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E-scooter use continues to rev up fracture diagnoses and hospital admissions compared to other modes of transportation

Eric H. Tischler [a,*], Benjamin Krasnyanskiy [a], Ryan M. Kong [a], Olivia Tracey [a], Sung Huang Laurent Tsai [b,c], Nishant Suneja [a,d]

[a] *Department of Orthopaedic Surgery and Rehabilitation Medicine, SUNY Downstate Health Sciences University, Brooklyn, NY, USA*
[b] *Department of Orthopaedic Surgery, Chang Gung Memorial Hospital, Keelung Branch, Keelung, 204, Taiwan*
[c] *School of Medicine, Chang Gung University, Taoyuan, 333, Taiwan*
[d] *Department of Orthopaedic Surgery, Brigham and Women's Hospital, Boston, MA, USA*

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ABSTRACT

Introduction: The COVID-19 pandemic was associated with an increase in popularity of e-scooter usage and a rise in e-scooter related injuries. Recent studies have elucidated trends within e-scooter injuries but there are few epidemiological studies that evaluate injury rates amongst multiple modes of transportation. This study seeks to investigate trends of e-scooter orthopedic fracture injuries compared to other traditional methods of transportation using a national database.
Methods: The National Electronic Injury Surveillance System (NEISS) database was queried between 2014 and 2020 for patients who were injured after usage of e-scooters, bicycles, or all-terrain vehicles. Primary analysis included patients with a diagnosis of fracture and utilized univariate/multivariate models to evaluate risk of hospital admission. Secondary analysis included all isolated patients to evaluate the odds of fracture development amongst modes of transportation.
Results: A total of 70,719 patients with injuries associated with e-scooter, bicycle, or all-terrain vehicle use were isolated. 15997 (22.6%) of these patients had a fracture diagnosis. Both e-scooters and all-terrain vehicles reported increased odds of fracture-related injury and direct hospitalization when compared to bicycles. E-scooter users reported a greater odds of both associated fracture (OR 1.25; 95%CI 1.03–1.51; $p = 0.024$) and hospital admission (OR: 2.01; 95%CI: 1.26–3.21; $p = 0.003$) in 2020 compared to 2014–2015.
Discussion: E-scooter related orthopedic injuries and hospital admissions had the largest incidence rate increase compared to bicycle and all-terrain vehicles between 2014 and 2020. E-scooter fractures were most commonly located in the lower leg in 2014–2017, the wrist in 2018–2019, and the upper trunk in 2020. In comparison, bicycle and all-terrain vehicle fractures was most commonly shoulder and upper trunk within the study period. Further research will help to promote further understanding of the e-scooter health care burden and in prevention of these injuries.
Level of evidence: 3.

1. Introduction

The expansion of the electric scooter (e-scooter) and e-scooter rideshare availability have altered personal transportation. Prior to the COVID pandemic, cities embraced e-scooter as an opportunity to fill the void for trips that are too far to walk, yet too close for subway or bus.[1] During the peri-pandemic period, e-scooter ridership use was observed to dramatically increase. Seattle scooter share program grew to nearly 1.4 million in just over one year from inception, while in Portland Oregon, rides nearly doubled from 385,422 in 2020 to 762,812 in 2021.[1]

The increased popularity of e-scooter use has required further safety and consequences of this mode of transportation. The incidence of e-scooter injuries treated in emergency departments in the US have nearly doubled between 2018 and 2019.[2] Trivedi et al.

* Corresponding author. Department of Orthopaedic Surgery and Rehabilitation Medicine SUNY Downstate Health Sciences University, 450 Clarkson Ave, MSC 30, Brooklyn, NY, 11203.
E-mail address: erictischler@gmail.com (E.H. Tischler).

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reported that of 193 observed e-scooter-related injuries, 182 (94.3%) patients were not wearing a helmet.[3] Recent studies have demonstrated that the most common injuries e-scooter accidents, include head trauma, fractures, and dislocations.[2,4–7] Tischler et al. and Shichman et al. both reported that fractures of the upper extremity were most common. Furthermore, patients with fractures of the upper leg, lower trunk, and associated head trauma/internal organ damage, had the greatest association with direct hospital admission.[2,4,8]

With regards to associated injuries, the rate of head injury due to e-scooter use was found to be more than double that of bicycle accidents.[5] Other injuries presenting with e-scooter usage include upper and lower extremity fracture as well as contusions, sprains, and lacerations without fracture.[3] Although recent studies have reported the detail and severity of e-scooter associated injuries, few epidemiological studies exist that evaluate injury rate among multiple modes of transportation. Therefore, the aim of this study is to evaluate e-scooter orthopedic fracture injuries compared to more traditional modes of transport using the 2014–2020 National Electronic Injury Surveillance System (NEISS) database.

2. Methods

2.1. Database/patient population

A retrospective review of the NEISS database was conducted between 2014 and 2020. NEISS database provides injury-related information from approximately 100 hospital emergency departments, selected as a probability sample for all hospital emergency departments nationwide.[9] The NEISS database is a nationally representative sample of emergency department visits in the United States, containing patient data from over 100 hospitals that were selected as a probability sample of all 5000+ hospitals with emergency departments.[8] NEISS database's large sample size and probability weighted sampling allows for generalizations to be made to the national population.[8]

Patients over 18 years old were included. To establish our initial cohort, ‘Electric Scooter’ (e-scooter) injuries were queried using the following product codes: 3215 (‘Mopeds or Power Assist Cycles’), 5022 (‘Scooter, powered’), and 5042 (‘Personal Transporters’ (stand-up), ‘Scooters/skateboards, powered’, ‘Hover-boards’, ‘Standup scooter’). Bicycle injuries were queried with product code 5040. All-terrain vehicle injuries were queried with the following product codes: 3285 (‘All-terrain vehicles, 3 wheels only; exclusively off road’), 3286 (‘All-terrain vehicles, 4 wheels; excl. dune buggies’), 3296 (‘All-terrain vehicles, more than 4 wheels; excl. dune buggies’), 3287 (‘All-terrain vehicles, number of wheels not specified; excl. dune buggies’), 3288 (‘Dune buggies/beach buggies’), 1744 (‘Motorized vehicles, not elsewhere classified, three or more wheels’), 5033 (‘Mountain or all-terrain bicycles or accessories’), 5035 (‘Minibikes, powered’), 5036 (‘Two-wheeled, powered, off-road vehicles, incl. dirt bikes and trail bikes; excl. mopeds and minibikes’). Age (18–25; 26–35; 36–50; 51+) and year of injury (2014–2015; 2016–2017; 2018–2019; 2020) were further stratified into respective groups.

