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MECHANICAL-CLINICAL MAPPING OF INJURY PATTERNS IN BICYCLE AND MOTORCYCLE CRASHES

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Abstract

The increasing prevalence of micromobility and motorized two-wheelers (MTWs) in urban areas has introduced complex patterns of accident mechanisms and injury outcomes. This study proposes a conceptual mapping that links the kinematic sequence of impact with the clinical end results of trauma in two-wheeler crashes. Drawing on selected real-world cases, the maps of how vehicle motion, user position, collision type, and energy transfer correspond to specific injury distributions across body regions. The approach emphasizes the interpretive integration of mechanical dynamics and medical response pathways. The proposed mechanical-clinical mapping provides a structured approach to understand how variations in impact geometry, vehicle speed, and rider behavior influence injury severity and treatment needs. The conceptual model introduced in this study lays the foundation for future multidisciplinary studies and supports the development of injury-aware safety design, training protocols, and urban policy for micromobility and MTW users.

Keywords: mechanical-clinical mapping, micromobility, urban transport, injury mechanism

1 Introduction

Roadway traffic injuries remain a major global public health concern, causing over one million deaths annually and resulting in substantial social and economic losses worldwide [1]. Despite improvements in vehicle safety technologies, vulnerable road users, particularly bicyclists and motorcyclists, continue to face disproportionately high injury risks due to their limited physical protection and direct exposure during crashes [2, 3]. The increasing promotion of active transport and micromobility in urban areas has further intensified interactions between two-wheeled vehicles and motorized traffic, amplifying injury risks in complex urban traffic environments [4].

Recent studies emphasize that micromobility should be evaluated not only through safety outcomes but also within a broader framework of energy efficiency, accessibility, and urban mobility performance. Bezgin [5] notes that while micromobility modes offer substantial benefits for sustainable transport and accessibility, their integration into dense urban traffic systems introduces new safety challenges, particularly for vulnerable road users. This perspective underscores the need for injury-focused analyses that complement urban mobility and planning-oriented assessments. Previous studies have shown that bicyclists and motorcyclists exhibit markedly different injury mechanisms and anatomical injury patterns. Bicycle crashes are often associated with falls or low-speed collisions. They are characterized by a higher prevalence of head and upper-extremity injuries.

In contrast, motorcycle crashes typically involve higher speeds and greater kinetic energy, leading to lower-extremity, thoracic, and spinal injuries with increased severities [6–8]. These differences are influenced by vehicle characteristics, rider behavior, and roadway design, highlighting the need for mode-specific injury analyses [9]. Protective equipment, particularly helmet use, has been widely recognized as a critical factor in reducing the severity of head injuries for both cyclists and motorcyclists [10, 11]. However, helmets alone are insufficient to prevent severe trauma in high-energy motorcycle crashes, where internal and multi-region injuries remain common despite protective gear use [12]. Use of helmets do not eliminate the potential injuries in lower speed bicycle and micromobility vehicle crashes either. Consequently, comprehensive injury prevention strategies must incorporate systemic approaches, including infrastructure design and speed management, rather than relying solely on individual-level interventions.
Urban traffic conditions play a decisive role in shaping crash severity for vulnerable road users. Empirical evidence indicates that road speed, intersection density, and the presence of dedicated cycling infrastructure significantly influence both crash likelihood and injury severity [13, 14]. The Safe System approach emphasizes the nonlinear relationship between impact speed and injury risk, demonstrating that even small speed increases can result in disproportionately higher probabilities of fatal and serious injuries for cyclists and motorcyclists [15]. In addition to injury patterns, bicycle and motorcycle crashes differ substantially in their clinical and economic consequences. Motorcyclists are more likely to require surgical intervention, intensive care unit (ICU) admission, and longer hospital stays, reflecting higher injury severity and complexity compared with bicyclists [8, 16]. These differences translate into higher healthcare costs and increased resource utilization, underscoring the importance of comparative analyses that integrate clinical and economic dimensions. Despite the growing literature on vulnerable road user safety, direct comparative studies examining injury distribution, severity indicators, and healthcare utilization between bicyclists and motorcyclists within the same urban context remain limited. Many existing studies focus on a single transport mode or rely primarily on fatality data, thereby overlooking clinically relevant non-fatal injuries and treatment pathways [7, 8].

