ORIGINAL ARTICLE

Examining the Effect of Pedestrian Crashes on Vulnerable Populations in North Carolina

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BACKGROUND Over the last several years, pedestrian fatalities have increased in North Carolina; however, fatalities represent a small proportion of the total number of nonfatally injured pedestrians. Therefore, we linked statewide motor vehicle crash (MVC) and emergency department (ED) visit data to better understand the circumstances and characteristics of pedestrians treated in North Carolina emergency departments (EDs) for injuries related to crashes.

METHODS We linked information for pedestrians and bicyclists from 2017 North Carolina police-reported MVCs to population-based ED visit data using hierarchical deterministic methods.

RESULTS We linked 45% of pedestrian crash records to ED visit records (N = 1383 incident ED visits). The rate of pedestrians treated in North Carolina EDs for their injuries was 13.6 ED visits per 100,000 person years. For pedestrian injuries treated in North Carolina EDs, rates (per 100,000 person years in parentheses) were higher among men (15.5) and Black pedestrians (22.7) than women (10.6) and White pedestrians (8.2). Sociodemographic characteristics associated with serious injuries included age, sex, race/ethnicity, and expected source of payment for the ED visit. Crash characteristics associated with serious injuries included posted speed limit, ambient light, number of lanes, and striking vehicle type.

LIMITATIONS The study involved the use of secondary data, not collected specifically for pedestrian injury surveillance.

CONCLUSIONS Pedestrian injuries and fatalities place a considerable burden on the population of North Carolina, especially among persons of color and older adults. Injury prevention programs are actively addressing this problem, but more needs to be done.

The health benefits of walking as a method of transportation include combatting the obesity epidemic by increasing physical activity [1] and reducing motorized transportation's contribution to air pollution [2]. In addition, walking provides an essential form of transportation for the estimated 9% of US households without access to a personal vehicle [3]. However, in the setting of non-pedestrian-centered transportation infrastructure, common in the United States, pedestrians are vulnerable road users who are more susceptible to injury and death in motor vehicle crashes. In 2018, 6283 pedestrians were killed in traffic crashes in the United States, the highest number since 1990 [4]. In 2018, there were 225 pedestrian fatalities in North Carolina, representing a 31% increase since 2014 [5].

Methods

This study was approved by the University of North Carolina at Chapel Hill Institutional Review Board.

Data Sources and Study Population

In order to understand the circumstances, patient characteristics, and health outcomes of pedestrians injured in police-reported motor vehicle crashes in North Carolina, we linked motor vehicle crash and North Carolina Disease Event Tracking and Epidemiologic Collection Tool (NC DETECT) NC DETECT emergency department (ED) visit data.

The University of North Carolina Highway Safety Research Center (UNC HSRC) provided records for all pedestrians involved in North Carolina police-reported traffic crashes for the year 2017. UNC HSRC maintains a copy of the crash report data from the North Carolina Division of Motor Vehicles' (excluding the names of the individuals involved). The UNC HSRC crash data file only contains information for traffic crashes reported to police and that involve fatalities, injuries, total property damage greater than or equal to $1,000, or result in a vehicle being seized [6]. UNC HSRC identified pedestrian crash records as records with a Unit Type listed as a "Pedestrian," a Person Type listed as "3-Pedestrian," or a Vehicle Type listed as "24-Pedestrian."

The North Carolina Division of Public Health (NCDPH) provided ED visit records for all patients treated for injuries in 2017. These records are collected by NC DETECT, North Carolina's legislatively mandated statewide syndromic surveillance system [7]. NC DETECT includes ED visit records from all 24/7 acute-care hospital-affiliated civilian emergency departments in North Carolina. Patient ED visit records were identified as injury-related if the ICD-10-CM code started with an "S," "T," "V," "W," "X," or "Y."

Measures

From the UNC HSRC crash data, we examined race/Hispanic ethnicity (crash data do not disaggregate the 2 characteristics), North Carolina county of crash, hour of

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crash, posted speed limit, number of lanes, ambient light at time of crash, and striking vehicle type. We also examined North Carolina Association of Local Health Directors (NCALHD) region [8], poverty level, [9] and urbanicity [10] classified by county of crash.