2.2. Variables

Categorical variables collected included: secondary diagnosis, ED disposition, anatomic injury location, mechanism of injury, gender, and ethnicity (White, Black, Hispanic, Asian, Other). Secondary diagnoses included were: concussion (52), contusions/abrasions (53), hematoma (58), dislocation (55), laceration (59), and internal organ injury (62). Disposition was categorized as: direct hospital admission (2, 4, 5), no admission (1, 6), and death (8). Mode of transportation included e-scooters, bicycle, and all-terrain vehicles.

Anatomic injury location was categorized as neck, shoulder, upper trunk (axilla, thoracic spine, chest, rib), upper arm (humerus), lower arm (ulna, radius), elbow (radial head), wrist, hand (metacarpal), finger (phalanges/phalanx), lower trunk (lumbar spine, femoral neck, hip, pelvis, sacrum, coccyx), upper leg (femur, trochanter), lower leg (fibula, tibia), knee, foot, and toe. Mechanism of injury was identified through manual review of the patient injury narrative, for patients who had a diagnosed fracture, and were categorized as ground level fall or crash, collision with vehicle, collision with pedestrian, or unclear. Injuries which were caused during repair of the transport device or mounting/unmounting were excluded.

2.3. Comprehensive case sample

Year: 2020; Age: 42 years old; Sex: Male; Race: White; Anatomical Location: Shoulder; Primary Diagnosis: Closed Fracture; Secondary Diagnosis: None; Disposition: No Admission; Vehicle: Electric Scooter; Mechanism of Injury: Ground Level Fall or Crash.

Clinical Narrative: “42 male was riding electric scoter when patient fell off. Diagnosis: Left Shoulder fracture.”

2.4. Statistical analysis

Of patients with a primary fracture diagnosis, demographics, disposition, mechanisms of injury, anatomic location(s) of injury, and secondary diagnoses were analyzed. All patients were included; however, only 12.9% of patients reported secondary diagnosis. Binary and categorical variables were analyzed using Chi-square analysis. Weighted samples were used to estimate national incidence of fractures and hospital admissions amongst all modes of transport. During univariate and multivariate analysis, disposition was recategorized into a binary variable, including only direct hospital admission or no admission. Independent variables found to be significantly associated with direct hospital admission in the univariate analysis phase were included as covariates in multivariable logistic regression analysis.

In the second part of the study, all patients with all-terrain vehicle, bicycle, or e-scooter related injuries were included. Multivariable logistic regression analysis controlling for independent variables demonstrating univariate statistical significance was conducted to evaluate risk factors associated with presence of fracture diagnosis. A p-value <0.05 was used as a threshold for statistical significance. All analyses were performed using SPSS software version 28.0 (IBM Corp., Armonk, NY, USA).

3. Results

3.1. Cohort demographic

Between 2014 and 2020, A total of 70,719 patients with all-terrain vehicle, bicycle, and e-scooter related injuries were identified. Of these patients, 15,997 (22.6%) reported a fracture diagnoses and 9069 (12.9%) of patients reported a secondary diagnosis. Table 1 highlights fracture patient demographics, mechanisms of injury (MOI), and associated injuries. The mean cohort age was 44 (IQR: 29–57), with majority of individuals identifying as white (7570; 47.3%) and male (12,181; 76.1%).

3.2. Mechanism of injury

With respect to MOI, 12,614 (78.9%) were characterized as a

Table 1
This table presents the distribution of patient demographics, associated fracture location injuries, dispositions, and mechanism of injury from years 2014–2020; n (%).