2 Methodology

A retrospective, descriptive cross-sectional study was conducted to analyze traffic-related injuries involving two-wheeled vehicles. The study population comprised patients admitted to the Emergency Department of Bağcılar Training and Research Hospital in Istanbul between September 2020 and 2025 following traffic accidents. The dataset was derived exclusively from hospital emergency department records. Police crash reports or official traffic investigation documents were not accessed; therefore, the analysis focuses on clinically documented injury characteristics and treatment pathways rather than crash-scene reconstructions. The dataset was strictly stratified into two cohorts: bicycles and motorcycles. Data extraction, cleaning, and statistical analysis were executed using the Python programming language and relevant scientific computing libraries (pandas, NumPy, SciPy). During the data preprocessing stage, several cleaning procedures were applied to ensure consistency and analytical reliability. Records with missing or inconsistent vehicle type information were excluded. Age and categorical injury variables were standardized into numeric or binary formats where appropriate. Inconsistent or incomplete time entries were removed from temporal analyses. No imputation was performed for clinical severity variables; analyses were conducted only on valid recorded observations. In the data preprocessing phase, anatomical injury locations were parsed from diagnostic codes and categorized into six primary regions: I. Head, II. Chest, III. Upper Extremity, IV. Lower Extremity, V. Spine, and VI. Abdomen/Pelvis.

This reclassification was performed to avoid overlapping injury coding and to enable consistent anatomical comparison across cohorts. Clinical severity indicators, specifically the presence of fractures and the requirement for intensive care unit (ICU) admission, were recoded into binary variables. Additionally, temporal analysis was performed using Kernel Density Estimation (KDE) to visualize the hourly distribution of crash density throughout the day. Statistical analyses were determined based on the distribution characteristics of the variables. The normality of the continuous variable (age) was assessed using the Shapiro–Wilk test. Since age did not follow a normal distribution, the non-parametric Mann–Whitney U test was employed for group comparisons. For categorical variables, including injury regions, treatment modalities, and severity indicators, the Chi-Square test was utilized to evaluate differences in proportional distributions between independent groups. Statistical significance was defined as $p < 0.05$.

3 Results and discussion

A total of 1, 486 two-wheeled vehicle–related trauma cases presenting to Bağcılar Training and Research Hospital between September 2020 and 2025 were included in the analysis. The cohort comprised 698 bicyclists and 788 motorcyclists. The comparative evaluation revealed marked differences in demographic structure, temporal crash patterns, injury localization, and clinical severity, underscoring the heterogeneous nature of two-wheeler trauma.

Table 1 Statistical Analysis of Injury Distribution in Two-Wheeler Trauma

Variable	Test Used	P-Value	Significance
Age	Mann–Whitney U	< 0.001	***
ICU requirement	Chi-Square	0.003	**
Fracture presence	Chi-Square	0.175	ns
Head injury	Chi-Square	< 0.001	***
Chest injury	Chi-Square	0.008	**
Lower extremity injury	Chi-Square	< 0.001	***
Spine injury	Chi-Square	0.006	**
Upper extremity injury	Chi-Square	0.488	ns
Abdomen/pelvis injury	Chi-Square	0.021	*

Significance levels:
*** p < 0.001, ** p < 0.01, * p < 0.05, ns = not significant

3.1 Demographic and temporal characteristics

A statistically significant difference was observed in age distribution between bicyclists and motorcyclists ($p < 0.001$, Mann–Whitney U; table 1). As illustrated in figure 1, bicyclists were predominantly children and adolescents (median age ≈ 12 years), whereas motorcyclists were mainly young adults (median age ≈ 24 years) as expected by legal age restrictions imposed on motorcycle ridership. This pronounced demographic divergence identifies bicycle-related trauma as a critical pediatric public health issue and highlights the need for age-specific injury prevention strategies.