From the NC DETECT ED visit data, we examined sex, age, mode of transport to the ED, and expected source of payment for services rendered in the ED. We classified injury severity by adapting a definition developed by the National Transportation Safety Board [11]. We defined an injury as "serious" if it resulted in a hospital admission, death, and/or a diagnosis of a fracture (except fractures of fingers, toes, or nose); amputation; injury to the blood vessels, nerves, muscles, and tendons (except injuries to fingers and toes); a crushing injury (except injuries to fingers and toes); an injury to the internal organs; a burn (except first degree burns and burns to fingers and toes); an air/fat embolism; traumatic shock; and/or traumatic compartment syndrome.

Data Linkage and Analyses

We linked UNC HSRC crash and NC DETECT ED visit data using hierarchical deterministic methods. Records were excluded from linkage if they met one or more of the following criteria: the ED visit occurred before the crash; the ED visit occurred more than 14 days after the crash; the ED visit had a discharge disposition of "transferred" (to minimize one-to-many matches); the ED visit or crash record was missing date of birth *and* age; or the ED visit or crash record was missing 5-digit ZIP code of residence. Personal identifiers (sex, age, date of birth, 5-digit ZIP code of residence), pedestrian ICD-10-CM injury mechanism codes [12], and pedestrian chief complaint keywords were used as part of the linkage methodology. For the first round of linkage, we linked records based on patient date of birth and 5-digit ZIP code of residence (exact match required). The ED visit date and time also had to occur after the crash date and time but within 336 hours. The second round of linkage used age but linked records only that had matching sex and a pedestrian/bicycle crash injury ICD-10-CM injury mechanism code and/or a pedestrian/bicycle crash injury keyword located in the chief complaint. After linkage was complete, sensitive data elements (e.g., patient date of birth, ZIP code of residence) were removed from the analytic dataset, per the terms of the data use agreement with the NCDPH. For a comprehensive discussion of the methodology used, see the "North Carolina Linkage Study for Motor Vehicle Crashes Involving Pedestrians and Bicyclists: Police Crash Report Data & NC DETECT Emergency Department Visit Data" [13].

We calculated unadjusted population-based pedestrian injury-related ED visit rates by NCLHD Regions and 10-year age groups, stratified by sex (male and female) and race (White and Black). The National Center for Health Statistics' 2017 mid-year Bridged-Race Population Estimates were used for the denominator [14]. For counts and rates by NCLHD region, we classified regions into 4 levels based on the natural "breaks" or "jenks" inherent in the data [15].

In addition to ED visit rates, we also examined patient and crash characteristics, stratified by injury severity. For categorical variables, we reported counts and percentages and for continuous variables, we reported medians and interquartile ranges. For statistical comparisons, we used Wald chi-square and Wilcoxon tests for categorical and continuous variables, respectively. Significance was assessed at an alpha value of 0.05. Statistical analyses for this study were performed using SAS version 9.4 (SAS Institute, Cary, North Carolina) and ArcMap version 10.5 (ESRI, Redlands, California).

