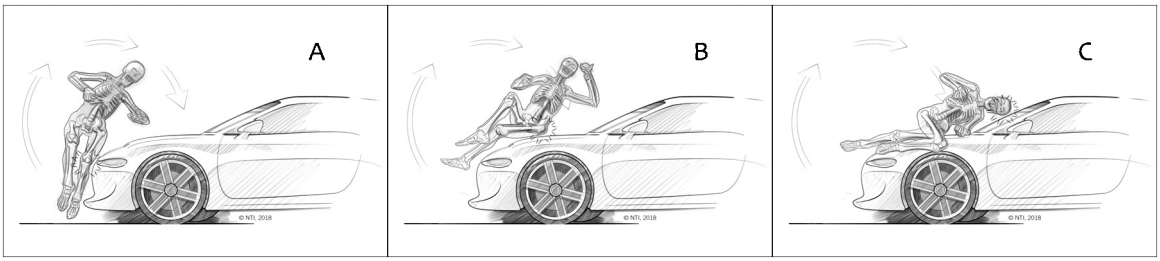

Fig. 1. The fulcrum effect resulting in lower extremity injury (A), pelvis injury (B), and head injury (C).

population is has an ambulatory disability; in line with the national United States rate of 7% [9]. To maintain mobility and independence, many individuals are opting for motorized scooters or wheelchairs; collectively known as assisted mobility devices (AMD). AMDs are not legal for street use as they are designed for use on sidewalks and other pedestrian areas. Like any other pedestrian, those using an AMD are at risk for injury due to an automobile collision. However, due to their seated position, the traditional understanding of pedestrian versus automobile kinematics may not apply. The purpose of this study is to describe the injury pattern of patients struck by automobiles while using AMDs in a seated position, as compared to standing pedestrians struck by automobiles.

Methods

After ethical approval by our institutional review board and the Arizona Department of Health Services Human Subjects Review Board, the Arizona State Trauma Registry was queried for pedestrians struck by automobiles from 2010 to 2015 using ICD-9 and ICD-10 codes [10]. As ICD-9 coding does not differentiate between ambulating pedestrians and those using a wheelchair or motorized scooter, the narrative section of the registry was reviewed by an experienced injury epidemiologist (PMG) for each patient. During scheduled research meetings, the other members of the research team evaluated random samples of the narrative section to confirm inter-rater reliability. No disagreements were found. Patients were stratified according to whether they were in a standing position (controls) or seated position (cases) when the collision occurred, as described in the narrative section of the data set. Patients were excluded if we were unable to determine patient position at the time of the collision, if they were riding a street legal moped-like device rather than an AMD, or if they died before transport to the hospital. Cases were matched by age and gender with controls in a 1:2 ratio. All data were provided in chronological order by the Arizona State Trauma Registry and once a seated pedestrian was identified, the next two standing pedestrians with an exact age and gender match to the case were selected as controls. Matching was done without replacement. The primary outcome was the rate of injury to body regions as defined by the Abbreviated Injury Scale (AIS) [11]. Secondary outcomes included Injury Severity Score (ISS), incidence of previously described injury patterns (ipsilateral dyad and lethal triad), hospital length of stay (LOS), intensive care unit (ICU) LOS, and mortality.

Analyses were performed with SPSS v. 24 (IBM SPSS Statistics for Windows, version 24 (IBM Corp., Armonk, N.Y., USA). Cochran-Mantel-Haenszel tests were used to analyze group (seated or unseated) by nominal variables with each matched triplet accounting for level. Pearson chi-square tests were used for other nominal by nominal associations that did not contain the grouping variable. Hospital and ICU length of stay variables were compared using paired samples t-tests. These tests compared the average of the two controls for the unseated group from each triplet to the seated case. Means are reported with standard deviations as M (SD). Statistical significance was defined as $p \leq 0.05$.