	2014–15				2016–17				2018–2019				2020				P-value
	All MOT	All-Terrain	Bicycle	E-Scooter	All MOT	All-Terrain	Bicycle	E-Scooter	All MOT	All-Terrain	Bicycle	E-Scooter	All MOT	All-Terrain	Bicycle	E-Scooter	
Patients (n = 15997)	4050	1150	2700	200	4388	1327	2718	343	4519	1288	2684	547	3040	988	1727	325	
Fracture Diagnosis; N(%)																	
Neck	84 (2.1)	27 (2.3)	56 (2.1)	1 (0.5)	116 (2.6)	33 (2.5)	74 (2.7)	9 (2.6)	129 (2.9)	46 (3.6)	72 (2.7)	11 (2.0)	123 (4.0)	58 (5.9)	52 (3.0)	13 (4.0)	<0.001
Shoulder	789 (19.5)	208 (18.1)	560 (20.7)	21 (10.5)	825 (18.8)	238 (17.9)	552 (20.3)	35 (10.2)	819 (18.1)	241 (18.7)	512 (19.1)	66 (12.1)	624 (20.5)	207 (21.0)	370 (21.4)	47 (14.5)	0.060
Upper Trunk	562 (13.9)	205 (17.8)	336 (12.4)	21 (10.5)	683 (15.6)	267 (20.1)	387 (14.2)	29 (8.5)	917 (20.3)	332 (25.8)	516 (19.2)	69 (12.6)	682 (22.4)	266 (26.9)	352 (20.4)	64 (19.7)	<0.001
Lower Trunk	387 (9.6)	117 (10.2)	260 (9.6)	10 (5.0)	426 (9.7)	145 (10.9)	257 (9.5)	24 (7.0)	478 (10.6)	125 (9.7)	312 (11.6)	41 (7.5)	379 (12.5)	129 (13.1)	216 (12.5)	34 (10.5)	<0.001
Upper Arm	148 (3.7)	43 (3.7)	98 (3.6)	7 (3.5)	130 (3.0)	29 (2.2)	86 (3.2)	15 (4.4)	172 (3.8)	49 (3.8)	100 (3.7)	23 (4.2)	135 (4.4)	38 (3.8)	82 (4.7)	15 (4.6)	0.009
Lower Arm	302 (7.5)	58 (5.0)	226 (8.4)	18 (9.0)	297 (6.8)	83 (6.3)	176 (6.5)	38 (11.1)	318 (7.0)	78 (6.1)	181 (6.7)	59 (10.8)	232 (7.6)	69 (7.0)	138 (8.0)	25 (7.7)	0.449
Elbow	226 (5.6)	28 (2.4)	184 (6.8)	14 (7.0)	265 (6.0)	25 (1.9)	208 (7.7)	32 (9.3)	293 (6.5)	35 (2.7)	203 (7.6)	55 (10.1)	215 (7.1)	34 (3.4)	158 (9.1)	23 (7.1)	0.061
Wrist	460 (11.4)	100 (8.7)	330 (12.2)	30 (15.0)	500 (11.4)	106 (8.0)	344 (12.7)	50 (14.6)	528 (11.7)	105 (8.2)	326 (12.1)	97 (17.7)	331 (10.9)	94 (9.5)	208 (12.0)	29 (8.9)	0.766
Hand	203 (5.0)	52 (4.5)	147 (5.4)	4 (2.0)	197 (4.5)	61 (4.6)	127 (4.7)	9 (2.6)	216 (4.8)	65 (5.0)	122 (4.5)	29 (5.3)	148 (4.9)	43 (4.4)	89 (5.2)	16 (4.9)	0.718
Finger	160 (4.0)	45 (3.9)	111 (4.1)	4 (2.0)	155 (3.5)	39 (2.9)	107 (3.9)	9 (2.6)	202 (4.5)	44 (3.4)	138 (5.1)	20 (3.7)	112 (3.7)	20 (2.0)	75 (4.3)	17 (5.2)	0.121
Upper Leg	94 (2.3)	34 (3.0)	50 (1.9)	10 (5.0)	128 (2.9)	57 (4.3)	59 (2.2)	12 (3.5)	167 (3.7)	67 (5.2)	81 (3.0)	19 (3.5)	109 (3.6)	38 (3.8)	51 (3.0)	20 (6.2)	<0.001
Lower Leg	344 (8.5)	135 (11.7)	179 (6.6)	30 (15.0)	373 (8.5)	135 (10.2)	184 (6.8)	54 (15.7)	421 (9.3)	144 (1.2)	209 (7.8)	68 (12.4)	296 (9.7)	106 (10.7)	132 (7.6)	58 (17.8)	0.160
Knee	112 (2.8)	28 (2.4)	75 (2.8)	9 (4.5)	100 (2.3)	33 (2.5)	58 (2.1)	9 (2.6)	160 (3.5)	42 (3.3)	87 (3.2)	31 (5.7)	171 (5.6)	43 (4.4)	101 (5.8)	27 (8.3)	<0.001
Foot	133 (3.3)	55 (4.8)	64 (2.4)	14 (7.0)	144 (3.3)	56 (4.2)	77 (2.8)	11 (3.2)	131 (2.9)	44 (3.4)	64 (2.4)	23 (4.2)	92 (3.0)	50 (5.1)	31 (1.8)	11 (3.4)	0.670
Toe	46 (1.1)	15 (1.3)	24 (0.9)	7 (3.5)	49 (1.1)	20 (1.5)	22 (0.8)	7 (2.0)	62 (1.4)	23 (1.8)	32 (1.2)	7 (1.3)	39 (1.3)	9 (0.9)	27 (1.6)	3 (0.9)	0.665
Gender; N(%)																	0.515
Male	3088 (76.2)	919 (79.9)	2026 (75.0)	143 (71.5)	3334 (76.0)	1065 (80.3)	2045 (75.2)	224 (65.3)	3416 (75.6)	1021 (79.3)	2000 (74.5)	395 (72.2)	2343 (77.1)	822 (83.2)	1259 (72.9)	262 (80.6)	
Female	962 (23.8)	231 (20.1)	674 (25.0)	57 (28.5)	1054 (24.0)	262 (19.7)	673 (24.8)	119 (34.7)	1103 (24.4)	267 (20.7)	684 (25.5)	152 (27.8)	697 (22.9)	166 (16.8)	468 (27.1)	63 (19.4)	
Ethnicity; N(%)																	<0.001
White 1	1853 (45.8)	619 (53.8)	1181 (43.7)	53 (26.5)	2011 (45.8)	728 (54.9)	1173 (43.2)	110 (32.1)	2226 (49.3)	726 (56.4)	1296 (48.3)	204 (37.3)	1480 (48.7)	556 (56.3)	810 (46.9)	114 (35.1)	
Black 2	255 (6.3)	43 (3.7)	191 (7.1)	21 (10.5)	315 (7.2)	75 (5.7)	204 (7.5)	36 (10.5)	428 (9.5)	108 (8.4)	213 (7.9)	107 (19.6)	347 (11.4)	107 (10.8)	155 (9.0)	85 (26.2)	
Hispanic 3	168 (4.1)	38 (3.3)	125 (4.6)	5 (2.5)	169 (3.9)	42 (3.2)	116 (4.3)	11 (3.2)	254 (5.6)	71 (5.5)	147 (5.5)	36 (6.6)	190 (6.3)	66 (6.7)	104 (6.0)	20 (6.2)	
Asian 4	59 (1.5)	3 (0.3)	53 (2.0)	3 (1.5)	68 (1.5)	5 (0.4)	62 (2.3)	1 (0.3)	55 (1.2)	2 (0.2)	40 (1.5)	13 (2.4)	63 (2.1)	4 (0.4)	46 (2.7)	13 (4.0)	
Other 5	1715 (42.3)	447 (38.9)	1150 (42.6)	118 (59.0)	1825 (41.6)	477 (35.9)	1163 (42.8)	185 (53.9)	1556 (34.4)	381 (29.6)	988 (36.8)	187 (34.2)	960 (31.6)	255 (25.8)	612 (35.4)	93 (28.6)	
Disposition; N(%)																	
Death	1 (0.0)	1 (0.1)	0 (0.0)	0 (0.0)	2 (0.0)	0 (0.0)	2 (0.1)	0 (0.0)	2 (0.0)	0 (0.0)	2 (0.1)	0 (0.0)	7 (0.2)	2 (0.2)	4 (0.2)	1 (0.3)	
Direct Hospital Admission	1141 (28.2)	382 (33.2)	707 (26.2)	52 (26.0)	1349 (30.7)	475 (35.8)	758 (27.9)	116 (33.8)	1637 (36.2)	544 (42.2)	911 (33.9)	182 (33.3)	1188 (39.1)	435 (44.0)	613 (35.5)	140 (43.1)	<0.001
No Admission	2908 (71.8)	767 (66.7)	1993 (73.8)	148 (74.0)	3037 (69.2)	852 (64.2)	1958 (72.0)	227 (66.2)	2880 (63.7)	744 (57.8)	1771 (66.0)	365 (66.7)	1845 (60.7)	551 (55.8)	1110 (64.3)	184 (56.6)	
Age; N(%)																	0.003
18–25	775 (19.1)	305 (26.5)	440 (16.3)	30 (15.0)	757 (17.3)	306 (23.1)	391 (14.4)	60 (17.5)	736 (16.3)	307 (23.8)	326 (12.1)	103 (18.8)	498 (16.4)	235 (23.8)	198 (11.5)	65 (20.0)	
26–35	842 (20.8)	281 (24.4)	516 (19.1)	45 (22.5)	903 (20.6)	343 (25.8)	485 (17.8)	75 (21.9)	932 (20.6)	336 (26.1)	455 (17.0)	141 (25.8)	615 (20.2)	277 (28.0)	259 (15.0)	79 (24.3)	
36–50	999 (24.7)	304 (26.4)	640 (23.7)	55 (27.5)	1138 (25.9)	370 (27.9)	672 (24.7)	96 (28.0)	1089 (24.1)	340 (26.4)	599 (22.3)	150 (27.4)	779 (25.6)	285 (28.8)	410 (23.7)	84 (25.8)	
51+	1434 (35.4)	260 (22.6)	1104 (40.9)	70 (35.0)	1590 (36.2)	308 (23.2)	1170 (43.0)	112 (32.7)	1762 (39.0)	305 (23.7)	1304 (48.6)	153 (28.0)	1148 (37.8)	191 (19.3)	860 (49.8)	97 (29.8)	
Mechanism of Injury; N(%)																	<0.001
Fall or Crash 1	3293 (81.3)	995 (86.5)	2146 (79.5)	152 (76.0)	3446 (78.5)	1101 (83.0)	2075 (76.3)	270 (78.7)	3478 (77.0)	1081 (83.9)	1978 (73.7)	419 (76.6)	2397 (78.8)	834 (84.4)	1343 (77.8)	220 (67.7)	
Collision with Vehicle 2	577 (14.2)	50 (4.3)	483 (17.9)	44 (22.0)	658 (15.0)	56 (4.2)	549 (20.2)	53 (15.5)	772 (17.1)	58 (4.5)	620 (23.1)	94 (17.2)	455 (15.0)	31 (3.1)	338 (19.6)	86 (26.5)	
Collision with Pedestrian 3	31 (0.8)	11 (1.0)	19 (0.7)	1 (0.5)	40 (0.9)	12 (0.9)	26 (1.0)	2 (0.6)	29 (0.6)	6 (0.5)	19 (0.7)	4 (0.7)	16 (0.5)	5 (0.5)	8 (0.5)	3 (0.9)	
Unclear 4	149 (3.7)	94 (8.2)	52 (1.9)	3 (1.5)	244 (5.6)	158 (1.9)	68 (2.5)	18 (5.2)	240 (5.3)	143 (11.1)	67 (2.5)	30 (5.5)	172 (5.7)	118 (11.9)	38 (2.2)	16 (4.9)	