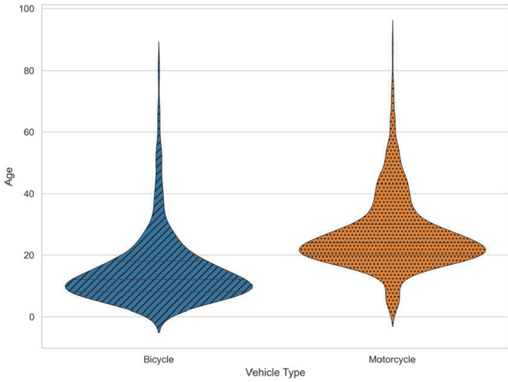

Figure 1 Age distribution of bicyclists and motorcyclists

Temporal analysis demonstrated distinct usage-related crash patterns (figure 2). Motorcycle accidents showed a clear bimodal distribution, peaking during morning (08:00–09:00) and evening (17:00–19:00) rush hours, consistent with commuter and occupational use. In contrast, bicycle accidents exhibited a unimodal afternoon peak (14:00–17:00), likely reflecting recreational activities and post-school exposure. Seasonal trends were similar in both groups, with higher accident frequencies during spring and summer months (figure 3), corresponding to increased outdoor mobility under favourable weather conditions.

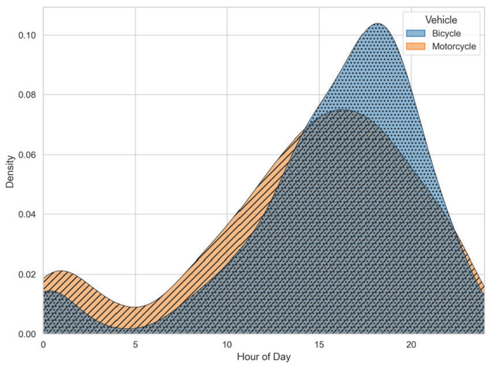

Figure 2 Circadian distribution of two-wheeler accidents

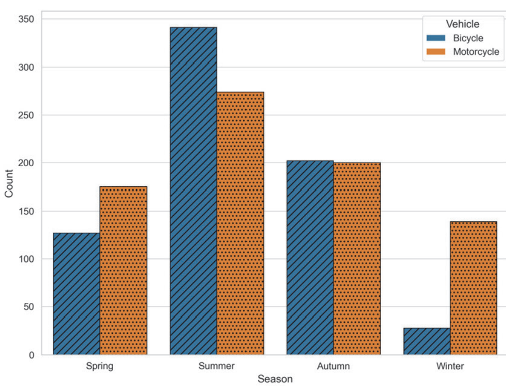

Figure 3 Seasonal distribution of bicycle and motorcycle accidents

3.2 Mechanical–clinical injury mapping

The anatomical distribution of injuries provided strong support for a mechanical–clinical relationship between vehicle type (a: bicycle, b: motorcycle and trauma type distribution pattern (table 1, figure 4).

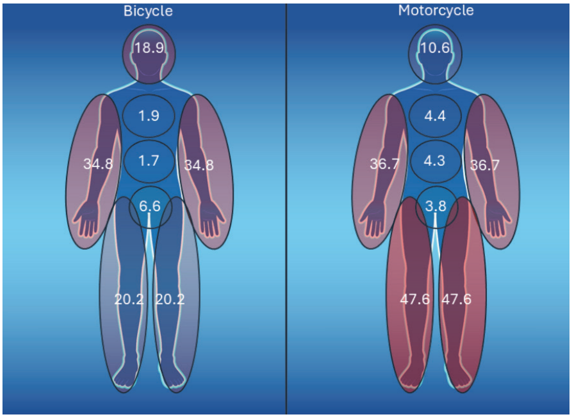

Figure 4 Anatomical distribution of injury regions by vehicle type: a) bicycle, b) motorcycle