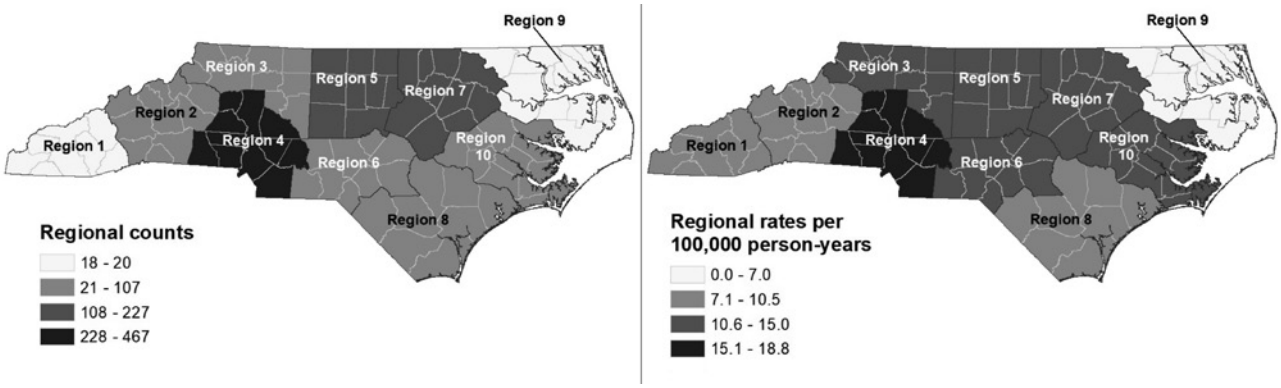
Results

While the median age of patients with non-serious injury was 33 (interquartile range [IQR]: 21-51), the median age for patients with serious injuries was higher at 43 (IQR: 25-58) (P = .009). We linked 45% of pedestrian crash records to ED visit records (N = 1383 incident ED visits). In 2017, the population-based ED visit rate for pedestrians injured in police-reported motor vehicle crashes (MVCs) was 13.6 ED visits per 100,000 person years. The number and rate of pedestrian injury-related ED visits was not uniform across the state, however (Figure 1). The NCLHD Region with the highest pedestrian injury count (n = 467) and ED visit rate (18.8 ED visits per 100,000 person years) was Region 4. Region 4 contains Mecklenburg County and is also the most populous region in the state. NCLHD Region 9 had the lowest pedestrian injury count (n = 18) and rate (7.0 ED visits per 100,000 person years). Region 9, located in the northeastern sector of North Carolina, is one of the least populous regions in the state.

In 2017, there were 773 male and 559 female pedestrians injured in police-reported MVCs. Figure 2 displays male and female pedestrian injury-related ED visit counts and rates. Males (15.5 ED visits per 100,000 person years) had 1.5 times the pedestrian injury-related ED visit rate of females (10.6 ED visits per 100,000 person years). Among males, 2 peaks were observed: one in young adulthood and one in early middle-age. Among females, this second peak was not observed.

Figure 3 displays ED visit counts and rates of White and Black pedestrians injured in police-reported MVCs in North Carolina. In 2017, ED visit counts were slightly higher among White pedestrians (n = 603), as compared to Black pedestrians (n = 537). However, Black pedestrians (22.7 ED visits per 100,000 person years) had nearly 3 times the ED visit rate of White pedestrians (8.2 ED visits per 100,000 person years). For some age groups, this difference was even more pronounced. For example, Black children aged 0-9 years had nearly 5 times the pedestrian injury-related ED visit rate of White children in the same age group. The only age group for which the White pedestrian injury-related ED visit rate exceeded Black pedestrians was for adults aged 80 years and older.

FIGURE 1.
North Carolina Emergency Department Visit Counts and Rates (per 100,000 person years) of Pedestrians Injured in Police-Reported Motor Vehicle Crashes, by Region: 2017[a-c]



[a]North Carolina regions classified according to categories developed by the NC Association of Local Health Directors [8].
[b]Pedestrian injuries classified according to county of crash.
[c]Map cut points based on natural breaks ("jenks" algorithm) produced in ArcMap.

Table 1 displays patient characteristics stratified by pedestrian injury severity. In 2017, 37% of pedestrians treated in North Carolina EDs involved in police-reported MVCs were seriously injured (n = 515). Among patients with serious injuries, a greater proportion were White, arrived via ambulance, and had an expected source of payment of Medicaid and Medicare. Thirty-six percent of all North Carolina pedestrians with serious injuries in the ED had an expected source of payment of Medicaid or Medicare in 2017, as compared to 28% of pedestrians with non-serious injuries.

Table 2 displays the crash characteristics of pedestrians involved in police-reported MVCs treated at North Carolina EDs. As compared to pedestrians with non-serious injuries, a greater proportion of pedestrians with serious injuries were injured in counties with higher levels of poverty. With most pedestrians injured in urban counties, there was little difference in county urbanicity, regardless of injury severity status. A higher proportion of pedestrians with serious injuries were injured late at night and under dark, unlighted conditions, as compared to pedestrians with non-serious injuries. In terms of roadway characteristics, pedestrians with serious injuries were overrepresented on 4- and 5-lane roads and roads with posted speed limits of 45 miles per hour and higher. Pedestrians with serious injuries were also more likely to be struck by a truck as compared to their less severely injured counterparts.

Discussion

Our results indicate that higher rates of pedestrian crashes and increased injury severity are associated with male sex, race/ethnicity, and socioeconomic status (SES). Study findings also indicate that aging populations are more susceptible to severe pedestrian crash injuries.

