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The Impact of Helmet Use on Maxillofacial Injuries in Children During Bicycle, Scooter, and Recreational Sports

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Abstract

Background. Maxillofacial injuries are an evolving challenge among children using micromobility devices. While open-face helmets effectively prevent neurocranial injuries, their role in preventing trauma to specific facial thirds, like dentoalveolar injuries, is complex. The expansion of e-mobility also generates new severe trauma patterns.

Aim. To provide a narrative synthesis of recent literature on the impact of helmet use on the risk, severity, and pattern of pediatric maxillofacial injuries. The analysis addresses the "protection gradient," e-mobility safety gaps, and limitations of registry data.

Material and methods. A narrative review of scientific publications (including cohort studies, meta-analyses, and technical reports) published up to 2026 was conducted.

Results. Helmets reduce the overall risk of maxillofacial injuries (RR 0.38 for facial bone fractures). However, a distinct "protection gradient" exists: protection is highest for the upper face but virtually absent for the lower face, leaving the mandible unprotected. While adult cohorts suggest helmets may increase isolated dentoalveolar injury risk, pediatric data remain inconclusive. The rise of e-mobility has led to trauma kinematics resembling motorcycle accidents, compounded by low helmet use (~4%).

Conclusions. Conventional helmets prevent severe craniocerebral trauma but inadequately protect the entire viscerocranium. The increasing mass and speed of micromobility vehicles necessitate updated pediatric protection standards. Lightweight full-face helmets with chin bars show potential, but targeted legislation and further pediatric research are needed.

Keywords: maxillofacial injuries, children, bicycle helmet, micromobility, e-scooter, injury prevention

1. Introduction

Technological advancements, changing recreational habits, and the transformation of urban transport systems have fundamentally altered the physical activity profile of children and adolescents. Accidents associated with single-track vehicles, such as bicycles and scooters, as well as injuries sustained during recreational sports, currently represent one of the leading causes of pediatric medical interventions in Emergency Departments (EDs) [1]. As DeGeorge et al. [2] state in their analyses on preventing unintentional childhood injuries, trauma prevention must consider environmental and demographic determinants, such as socioeconomic status and residential areas.

The rising rate of head and neck injuries is particularly notable. According to an epidemiological study involving over 5,000 children in Singapore, these injuries account for nearly 29% of all physical trauma related to recreational vehicles [1]. In the United States, a recent analysis of National Electronic Injury Surveillance System (NEISS) data conducted by Collins et al. [3] for the years 2014–2023, encompassing over 308,000 micromobility-related injuries, reveals that maxillofacial injuries constitute 37.99% of these cases. As reported by Sorenson et al. [4], even among conventional cyclists, over 10.4% of all injuries involve facial trauma, of which 13% are fractures, with the most vulnerable structures being the nasal bones (40%), orbits (23%), and mandible (20%).

Protective helmets have been a fundamental tool in primary prevention. Their efficacy in preventing neurocranial injuries is well documented. According to technical reports by the American Academy of Pediatrics (AAP) led by Lee et al. [5, 6], standard bicycle helmets reduce the risk of head and brain injuries by 63–88%, and demonstrate a risk reduction of approximately 34% (OR 0.66) in winter sports. However, despite these statistics for the neurocranium, the protection of the viscerocranium (facial skeleton) is significantly more complex. Contemporary medical literature points to design limitations in open-face helmets, which fail to dissipate kinetic energy directed at the lower third of the face. The situation is further complicated by the unprecedented surge in the popularity of fast, electric-powered devices (e-bikes, e-scooters), which redefine the kinematics of recreational injuries among minors [7, 8, 9, 10, 11].

Research Objective

The primary research objective of this review is to evaluate the impact of conventional and full-face helmet use on the risk reduction and anatomical distribution of maxillofacial injuries in the pediatric population, both in traditional recreational activities and during the use of electric micromobility devices.