(*continued on next page*)

Table 1 (*continued*)

	2014–15				2016–17				2018–2019				2020				P-value
	All MOT	All-Terrain	Bicycle	E-Scooter	All MOT	All-Terrain	Bicycle	E-Scooter	All MOT	All-Terrain	Bicycle	E-Scooter	All MOT	All-Terrain	Bicycle	E-Scooter	
Secondary DX; N(%)																	0.919
Concussion 1	NA	NA	NA	NA	NA	NA	NA	NA	38 (0.8)	8 (0.6)	27 (1.0)	3 (0.5)	38 (1.3)	9 (0.9)	28 (1.6)	1 (0.3)	
Contusion, abrasions 2	NA	NA	NA	NA	NA	NA	NA	NA	216 (4.8)	52 (4.0)	127 (4.7)	37 (6.8)	279 (9.2)	94 (9.5)	153 (8.9)	32 (9.8)	
Hematoma 3	NA	NA	NA	NA	NA	NA	NA	NA	14 (0.3)	4 (0.3)	7 (0.3)	3 (0.5)	17 (0.6)	4 (0.4)	11 (0.6)	2 (0.6)	
Dislocation 4	NA	NA	NA	NA	NA	NA	NA	NA	42 (0.9)	16 (1.2)	18 (0.7)	8 (1.5)	59 (1.9)	17 (1.7)	37 (2.1)	5 (1.5)	
Laceration 5	NA	NA	NA	NA	NA	NA	NA	NA	126 (2.8)	39 (3.0)	65 (2.4)	22 (4.0)	156 (5.1)	48 (4.9)	90 (5.2)	18 (5.5)	
Internal Organ Injury 6	NA	NA	NA	NA	NA	NA	NA	NA	263 (5.8)	80 (6.2)	153 (5.7)	30 (5.5)	338 (11.1)	110 (11.1)	190 (11.0)	38 (11.7)	

ground level fall or crash, 2462 (15.4%) as a collision with motor vehicle, and 116 (0.7%) as collision with pedestrian. MOI was not determined in 805 (5.0%) patients due to insufficient information. After isolating cohorts by mode of transport and year, ground level fall or crash persisted as the most common MOI for all modes of transport Table 1.