Results

Six thousand two hundred and ninety-seven patients from the Arizona State Trauma Registry were reviewed. Seventy pedestrians in a seated position struck by an automobile were identified. These cases were matched by age and gender to 140 standing pedestrians struck by an automobile. All but two seated pedestrians were matched with two standing pedestrians of the exact age and gender. For two seated pedestrians over 85 years old, the age match criteria were expanded to within one year of the seated pedestrian's age to find a match. Of the 70 seated pedestrians, 66% were male and the average age was 58 (18) years, ranging from 17 to 97. When each comorbidity was analyzed separately, differences between groups did not emerge, however, when dichotomized for the presence of 1 or more comorbidities, seated pedestrians were more likely to have medical co-morbidities than the standing pedestrians: 89% vs 66%, p = .002 (Table 1). Seated pedestrians were also more likely to be functionally dependent; 21% vs. 1%, p = 0.004.

Twenty-five (36%) of the seated pedestrians required ICU admission versus 60 (43%) of the standing pedestrians, p = 0.3. There was not a significant difference in the mean ICU LOS between the seated and standing pedestrians, 2.6 (5.2) versus 2.9 (4.2) days, p = 0.7, respectively. Nor was there a significant difference in mean hospital LOS, 5.3 (7.3) versus 5.1 (5.6) days, p = 0.8. For all patients, the presence of a co-morbidity was associated with an increased hospital LOS 5.9 (8.5) vs 3.2 (3.8) days, p = 0.002 but not ICU LOS 2.4 (4.7) vs 1.4 (2.8) days, p = 0.06.

For the anatomic regions of head, abdomen/pelvis, thorax, lower extremity and upper extremity, there was no difference between the two groups regarding the frequency of injury (Table 2). Due to the multiple injuries that can be included into a single AIS body region, individual injuries thought to be most likely for each position based on kinematics were also evaluated. Tibial fractures were chosen because of the difference in weight bearing status at the time of collision between the two groups. Chest wall,

Table 1
Comorbid conditions present at the time of admission.

	Seated N = 70 (100%)	Standing N = 140 (100%)	P-value
Any comorbidity	62 (89)	93 (66)	0.002
Anticoagulated	5 (7)	2 (1)	0.5
Diabetes	19 (27)	17 (12)	0.01
CVA	5 (7)	1 (1)	0.2
Functional Dependence	15 (21)	2 (1)	0.004
Hypertension	27 (39)	46 (33)	0.7
Smoker	8 (13)	23 (16)	0.8
Cirrhosis	6 (9)	18 (13)	0.5
Congestive Heart Failure	4 (6)	1 (1)	0.1
Dialysis	3 (4)	0 (0)	0.5

Table 2
Frequency of injury observed in each AIS region.

	Seated N = 70 (100%)	Standing N = 140 (100%)	P-value
Head	25 (36)	70 (50)	0.2
Abdomen/Pelvis	19 (27)	30 (21)	0.4
Thorax	24 (34)	48 (34)	1
Lower Extremity	42 (60)	90 (64)	0.8
Upper Extremity	31 (44)	60 (43)	0.5

pulmonary, pelvic, and femur injuries were chosen because of the difference in position between the two groups at the time of impact. There was no difference in the rate of pelvic, femur, or tibial fractures between the two groups (Table 3). Both groups were similarly likely to suffer multiple rib fractures; however, the seated pedestrians were more likely to have associated pulmonary contusions (14% vs 4%, p = 0.05) (Table 3).

The lethal triad and ipsilateral dyad injury patterns were observed with similar frequency in both groups. Two lethal triad patterns were observed in the seated group and two were observed in the standing group (3% vs. 1%, p = 0.5). The ipsilateral dyad was identified in 13 (19%) of the seated pedestrians and in 25 (18%) of the standing pedestrians; p = 0.8. There was no difference between the group means ISS: 12.0 (14.0) for the seated group and 14.6 (10.8) for the standing group (p = 0.2). Mortality between the two groups was not significantly different: 13% in the seated group and 16% in the standing group (p = 0.5).

Discussion

We sought to investigate the difference in injury pattern for pedestrians struck by an automobile while in the seated position versus those in the standing position. The two groups were matched by age and gender. Patients in the seated position were more likely to have a reported comorbidity. This is to be expected, given the need for an AMD. However, there was no difference in the rate at which AIS regions were injured.