Head injuries were significantly more frequent among bicyclists ($p < 0.001$). Given the younger age profile of this group, this finding suggests inadequate helmet use, limited enforcement, or suboptimal protective equipment in pediatric and adolescent cyclists. In contrast, motorcyclists demonstrated significantly higher rates of lower extremity injuries ($p < 0.001$), consistent with motorcycle-specific crash mechanics such as lateral impacts and leg entrapment beneath the engine block. These mechanisms are rarely encountered in bicycle crashes and reflect the greater mass and structural rigidity of motorized vehicles. Furthermore, thoracic ($p = 0.008$) and spinal injuries ($p = 0.006$) were significantly more prevalent in motorcyclists. This distribution is indicative of high-energy trauma and greater kinetic energy transfer, which are characteristic of motorized collisions. No significant differences were observed for upper extremity injuries ($p = 0.488$), suggesting comparable exposure of the arms in both vehicle types during falls or impact events. Abdomen and pelvis injuries were also more common in motorcyclists ($p = 0.021$), further reflecting the severity of impact dynamics.

3.3 Clinical severity and management

Although the overall presence of fractures did not differ significantly between bicyclists and motorcyclists ($p = 0.175$, table 1), indicators of clinical severity showed meaningful divergence. ICU admission was significantly more frequent among motorcyclists ($p = 0.003$), as depicted in figure 5, underscoring the higher injury severity associated with motorized crashes. Treatment patterns mirrored this severity gradient (figure 6). Motorcyclists were more likely to undergo surgical interventions, whereas bicyclists were predominantly managed conservatively or with minor procedures. This suggests that bicycle-related trauma, while common, often results in lower-acuity injuries, whereas motorcycle accidents are more likely to produce complex, multi-system trauma requiring advanced care.

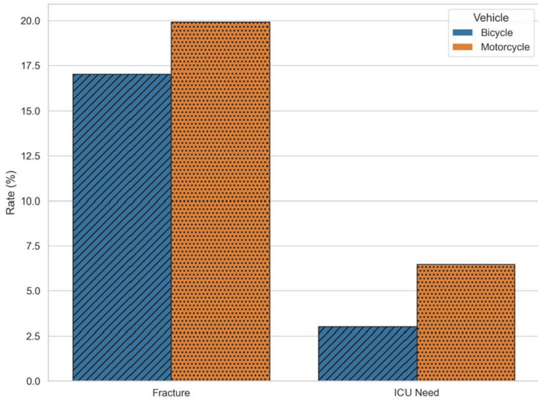

Figure 5 Clinical severity indicators in two-wheeler trauma

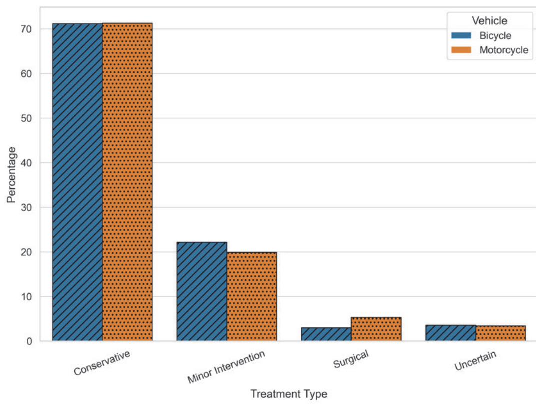

Figure 6 Treatment modalities by vehicle type

3.4 Implications for urban traffic safety

The findings demonstrate that two-wheeler trauma cannot be addressed as a single homogeneous entity. The statistically distinct injury profiles of cranial vulnerability in young bicyclists versus high-energy lower extremity, thoracic, and spinal trauma in motorcyclists necessitate differentiated prevention strategies. For motorcyclists, interventions should prioritize speed regulation and enhanced lower-body protective equipment. For bicyclists, particularly children and adolescents, stricter helmet enforcement and the development of protected cycling infrastructure are paramount. The integration of kinematic insights with clinical outcomes, as demonstrated in this study, provides a robust mapping for targeted injury prevention and urban safety planning.