Research Problems

1. How do the biomechanical properties of a classic open-face helmet contribute to the "protection gradient" between the upper and lower facial thirds?
2. Does the current literature strictly support the hypothesis that open-face helmets increase the risk of dentoalveolar injuries in children, or is this an extrapolation from adult data?
3. To what extent does the advent of e-mobility alter the severity and frequency of pediatric maxillofacial injuries?

Research Premises

Premise 1: The use of conventional bicycle helmets exhibits a "protection gradient," effectively protecting the upper facial thirds but providing limited to no protective benefit for the lower face.

Premise 2: The use of e-mobility devices by children is associated with a notable increase in the risk of severe maxillofacial injuries, revealing the inadequacy of classic helmets for this mode of transport.

2. Research materials and methods

2.1. Participants

The analyzed population included pediatric patients and adolescents (ages 0–18) who sustained physical injuries resulting from micromobility participation (bicycles, scooters, e-bikes, e-scooters) and recreational activities (winter sports, equestrianism). Exposure was defined as the confirmed use of protective headgear at the time of the incident, while the control state was the absence of helmet use. The assessed outcomes were maxillofacial injuries, including facial bone fractures, soft tissue lacerations, and dentoalveolar trauma.

2.2. Procedure / Test protocol / Skill test trial / Measure / Instruments

A narrative review was conducted based on an extensive literature search of English-language databases (MEDLINE/PubMed, Embase, Cochrane CENTRAL, Scopus) for articles published up to 2026. Search terms included combinations of helmet, head protection, maxillofacial injury, facial fracture, dentoalveolar trauma, micromobility, e-scooter, pediatric, and adolescent. The primary extracted measures were crude relative risks (RR) and adjusted odds ratios (aOR) reported in the original publications.

2.3. Data collection and analysis / Statistical analysis

2.3.1. Statistical Software

Given the narrative nature of this review, which relies on previously published primary studies, no re-calculations of statistics or formal meta-analytical software processing were performed on patient-level data. The study synthesizes metrics as published by the original authors.

2.3.2. AI

Artificial intelligence (AI) tools were utilized for two specific, clearly delimited purposes in this study. First, AI-assisted text analysis was applied to the extracted literature to support the identification of recurring thematic patterns and to help organize the reviewed evidence into coherent conceptual categories (e.g., etiology, pathophysiology, epidemiology, diagnostics, and prevention). Second, AI was used to refine the academic English of the manuscript, ensuring clarity, terminological consistency, and adherence to scientific writing standards.

It is important to emphasize that all AI tools were used strictly as assistive instruments under continuous human supervision. The selection of sources, critical appraisal of the included studies, interpretation of results, and formulation of all conclusions were performed exclusively by the human authors, who are responsible for the scientific content of this review. The AI tools served primarily to enhance efficiency in literature organization, thematic synthesis, and linguistic refinement, and did not replace expert human judgment at any stage of the analytical or interpretive process. The authors have reviewed, verified, and approved all content in its final form and take full responsibility for the integrity and accuracy of the work.

2.3.3. Statistical Methods

The primary cohort studies reviewed employed multivariable logistic regression models to control for potential systemic selection bias and adjust for confounding factors (e.g., age, risk-taking behaviors, socioeconomic status), allowing for the extraction of adjusted odds ratios (aOR) and relative risks (RR).

3. Research results

3.1. Epidemiology and Baseline Efficacy of Conventional Helmets

The baseline efficacy of pediatric helmets in preventing facial trauma is supported by a recent single-center retrospective cohort study by van Krimpen et al. (2026) [12], conducted in Rotterdam. In an analysis of N=210 children with a median age of 16 years (IQR 13–17), the researchers demonstrated that helmet use is associated with a reduction in overall maxillofacial injury risk (RR 0.60, 95% CI 0.42–0.89). The relative risk for facial bone fractures was estimated at 0.38 (95% CI 0.16–0.95). However, the wide confidence interval and the adolescent-skewed demographic warrant caution when generalizing these absolute numbers to younger pediatric populations. Nevertheless, these findings align with a broad meta-analysis by Stassen et al. (2024) [13], which included 11 studies overall, demonstrating that helmet use reduces maxillofacial injuries in cyclists by approximately 32% (OR 0.68).