We determined that Black pedestrians, among both adult and pediatric populations, had higher rates of crash-related ED visits as compared to their White counterparts. These findings are consistent with other studies examining racial

FIGURE 2.
North Carolina Emergency Department Visit Counts and Rates (per 100,000 person years) of Pedestrians Injured in Police-Reported Motor Vehicle Crashes, by Sex and Age Group: 2017

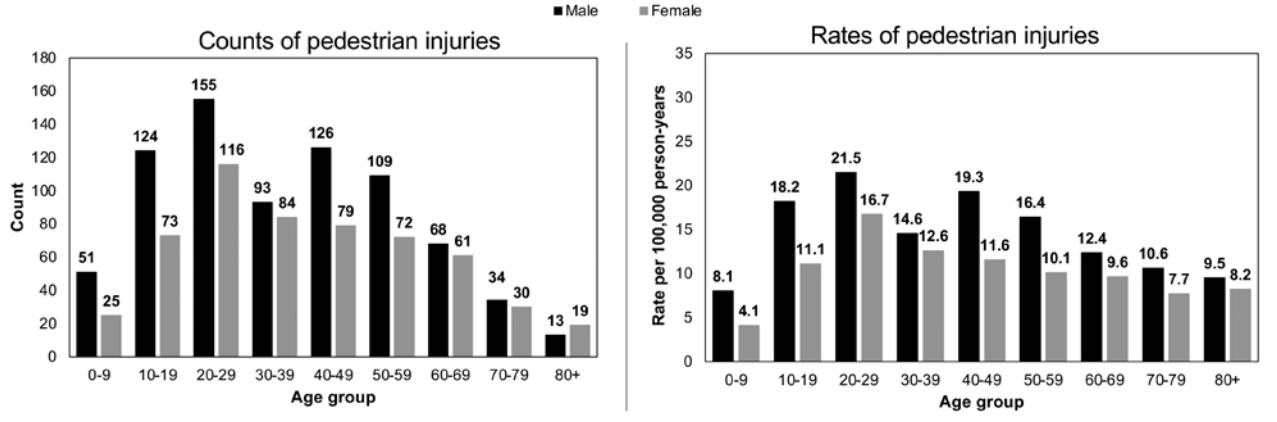
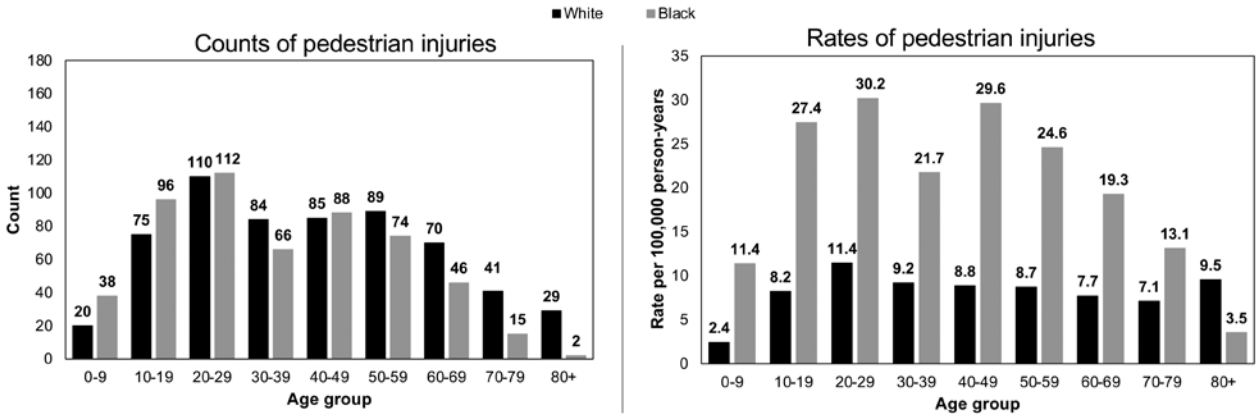


FIGURE 3.
North Carolina Emergency Department Visit Counts and Rates (per 100,000 person years) of Pedestrians Injured in Police-Reported Motor Vehicle Crashes, by Black/White Race and Age Group: 2017



disparities in pedestrian health outcomes [16]. For example, in a data review of the United States National Trauma Bank, Maybury and coauthors [17] determined that Black Americans had 22% greater odds of mortality and Hispanic/Latino Americans had 33% greater odds of mortality related to pedestrian injuries as compared to their White counterparts. Additionally, in a study analyzing pedestrian outcomes in Austin, Texas, researchers determined that predominately White neighborhoods, as compared to predominately Hispanic/Latino neighborhoods, generated more walking trips and had fewer pedestrian injuries [18], highlighting the influence of both racial and economic factors on disparities in pedestrian safety. Our findings relating to racial disparities among pediatric pedestrian populations are also consistent with previous studies examining racial disparities in pediatric pedestrian injury outcomes. When considering all causes of intentional and unintentional injury among children aged 0-4, mortality ratios are higher in Black and American Indian/Alaskan Native pediatric populations as compared to Whites [19]. In a national study, researchers also determined that child injury outcomes are worse for minority children, with Black/African American status being an independent predictor for mortality [20]. Socioeconomic status is also a predictor for pediatric pedestrian injury [20], reinforcing our earlier observations regarding the relationship between poverty and pedestrian safety outcomes.