3.3. *Fracture injury*

The majority of absolute fracture diagnoses were associated with bicycles (9829; 61.4%), followed by all-terrain vehicle (4753; 29.7%), and e-scooter (1415; 8.8%). Shoulder and upper trunk fractures were most common fracture diagnoses amongst all modes of transport. Furthermore, incidence of upper trunk fractures significantly increased from 2014 to 2020 ($p < 0.001$) Table 1. With regards to e-scooter-related injuries, lower leg fractures were the most common in 2014–15 (15.0%) and 2016-17 (15.7%), while wrist fractures were most common in 2018–19 (17.7%) and upper trunk fractures in 2020 (19.7%) Table 1. Among all modes of transport neck, upper trunk, and lower extremity fractures were associated with increased odds of hospital admission compared to upper extremity and toe fractures.

3.4. *Multivariate logistic regression - hospital admission*

A progressive increase in the national incidence rates of both fracture diagnosis(Fig. 1) and direct hospitalizations (Fig. 2) were observed over time for bicycle, all-terrain vehicle, and e-scooters. All-terrain (OR: 1.62; 95%CI 1.48–1.78; $p < 0.001$) and e-scooter use (OR: 1.29; 95%CI 1.11–1.49; $p < 0.001$) reported significant increased odds of hospital admission compared to bicycle use. (**Table 2**). E-scooter use reported over a 200% increase in direct hospital admissions when compared to 2014-15 (OR: 2.01; 95%CI: 1.26–3.21; $p = 0.003$) (Table 2) (see Fig. 3).

Upon evaluation of MOI, collision with a vehicle resulted in increased odds of hospital admission for individuals riding all-terrain vehicles (OR: 3.03; 95%CI: 2.12–4.31; $p < 0.001$), bicycles (OR: 2.31; 95%CI: 2.03–2.62; $p < 0.001$), and e-scooters (OR: 1.77; 95%CI: 1.27–2.46; $p < 0.001$) when compared to ground level fall or crash (**Table 2**). In 2020, e-scooter users had greater than twice the odds of being admitted, as compared to 2014-15 (OR: 2.01; 95%CI: 1.26–3.21; $p = 0.003$) (**Table 2**).

3.4.1. *Multivariate logistic regression - fracture diagnosis*

Both e-scooters (OR: 1.43; 95%CI: 1.34–1.52; $p < 0.001$) and all-terrain vehicles (OR: 1.32; 95%CI: 1.27–1.37; $p < 0.001$) had greater odds of an associated fracture-related injury when compared to bicycle injuries (**Table 3**). Although males were more likely to have a fracture diagnosis due to all-terrain (OR: 1.62; 95%CI: 1.50–1.75; $p < 0.001$) and e-scooter (OR: 1.38; 95%CI: 1.22–1.57; $p < 0.001$) use, this was not observed among bicyclists (OR: 0.99; 95%CI: 0.95–1.04; $p = 0.812$) (**Table 3**). E-scooter users reported 1.25 increased odds of sustaining a fracture in 2020 compared to 2014–2015 (OR 1.25; 95%CI 1.03–1.51; $p = 0.024$) (Table 3).

4. Discussion

The purpose of this study was to evaluate the 2014–2020 trend of e-scooter related orthopedic fractures compared to additional modes of transport. Our findings demonstrate that e-scooter related orthopedic fracture injuries and hospital admissions demonstrated the largest incidence rate increase over time when compared to bicycle and all-terrain vehicles. Interestingly, e-scooter fracture anatomic location incidence rates varied over time, with greatest incidence of fractures of the lower leg in 2014–2015

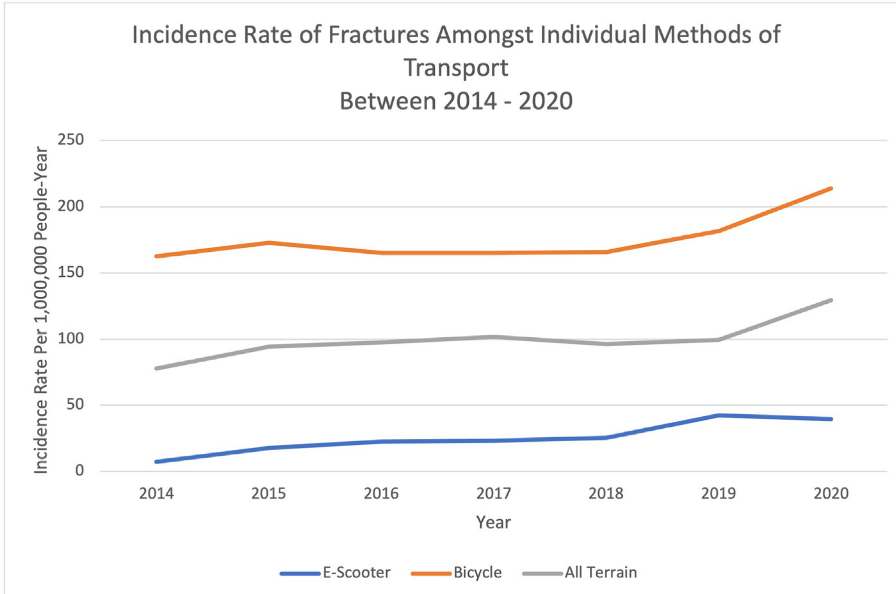

Fig. 1. This figure displays the estimate of national incidence of fractures related to E-Scooter, Bicycle, and All-Terrain Vehicle use.