4 Conclusion

This study demonstrates that bicycle and motorcycle-related injuries constitute fundamentally different trauma profiles shaped by vehicle kinematics and user demographics. Bicycle injuries predominantly affect children and adolescents and are characterized by a higher prevalence of cranial trauma, highlighting ongoing deficiencies in helmet use and pediatric traffic safety. In contrast, motorcycle crashes result in higher-energy trauma patterns, including increased lower extremity, thoracic, and spinal injuries, as well as a greater need for intensive care. These findings indicate that two-wheeler safety cannot be addressed through a single, uniform approach. Instead, targeted prevention strategies are required, focusing on helmet enforcement and protected infrastructure for young bicyclists, and speed control and enhanced protective equipment for motorcyclists. The mechanical–clinical perspective provided by this study offers a practical mapping for injury prevention and urban traffic safety planning. Possible variations in reflexes, response agility and peripheral attention towards impending danger between children and adults is also a matter that needs further research and evaluation.

References

[1] World Health Organization: Global status report on road safety 2023: country and territory profiles, 2024.

[2] Peden, M.M.: World report on road traffic injury prevention, World Health Organization, 2004.

[3] Elvik, R.: Risk of road traffic injury in Norway 1970–2022, Accident Analysis & Prevention, 202 (2024), 107587

[4] Hartmann, T.: Virtual Management of Complex Infrastructure: Information Systems in the Age of BIG DATA, 4th International Conference on Road and Rail Infrastructure - CETRA 2016, pp. 21-36, Šibenik, Croatia, 23-25 May 2016.

[5] Bezgin, N.Ö.: An Insight into Energy Efficiency, Mobility, Accessibility, and Safety Characteristics of Micromobility, Micromobility: Perspectives from Engineering, Urban Planning, Health Sciences and Social Sciences, pp. 55-71, 2025.

[6] Rivara, F.P., Thompson, D.C., Thompson, R.S.: Epidemiology of bicycle injuries and risk factors for serious injury, Injury prevention, 3 (1997) 2, pp. 110-114

[7] Chiang, V.X., Cheng, J.Y., Zhang, Z.C., Teo, L.T.: Comparison of severity and pattern of injuries between motorcycle riders and their pillions: a matched study, Injury, 45 (2014) 1, pp. 333-337

[8] Pai, C.W., Lin, H.Y., Tsai, S.H., Chen, P.L.: Comparison of traffic-injury related hospitalisation between bicyclists and motorcyclists in Taiwan, PLoS One, 13 (2018) 1, e0191221

[9] Hurt, H.H.: Motorcycle accident cause factors and identification of countermeasures, Traffic Safety Center, volume 2, University of Southern California, Los Angeles, California, 1981.

[10] Bailly, N., Schäuble, A., Guesneau, M., Wei, W., Petit, Y.: Assessing bicycle helmet protection for head and neck in E-scooter falls, Traffic Injury Prevention, 26 (2025) 7, pp. 866-873

[11] Lajunen, T., Stephens, A.N., Sullman, M.J.M.: The relationship between parental bicycle helmet use and that of their children, Transportation Research Part F: Traffic Psychology and Behaviour, 113 (2025), pp. 124-135

[12] Jung, S., Xiao, Q., Yoon, Y.: Evaluation of motorcycle safety strategies using the severity of injuries, Accident Analysis & Prevention, 59 (2013), pp. 357-364

[13] Teschke, K., et al.: Route infrastructure and the risk of injuries to bicyclists: a case-crossover study, American journal of public health, 102 (2012) 12, pp. 2336-2343

[14] Reynolds, C.C., Harris, M.A., Teschke, K., Cripton, P.A., Winters, M.: The impact of transportation infrastructure on bicycling injuries and crashes: a review of the literature, Environmental health, 8 (2009) 1

[15] Lubbe, N., Wu, Y., Jeppsson, H.: Safe speeds: fatality and injury risks of pedestrians, cyclists, motorcyclists, and car drivers impacting the front of another passenger car as a function of closing speed and age, Traffic safety research, 2 (2022)

[16] Eastridge, B.J., Shafi, S., Minei, J.P., Culica, D., McConnel, C., Gentilello, L.: Economic impact of motorcycle helmets: from impact to discharge, Journal of Trauma and Acute Care Surgery, 60 (2006) 5, pp. 978-984