TABLE 1.
Patient Characteristics of Pedestrians Injured in Police-Reported Motor Vehicle Crashes Treated at North Carolina Emergency Departments, Stratified by Injury Severity: 2017[a]

Patient characteristic[b]	Serious injury n = 515	Non-serious injury n = 868	*P* value
Sex, n (%)			.027
Male	310 (61.9)	463 (55.7)	
Female	191 (38.1)	368 (44.3)	
Race/Hispanic ethnicity,[b] n (%)			.002
White	261 (52.5)	342 (42.1)	
Black/African American	172 (34.6)	365 (45.0)	
Hispanic	37 (7.4)	64 (7.9)	
Other race	27 (5.4)	41 (5.0)	
Mode of transport, n (%)			<.001
Ambulance	402 (86.8)	541 (67.9)	
Other mode[c]	61 (13.2)	256 (32.1)	
Expected source of payment, n (%)			.026
Private insurance company	120 (25.3)	222 (25.6)	
Uninsured	92 (19.4)	172 (19.8)	
Medicaid	104 (21.9)	153 (17.6)	
Medicare	67 (14.1)	73 (8.4)	
Other type of payment[d]	92 (19.4)	184 (21.2)	

Note. Missing: sex, n = 66; race/ethnicity, n = 89; mode of transport, n = 138; expected source of payment, n = 119.
[a]Injury severity definition adapted from National Transportation Safety Board [11].
[b]Race and Hispanic ethnicity are not disaggregated in the North Carolina crash data.
[c]Other mode consists of walk-ins and other modes of transport to the emergency department.
[d]Other expected source of payment consists of workers' compensation, other type of governmental payment, and other type of payment.

TABLE 2.
Crash Characteristics of Pedestrians Injured in Police-Reported Motor Vehicle Crashes Treated at North Carolina Emergency Departments, Stratified by Injury Severity: 2017[a]

Crash characteristic	Serious injury n = 515	Non-serious injury n = 868	*P* value
County of crash urbanicity,[b] n (%)			.902
Urban	435 (84.5)	731 (84.2)	
Rural	80 (15.5)	137 (15.8)	
County of crash poverty level,[c] n (%)			.003
Poverty level—above 75th percentile	179 (34.8)	236 (27.2)	
Poverty level—below 75th percentile	336 (65.2)	632 (72.8)	
Hour of crash, n (%)			.011
0:00-3:59	29 (5.6)	45 (5.2)	
4:00-7:59	56 (10.9)	83 (9.6)	
8:00-11:59	83 (16.1)	137 (15.8)	
12:00-15:59	86 (16.7)	204 (23.5)	
16:00-19:59	152 (29.5)	268 (30.9)	
20:00-23:59	109 (21.2)	131 (15.1)	
Posted speed limit (MPH), n (%)			<.001
5-10	24 (6.0)	76 (12.2)	
15-20	20 (5.0)	64 (10.2)	
25-30	49 (12.3)	112 (17.9)	
35-40	140 (35.3)	216 (34.6)	
45-50	110 (27.7)	110 (17.6)	
55+	54 (13.6)	47 (7.5)	
Number of lanes, n (%)			.001
1 lane	23 (5.3)	47 (6.6)	
2 lanes	217 (50.1)	427 (60.4)	
3 lanes	37 (8.5)	56 (7.9)	
4 lanes	72 (16.6)	96 (13.6)	
5+ lanes	84 (19.4)	81 (11.5)	
Ambient light at time of crash, n (%)			<.001
Daylight	268 (52.1)	541 (62.5)	
Dawn/Dusk	25 (4.9)	43 (5.0)	
Dark—lighted	112 (21.8)	165 (19.1)	
Dark—unlighted/unknown	109 (21.2)	116 (13.4)	
Striking vehicle type, n (%)			.033
Passenger car	230 (51.1)	399 (54.2)	
SUV	98 (21.8)	184 (25.0)	
Light truck	78 (17.3)	100 (13.6)	
Van	22 (4.9)	36 (4.9)	
Heavy truck	14 (3.1)	7 (1.0)	
Other vehicle[d]	8 (1.8)	10 (1.4)	