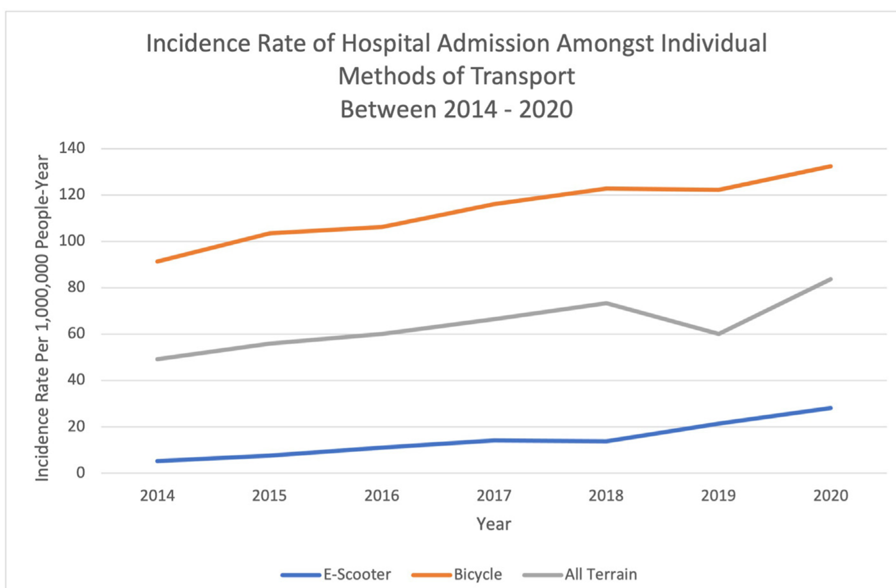

Fig. 2. This figure displays the estimate of national incidence of hospital admissions related to E-Scooter, Bicycle, and All-Terrain Vehicle use.

and 2016–2017 (15% and 15.7%, respectively), wrist in 2018–2019 (17.7%), and upper trunk in 2020 (19.7%). Contrastingly, shoulder and upper trunk injuries were consistently the most common anatomic injury sites among bicycle and all-terrain vehicle injuries. This may be explained by Shah et al. who observed varying MOI typologies among e-scooter and bicyclists, of which sustaining both blunt force and bracing impact with outstretched arm are associated with upper extremity fractures.[10]

Previous literature has reported that of e-scooter upper and lower limb fractures, 89.2% and 15.7% occurred in a rider fall mechanism and rider-vehicle collisions, respectively. Similarly, this study demonstrated fall or crash as the most common mechanisms of injury among e-scooter use (>67%), as well as with bicycle (>73%) and all-terrain vehicle (>83%) injuries. This is consistent with previous studies that indicate most e-scooter related injuries are due to falls.[3,11] Further epidemiological analysis is to required to assess mechanism of injury and fracture pattern.

With regards to severity of injury and required hospitalization, the odds of direct hospital admission increased over time for all modes of transport. Of note, e-scooter demonstrated the largest increase in hospital admission incidence rate. Collision with vehicle MOI reported the greatest odds for hospital admission. In addition to orthopedic injury, previous literature has reported associated head trauma due to lack of helmet use. Trivedi et al. identified a 57.7% incidence of craniofacial trauma with e-scooter use, the majority of which presented with concomitant with appendicular extremity injuries.[3] This is attributed to falling on outstretched arms or legs and lack of helmet use.[2,3,5] Meyer et al. conducted a

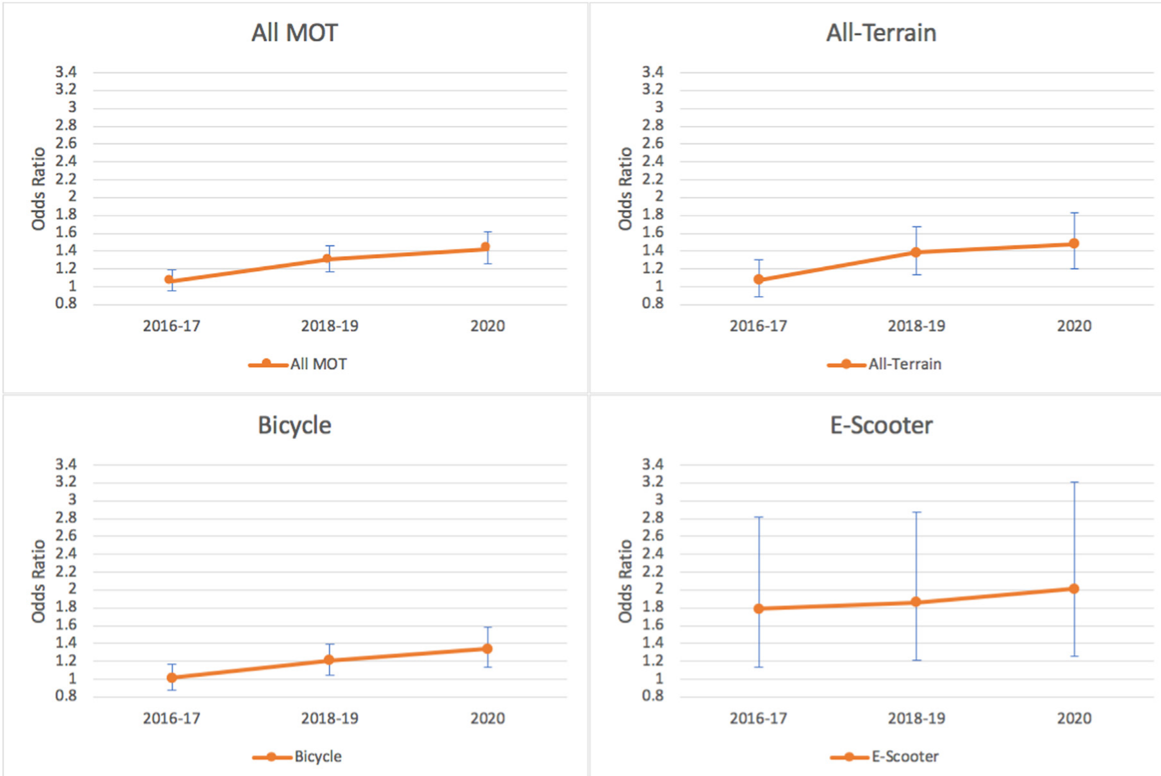

Fig. 3. Trend of odds of national direct hospital admission for mode of transport, with respect to 2014–2015.