3.2. The Protection Gradient and the Dental Trauma Hypothesis

Despite the overall reduction in maxillofacial trauma, the anatomical distribution of injuries reveals a critical limitation. Benjamin et al. [14] described the biomechanical "protection gradient" regarding soft tissue injuries, demonstrating high protection for the upper face but virtually no protective benefit for the lower face.

It is frequently hypothesized that this geometric deficit leads to a "dental paradox"—a scenario where the rigid front edge of an open-face helmet acts as a fulcrum during a rotational fall, potentially increasing the risk of dentoalveolar injuries. However, a critical review of the literature indicates that evidence for this paradox is largely extrapolated from adult and mixed populations. For instance, Chalathadka et al. [15] investigated two-wheeler drivers in a tertiary center, a demographic not exclusively comprising children. Similarly, the frequently cited elevated odds ratio (OR 1.54) for dentoalveolar injuries among helmeted individuals comes from Døving et al.'s [16] 12-year prospective cohort at a reference trauma center, which was heavily dominated by adult patients. Stanbouly et al. [17] similarly concluded that bicycle helmets effectively absorb energy directed at the midface but are ineffective against forces acting on the mandible.

In strictly pediatric data, the evidence for the dental paradox is much weaker and does not reach statistical significance. Benjamin et al. [14] observed only a marginal 10% difference (OR 1.10) in dentoalveolar injuries for helmeted users. In a strictly pediatric population (ages 1–19), Linn et al. [18] found that dental injuries occurred slightly more often among helmet users, but the difference was not statistically significant (OR 1.29, 95% CI 0.76–2.20). Thus, although the numerical direction across studies is consistent (a nominally higher rate of dental injuries in helmet users), the effect is non-significant in pediatric cohorts. Consequently, while helmets fail to adequately protect the lower face, claiming they actively increase dental trauma in children requires cautious interpretation. Nonetheless, recognizing the lack of lower-face protection, Abbott et al. (2024) [19], on behalf of the International Association of Dental Traumatology (IADT), recommend considering prophylactic faceshields and mouthguards for children during recreational "wheeled" activities.

3.3. E-scooters, E-bikes, and the Growing Surgical Burden

The micromobility revolution has substantially altered injury statistics. In the US, studies by Shannon et al. (2025) [7] and Burford et al. (2024) [8] highlight a considerable burden on public health systems from e-bikes and e-scooters. Hoveidaei et al.'s [9] analysis of a national database (2010–2022) observed a marked 1310% increase in orthopedic and maxillofacial fractures from e-scooters.

In the pediatric sphere, Easwaran et al. (2026) [10] demonstrated a 267.6% increase in injuries on e-bikes and e-scooters, emphasizing that these accidents frequently result in severe head trauma. Petitet et al. (2026) [11] documented a sharp increase in severe head trauma cases, rising from a single case in 2021 to 25 cases in 2025 in their registry, noting that approximately half of the injured minors were below the legal riding age and the severity of injuries is comparable to those seen in motorcycle accidents.

A crucial context regarding socioeconomic factors and selection bias is provided by Henrich et al. (2026) [20]. In their pediatric single-center study comprising 285 cases, they reported a concerning drop in overall helmet use (from 31.1% to 23.4%) alongside a rapid emergence of electric vehicle injuries (rising from 0% to 37.7%). They identified a strong correlation with lower socioeconomic status and ethnic background. Notably, helmet use in this cohort did not correlate with a lower Injury Severity Score (ISS). The authors attribute this to selection bias—helmets likely prevent many less severe injuries from ever presenting to the trauma center, leaving predominantly high-energy impacts in the dataset. This highlights a fundamental limitation of the entire review, which heavily relies on data from trauma centers and registries (like NEISS) that are inherently susceptible to coding errors and selection bias.