Note. Abbreviations: MPH, miles per hour; SUV, sport utility vehicle. Missing: posted speed limit, n = 361; number of lanes, n = 243; ambient light, n = 4; striking vehicle type, n = 197.
[a]Injury severity definition adapted from National Transportation Safety Board [11].
[b]Based on United States Department of Agriculture rural-urban classification system [10].
[c]Based on American Community Survey 5-year estimates [9] .
[d]Other vehicle consists of buses, motorcycles, mopeds, motor homes, police cars, and ambulances.

We also observed a strong relationship between age and injury severity. This finding is consistent with a body of literature pertaining to disparities in pedestrian crash outcomes among aging populations. Nationally, older adult pedestrians are more likely to suffer from severe injuries sustained from a MVC [21]. Additionally, a retrospective analysis of the National Trauma Bank from 2002 to 2006 determined that not only did older patients suffer more severe injuries than their younger counterparts, they were also 6 to 8 times more likely to die from pedestrian-related injuries [22]. These disparities in health outcomes among older populations could be attributed to greater susceptibility to health complications upon hospital admission [23].

Given the alignment of our results with state-level and national trends, prevention strategies should include improving pedestrian infrastructure in high-poverty areas, education on avoiding pedestrian crashes for both drivers and pedestrians, and policies that prioritize transportation equity in vulnerable communities. The North Carolina Department of Transportation has current efforts to reduce pedestrian crashes. Vision Zero is a collaborative initiative to eliminate roadway deaths and injuries in North Carolina [24]. The pedestrian-focused initiative Watch For Me NC uses public education and community engagement to reduce pedes-

trian and bicycle crashes and appears to positively influence driver behavior [25, 26]. Finally, WalkSmartNC is a study focusing on crowd-sourcing pedestrian safety information in downtown Raleigh [27]. While these state-level initiatives appear to have some positive effects, our findings assert the necessity of a specific focus on pedestrian outcomes among communities of color and low-SES communities. Future state-level intervention strategies should incorporate flexibility for tailoring so that intervention components might better address the particular needs of vulnerable communities in order to increase relevance and efficacy.

More research is needed regarding all motor vehicle crash injuries, particularly into determining the communities most at risk. Linking crash data with health data can provide a more complete picture of crash circumstances and health outcomes. Efforts are now underway to create the North Carolina Crash Injury Surveillance System, which would function as a sustainable repository of linked data to further research and evaluation.

Limitations

Overall, we were able to link 45% of pedestrian crash records to ED visits, which is comparable to other studies that have linked crash reports to hospital administrative datasets; however, our ability to match was likely limited by the lack of personal identifiers available for linkage [28, 29]. NC DETECT ED visit data are collected by hospitals for clinical, billing, and other administrative purposes and do not include names, medical record numbers, and/or other personal identifiers. In addition, our match rate was depressed by the inclusion of pedestrian fatalities. In North Carolina police-reported crash data, there is no way to conclusively determine the proportion of pedestrians who die at the scene or in transport to the hospital, although it is assumed that this number is high. Our linked data supports this assumption, as we were unable to link records for 81% of pedestrian fatalities. Likewise, our match rate was also depressed by including pedestrians who were reported as being "not injured" by the investigating police officer. However, 21% of pedestrians reported as "not injured" on crash reports had matching ED visit records; 5 of these patients were later admitted to the hospital due to their injuries. Finally, pedestrians with less serious injuries may seek treatment at urgent care centers and outpatient clinics or treat their injuries at home. Therefore, these individuals' patient data would not be captured in the NC DETECT ED visit dataset.

The linked analysis dataset only includes pedestrian crashes that were reported to the police. Underreporting of pedestrian crashes to the police has been noted and has been found to vary by demographics. Among injured pedestrians needing hospital care, being male and/or Black decreased the likelihood of having an associated crash report, suggesting that these populations may be more overrepresented than our analysis suggests [29].

The use of population-based rates may not be representative of exposure given the potential differences in demographics in different regions across the state. However, exposure-based denominators are not available on a statewide basis.

Conclusion

In North Carolina, older adults, persons of color, and the uninsured are overly represented as pedestrian crash victims and those with the most severe injury outcomes. NCMJ

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