prospective analysis of 68 e-bicycle accidents and determined that increased proportion of seriously injured people compared to cyclists are electromobility, driving under the influence of alcohol and inadequate wearing of a helmet on e-scooters when head injuries dominate.[12]

To our knowledge, this is the largest national database study to specifically evaluate e-scooter related fracture trajectory and risk factors associated with direct hospital admission compared to other modes of transportation. Specific limitations must however be addressed. The National Electronic Injury Surveillance System captures data from a wide demographic, but the course of patient management is limited to the final ED disposition. Neither long term inpatient nor outpatient treatment outcomes were accessible. Additionally, NEISS's coding mechanism for anatomic group and severity of injury are limited. For example, lower trunk includes: pelvis, femoral neck, tibia/fibula, lumbar vertebrae. Furthermore, diagnoses injury codes do not differentiate between open/closed fractures, fracture pattern, laterality, or multiple fractures. Clinical and treatment management varies among fracture status. Schichman et al. reported that among 3331 e-scooter injuries, 716 (21.5%) fractures were identified, of which 31% required operative fixation. Open reduction internal fixation was the most common procedure for both upper and lower extremities.[13]

Combining the findings of this study with institutional database findings will provide a more in depth understanding of the e-scooter health care burden. Given these limitations, this study highlights that e-scooter fracture related injuries continue to progress relative to other modes of transportation. Thus, it is critical that continued public health and educational efforts are required to mitigate these preventable injuries. Addressing issues such as incompatible infrastructure, traffic laws, age and helmet compliance may aid in rates of preventable trauma, hospitalization, and surgical intervention.

5. Conclusion

E-scooter related orthopedic fracture injuries and hospital admissions, when compared to bicycle and all-terrain vehicles, had the largest incidence rate increase over time between 2014 and 2020. In terms of E-scooter fracture anatomic location, the greatest incidence was in the lower leg in 2014–2015 and 2016–2017, wrist in 2018–2019, and upper trunk in 2020. This shift in fracture presentation may be attributed to mechanism of sustained impact, speed, as well as design of E-scooter. In contrast, bicycle and all-terrain vehicle fractures was most commonly shoulder and upper trunk within the study period. Fall or crash was the most common mechanism of injury with e-scooters, and all-terrain vehicle injuries, while collision with vehicle MOI had the greatest odds for hospital admission for all modes of transportation. Further research with institutional database findings in combination with findings from this national study will help to promote further understanding of the e-scooter health care burden and provide more evidence-based data on both prevention and treatment of these injuries.

Table 2
Multivariate Analysis evaluating independent variables associated with direct hospital admission. OR [95%CI] p-value; p-value <0.05 statistically significant.

Variable	All MOT	All-Terrain	Bicycle	E-Scooter
Total n	15997	4753	9829	1415
Age; OR [95%CI] P-value				
18-25	Ref	Ref	Ref	Ref
26-35	1.124 [0.978−1.291] 0.099	0.950 [0.779−1.159] 0.613	1.331 [1.066−1.661] 0.012	1.551 [1.003−2.400] 0.049
36-50	1.192 [1.044−1.361] 0.009	1.006 [0.826−1.224] 0.953	1.470 [1.195−1.808] <0.001	1.439 [0.939−2.204] 0.094
51+	1.788 [1.574−2.032] <0.001	1.439 [1.171−1.769] <0.001	2.224 [1.832−2.698] <0.001	1.810 [1.189−2.756] 0.006
Year; OR [95%CI] P-value				
2014-15	Ref	Ref	Ref	Ref
2016-17	1.063 [0.951−1.187] 0.282	1.075 [0.888−1.302] 0.455	1.013 [0.876−1.171] 0.863	1.786 [1.130−2.823] 0.013
2018-19	1.308 [1.171−1.460] <0.001	1.383 [1.140−1.678] 0.001	1.209 [1.046−1.396] 0.010	1.864 [1.210−2.873] 0.005
2020	1.425 [1.259−1.614] <0.001	1.483 [1.199−1.834] <0.001	1.341 [1.135−1.584] <0.001	2.013 [1.263−3.210] 0.003
Gender; OR [95%CI] P-value				
Male	1.098 [0.997−1.210] 0.058	1.069 [0.898−1.273] 0.450	1.044 [0.919−1.185] 0.509	1.581 [1.139−2.194] 0.006
Mode of Transportation; OR [95%CI] P-value				
Bike	Ref	NA	NA	NA
E-scooter	1.286 [1.113−1.486] <0.001	NA	NA	NA
All-terrain	1.622 [1.475−1.783] <0.001	NA	NA	NA
Mechanism of Action; OR [95%CI] P-value				
Fall or Crash	Ref	Ref	Ref	Ref
Collision with Vehicle	2.222 [1.992−2.479] <0.001	3.025 [2.121−4.314] <0.001	2.307 [2.031−2.620] <0.001	1.765 [1.265−2.464] <0.001
Collision with Pedestrian	1.097 [0.687−1.752] 0.698	1.636 [0.722−3.710] 0.238	0.915 [0.486−1.723] 0.783	0.655 [0.114−3.759] 0.635
Unclear	0.917 [0.767−1.098] 0.346	0.849 [0.680−1.060] 0.150	1.134 [0.802−1.602] 0.477	0.725 [0.397−1.325] 0.296
Race; OR [95%CI] P-value				
White	Ref	Ref	Ref	Ref
Black	0.969 [0.832−1.128] 0.685	0.975 [0.736−1.293] 0.861	0.942 [0.763−1.163] 0.580	1.067 [0.722−1.576] 0.745
Hispanic	1.120 [0.929−1.350] 0.236	1.896 [1.371−2.623] <0.001	0.838 [0.651−1.079] 0.171	1.308 [0.682−2.506] 0.419
Asian	1.042 [0.742−1.462] 0.812	0.422 [0.077−2.304] 0.319	1.017 [0.690−1.499] 0.934	1.593 [0.635−3.995] 0.321
Other	0.950 [0.871−1.037] 0.251	1.000 [0.860−1.163] 0.999	0.913 [0.814−1.024] 0.121	0.964 [0.704−1.320] 0.819
Fracture Diagnosis; OR [95%CI] P-value				
Neck	9.341 [7.041−12.392] <0.001	10.268 [6.379−16.526] <0.001	10.836 [7.363−15.947] <0.001	2.599 [1.056−6.400] 0.038
Shoulder	0.534 [0.445−0.641] <0.001	0.521 [0.383−0.710] <0.001	0.569 [0.444−0.729] <0.001	0.389 [0.213−0.713] 0.002
Upper Trunk	2.622 [2.188−3.141] <0.001	2.471 [1.827−3.342] <0.001	2.890 [2.256−3.702] <0.001	2.396 [1.340−4.283] 0.003
Lower Trunk	7.272 [5.966−8.863] <0.001	5.027 [3.616−6.990] <0.001	9.543 [7.285−12.500] <0.001	4.894 [2.554−9.381] <0.001
Upper Arm	1.117 [0.872−1.429] 0.382	1.281 [0.835−1.964] 0.256	1.114 [0.797−1.557] 0.529	0.762 [0.361−1.609] 0.476
Lower Arm	0.742 [0.595−0.924] 0.008	0.862 [0.587−1.266] 0.450	0.740 [0.548−0.998] 0.049	0.512 [0.271−0.970] 0.040
Elbow	0.655 [0.519−0.828] <0.001	0.434 [0.250−0.754] 0.003	0.803 [0.598−1.077] 0.143	0.363 [0.179−0.737] 0.005
Wrist	0.362 [0.288−0.454] <0.001	0.398 [0.268−0.593] <0.001	0.379 [0.280−0.513] <0.001	0.239 [0.119−0.481] <0.001
Hand	0.366 [0.274−0.488] <0.001	0.510 [0.323−0.805] 0.004	0.300 [0.198−0.455] <0.001	0.255 [0.101−0.642] 0.004
Finger	0.212 [0.148−0.302] <0.001	0.410 [0.238−0.706] 0.001	0.148 [0.087−0.251] <0.001	0.123 [0.035−0.433] 0.001
Upper Leg	19.953 [14.455−27.541] <0.001	18.110 [10.734−30.557] <0.001	30.465 [18.667−49.718] <0.001	5.923 [2.655−13.212] <0.001
Lower Leg	2.906 [2.378−3.551] <0.001	3.137 [2.241−4.391] <0.001	2.719 [2.056−3.595] <0.001	2.683 [1.503−4.789] <0.001
Knee	1.454 [1.142−1.852] 0.002	1.119 [0.716−1.751] 0.621	1.549 [1.124−2.134] 0.008	1.628 [0.819−3.240] 0.165
Foot	0.370 [0.268−0.510] <0.001	0.332 [0.200−0.551] <0.001	0.403 [0.249−0.653] <0.001	0.333 [0.136−0.815] 0.016
Toe	0.176 [0.095−0.327] <0.001	0.162 [0.060−0.439] <0.001	0.147 [0.054−0.400] <0.001	0.368 [0.095−1.416] 0.146