Reyes et al. [21] established that patients riding e-bikes exhibit a higher risk of severe facial trauma than victims riding light combustion motorcycles (aOR 1.78). However, it is essential to nuance this finding: while the risk of facial trauma specifically was higher for e-bikes, the overall Injury Severity Score (ISS) remained highest for motorcyclists, and the risk of head injury was comparable between the two groups. The facial vulnerability in e-bike users is exacerbated by poor compliance; Seitakari et al. [22] show in their retrospective cohort that only about 4% of e-scooter accident victims wear a helmet, compared to 28% for conventional cyclists.

3.4. Limitations in Winter and Equestrian Sports

In winter sports, the AAP (2022) [6] notes that helmets reduce head injuries (OR 0.41 for children under 13) without increasing cervical spine injury risk. Summers et al. [23] confirmed protection against concussions in a cohort of 6,299 children. However, these helmets leave the face exposed.

In equestrian sports, the inadequacy of standard riding helmets for facial protection is highly evident. Puolakkainen et al. (2021) [24] demonstrated that 84.6% of horse-related head injuries were isolated facial fractures, with nearly half requiring immediate surgery. Facial fractures are the strongest predictor of hospitalization after a fall from a horse (OR 32). The head is a frequent target, and hoof kicks often bypass the cranial vault entirely, accounting for extensive pediatric fractures in 29.3% of cases. Furthermore, Wolyncewicz et al. [25] noted that in children, "unmounted" accidents (handling the animal on the ground) lead to the most severe maxillofacial fractures, as children rarely wear helmets during these activities.

3.5. Biomechanical Analysis and Full-Face Implementation: Uneven Quality of Evidence

Biomechanical tests by Meng et al. (2023) [26] using THOR dummies revealed nuanced dynamics regarding full-face protection. While full-face bicycle helmets reduced loads during lower-face impacts, they did not significantly reduce forces exerted on the midface. Furthermore, full-face motorcycle helmets paradoxically caused a slight increase in forces applied to the lower face in certain specific impact vectors. Additionally, the use of full-face bicycle helmets was associated with a statistically significant increase in cervical neck strain (21.7%, $p=0.039$).

Despite these biomechanical nuances, clinical data from the automotive industry strongly support chin-bar protection. Brewer et al. [27] demonstrated that patients using full-face motorcycle helmets sustained facial fractures at a rate of 7%, compared to 27% for those using open-face helmets ($p=0.004$). However, it must be emphasized that the evidence advocating for full-face helmets is uneven, relying heavily on adult motorcycle cohorts and dummy tests. Direct pediatric data for e-mobility is lacking. Furthermore, a meta-analysis by Cavalcante et al. [28] found no significant difference between open and full-face helmets regarding the frequency of lower-third facial fractures, which somewhat weakens the unequivocal recommendation for chin-bar mandates and underscores the need for pediatric-specific studies. Studies by Sung [29], Hirobe [30], Tabary [31], and Nguyen [32] present a consistent picture that transferring kinetic loads to a full-face helmet frame reduces TBI severity, but the complete protection of the lower face remains a complex challenge.

3.6. Narrative Synthesis of Primary Premises

Premise 1: The Protection Gradient.

The narrative synthesis strongly supports the premise that open-face helmets exhibit a distinct protection gradient. Based on evidence from Benjamin [14] and the clinical patterns observed, helmets provide substantial protection to the neurocranium and upper face, but virtually no protective benefit for the lower facial soft tissues and mandible. However, the hypothesis that helmets actively increase dentoalveolar injuries in children (the dental paradox) remains unsupported by robust pediatric-specific data, as most elevated odds ratios (e.g., OR 1.54) stem from adult-dominated cohorts, while pediatric studies show non-significant effects in the same numerical direction [14, 16, 18].

Premise 2: E-mobility Risk Profile.