The seated group was just as likely to suffer tibial and femur fractures as the standing group. The tibia is in the same position and the knee at roughly the same height for both seated and standing pedestrians. In the seated position, the pelvis is at the level of most automobile bumpers, and in the standing position, the fulcrum effect may explain the prevalence of pelvic fractures. While the kinematics may be different, it appears that these structures are injured at the same rate regardless of the position of the pedestrian before being struck. It is possible that the specific types of tibial, femur, and pelvic fractures are different between the two groups, however our study was not designed to detect this level of detail.

Multiple rib fractures are a significant source of morbidity and mortality in elderly patients [12,13]. Rib fractures associated with underlying pulmonary contusion constitute an even more severe injury that is difficult to manage [14,15]. In our data, despite no difference in the rate of multiple rib fractures between the two groups, the seated pedestrians were more likely to have pulmonary contusions. A possible explanation could be different levels of energy transfer between a direct impact to the chest in the seated group and a rotational impact to the chest in the standing group.

Table 3
Analysis of specific injuries thought to be most related to patient position.

	Seated N = 70 (100%)	Standing N = 140 (100%)	P-value
Multiple Rib Fractures	10 (14)	19 (14)	0.9
Pulmonary Contusion	10 (14)	6 (4)	0.05
Pelvis Fracture	16 (23)	23 (17)	0.2
Femur Fracture	4 (6)	14 (10)	0.4
Tibial Fracture	9 (13)	28 (20)	0.6

The lethal triad and ipsilateral dyad were found in both groups at similar rates. Our study found the rate of lethal triad to be 3% and 1% in the seated and standing groups respectively. For the ipsilateral dyad the rates were 19% and 18%. Brainard et al. found the lethal triad in 9% of pedestrians struck by automobiles and the ipsilateral dyad in 33% [4]. Since Brainard's paper was published the proportion of automobiles on the road that fall into the light truck or SUV category has risen. Perhaps the relatively higher bumpers and hoods on these automobiles change the kinematics of pedestrian versus automobile collisions enough that the fulcrum effect is lost or significantly altered. This would explain the lack of difference between the two groups in our study as well as the large difference between our study and the Brainard study. Data differentiating light truck, SUV, or passenger car involvement in these collisions were not available and is a limitation of this study.

A strength of the present study is the utilization of the Arizona Department of Health Services state-wide trauma patient registry, allowing us to describe the epidemiology of seated pedestrian injuries at a state level, rather than relying on single-institution experience. Nonetheless, using a statewide database precludes the ability to obtain detailed patient data from direct review of hospital records. An additional limitation is the difficulty in identifying cases of interest in the state registry. As described above, there is no ICD-9 code specific to the seated pedestrian, and it is possible that we were unable to identify all seated pedestrian injuries contained in the database. Patients who die prior to transport to the hospital are not included in the Arizona Trauma Registry, therefore, we may have missed differences in highly lethal injury patterns. Lastly, knowing that the height of the bumper can change the injury pattern, our inability to determine the exact make of each automobile (passenger car, SUV, or light truck) involved in each collision is a major limitation.

Conclusions

As a significant proportion of our population continues to age into the eighth and ninth decades of life we can expect to see increased use of AMDs. Pedestrians in a seated position represent a unique patient population with its own set of challenges, including different injury patterns, co-morbidities, and frailty. From the prevention standpoint, pedestrians with a lower profile present unique visibility challenges. Additional studies are needed to further describe specific injury patterns and outcomes for seated pedestrians.

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Conflict of interest statement

Authors Jeffery P Salomone, Pamela W Goslar, and Jordan A Weinberg have no conflicts of interest to report.

James N Bogert has two potential conflicts of interest to report.

1 Consultant to Acute Innovations: Medical device manufacturer for surgical treatment of rib fractures.
2 Speakers Bureau for Prytime Medical: Medical device manufacturer of the ER-REBOA device used for endovascular occlusion of the aorta as a method of hemostasis in trauma.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.injury.2018.10.025.

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