Table 3
Multivariate Analysis evaluating independent variables associated with presence of orthopedic fracture. OR [95%CI] p-value; p-value <0.05 statistically significant.

Variable	All MOT	All-Terrain	Bicycle	E-Scooter
Total n	70719	18775	46277	5667
Age; OR [95%CI] P-value				
18-25	Ref	Ref	Ref	Ref
26-35	1.250 [1.186−1.318] <0.001	1.206 [1.105−1.316] <0.001	1.250 [1.162−1.343] <0.001	1.456 [1.232−1.721] <0.001
36-50	1.473 [1.399−1.550] <0.001	1.553 [1.421−1.697] <0.001	1.448 [1.351−1.551] <0.001	1.622 [1.374−1.914] <0.001
51+	1.717 [1.636−1.803] <0.001	1.364 [1.245−1.495] <0.001	1.872 [1.757−1.994] <0.001	1.874 [1.590−2.209] <0.001
Year; OR [95%CI] P-value				
2014-15	Ref	Ref	Ref	Ref
2016-17	1.058 [1.011−1.107] 0.015	1.125 [1.033−1.225] 0.007	1.028 [0.972−1.088] 0.329	1.060 [0.880−1.278] 0.538
2018-19	1.170 [1.118−1.225] <0.001	1.301 [1.192−1.419] <0.001	1.116 [1.055−1.182] <0.001	1.166 [0.980−1.389] 0.084
2020	1.541 [1.462−1.625] <0.001	1.712 [1.553−1.887] <0.001	1.494 [1.398−1.598] <0.001	1.248 [1.030−1.513] 0.024
Gender; OR [95%CI] P-value				
Male	1.180 [1.135−1.227] <0.001	1.624 [1.504−1.753] <0.001	0.994 [0.947−1.044] 0.812	1.384 [1.219−1.570] <0.001
Mode of Transportation; OR [95%CI] P-value				
Bike	Ref	NA	NA	NA
E-scooter	1.428 [1.343−1.519] <0.001	NA	NA	NA
All-terrain	1.317 [1.267−1.369] <0.001	NA	NA	NA
Race; OR [95%CI] P-value				
White	Ref	Ref	Ref	Ref
Black	0.613 [0.578−0.651] <0.001	0.694 [0.616−0.783] <0.001	0.553 [0.512−0.598] <0.001	0.859 [0.732−1.009] 0.064
Hispanic	0.824 [0.762−0.891] <0.001	0.945 [0.809−1.105] 0.482	0.769 [0.698−0.847] <0.001	1.113 [0.847−1.463] 0.443
Asian	1.023 [0.889−1.176] 0.752	0.734 [0.426−1.264] 0.264	1.012 [0.867−1.180] 0.882	1.319 [0.849−2.052] 0.218
Other	0.901 [0.868−0.935] <0.001	0.942 [0.879−1.010] 0.094	0.854 [0.815−0.894] <0.001	1.092 [0.956−1.248] 0.194

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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