The synthesized literature strongly supports the premise that e-mobility vehicles generate a higher risk of severe maxillofacial trauma compared to traditional bicycles. Recent analyses of trauma registries show that the kinetic energy and mass of e-bikes and e-scooters result in specific facial surgical incidents comparable to, or exceeding, certain motorcycle accidents (aOR 1.78), highlighting a critical gap in current pediatric safety practices [9, 21, 22].

4. Discussion

A comprehensive analysis of recent literature indicates that while standard open-face bicycle helmets are highly effective for neurocranial protection, their structural limitations leave the lower face exposed. The findings of van Krimpen [12] and the meta-analysis by Stassen [13] reaffirm the necessity of helmet use to prevent primary cranial impact. However, the "protection gradient" described by Benjamin [14] clarifies that during rotational falls, the lower maxillo-mandibular complex remains unprotected. While the claim that helmets actively cause dental injuries is primarily extrapolated from adult cohorts (Døving [16]) and is non-significant in pediatric data (Linn [18]), the undeniable lack of lower-face protection justifies recommendations by dental associations to employ supplementary protection, such as sports mouthguards, in high-risk wheeled activities.

A notable shift in trauma epidemiology is driven by the rise of e-bikes and e-scooters. The mass of these devices, combined with speeds reaching 25–30 km/h, generates kinetic energy substantially greater than that of traditional pediatric bicycles. The severe maxillofacial reconstructive surgeries documented by Easwaran [10] and Petitet [11] reflect a changing landscape in which urban micromobility injuries increasingly resemble motor vehicle trauma. With compliance rates as low as ~4% for e-scooters [22], and with declines in overall helmet use strongly linked to lower socioeconomic status [20], the burden on public health systems is escalating.

Limitations of the Review

This narrative review is subject to inherent limitations. Much of the synthesized data originates from retrospective cohorts and national registries (e.g., NEISS), which are susceptible to recall bias and inconsistencies in clinical coding. Furthermore, as highlighted by Henrich et al. [20], selection bias plays a significant role in trauma center data: helmets likely prevent many mild to moderate injuries from ever presenting to the ED, thereby skewing the Injury Severity Score (ISS) of the helmeted cohort that does present for care. This bias limits the ability to accurately gauge the full protective scope of helmets at a population level. Finally, the extrapolation of biomechanical and dental trauma outcomes from adult or motorcycle populations to pediatric cyclists requires careful interpretation, as the quality of direct pediatric evidence remains uneven.

5. Conclusions

Based on the narrative synthesis of the literature (1998–2026), the following conclusions are drawn:

1. The baseline efficacy of open-face helmets in reducing the overall risk of maxillofacial fractures is supported by current cohort data, reinforcing recommendations for mandatory standard helmet use in pediatric micromobility.
2. A physical "protection gradient" leaves the lower facial third and dentoalveolar complex poorly protected. While claims of an active increase in pediatric dental trauma require further targeted study, the lack of lower-face protection supports involving dental specialists in ED treatment protocols.
3. The rise in e-mobility has led to a marked increase in high-energy maxillofacial injuries, compounded by remarkably low helmet utilization rates (reported at ~4% in one cohort study). The kinematics of e-vehicles suggest that pediatric head protection standards should be re-evaluated.
4. There is a clinical rationale for investigating and potentially standardizing lightweight, ventilated full-face (chin-bar) helmets for high-speed electric micromobility and specific high-impact recreational sports, though this is currently based largely on extrapolated adult data and necessitates further pediatric research to address biomechanical trade-offs such as potential cervical strain.

Disclosure

Supplementary Materials

Not applicable.

Author Contributions

Conceptualization: SP, KS, AM

Methodology: SP

Software: SP

Check: KS, AM

Formal analysis: SP

Investigation: AM

Resources: SP, KS

Data curation: SP

Writing - rough preparation: SP

Writing - review and editing: AM

Visualization: SP, KS

Supervision: AM

Project administration: SP

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Informed Consent Statement

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Conflicts of Interest

The authors declare no conflict of interest.

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