Motorcycle-Associated Ocular Injuries: A Narrative Review

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Purpose: Motorcycle-related injuries involving the eye and orbit are not well characterized, with a paucity of prospective studies focusing specifically on motorcycle-associated eye injuries nor literature reviews having been conducted on the subject. To better understand the injury types and descriptive characteristics of patients experiencing motorcycle-associated eye injuries, we sought to conduct a narrative review.

Methods: The research team utilized the following databases: PubMed, EMBASE, and Web of Science to query for English articles from peer-reviewed journals that provided some patient data regarding eye injury due to motorcycle or moped accidents or usage.

Results: A total of 65 studies were included in our qualitative synthesis. Of these studies, 40 (61.5%) were case reports, 20 retrospective case series (30.8%), and five (7.69%) were observational prospective studies. Among the 25 retrospective and prospective studies, 12 (48.0%) of these studies primarily focused on motorcycle-associated injuries. These 65 studies described a wide variety of motorcycle-associated eye injuries, including but not limited to orbital fractures and associated sequelae, foreign bodies, vitreoretinal trauma, neuro-ophthalmic trauma, corneal injuries, open globe injuries, lacerations, and globe avulsions.

Conclusion: The current state of the literature indicates that knowledge regarding the ocular manifestations of motorcycle accidents is limited to mostly case reports and few retrospective cohort studies focused specifically on motorcycle-associated eye injuries. However, it is evident that the types of motorcycle-associated eye injuries are legion and predominantly seen in adult males, potentially leading to severe injuries and loss of vision and blindness.

Keywords: motorcycle, ocular injury, eye, trauma, orbital fracture, ruptured globe, corneal injury, vitreoretinal damage, vehicular accidents

Introduction

Road traffic accidents lead to millions of injuries and are the leading cause of death in 5–29 year-olds globally.1 Among road traffic accidents, those associated with motorcycles carry a particularly high risk of injury and death, with the US federal government estimating that per mile traveled, motorcycle-related deaths were nearly 29 times higher than those associated with cars in 2019.2 The number of motorcycle fatalities is also increasing, with the most recent data in the United States showing a 9% increase in 2021 from 2020.3 The issue of motorcycle injury and deaths also disproportionately affects low- and middle-income countries, with countries with lower GDP per capita having an increased prevalence of motorcycle-related deaths compared to car-related deaths.4,5

The literature identifying and characterizing limb and head injuries associated with motorcycle crashes is well established, with closed fractures of the limbs and traumatic brain injuries identified as common injury types.6–12 However, motorcycle-related injuries involving the eye and orbit are not well characterized, with a paucity of large cohort studies focusing specifically on motorcycle-associated eye injuries nor literature reviews having been conducted...
on the subject, to our knowledge. While it can be reasoned that penetrating eye injuries and orbital fractures may be common and motorcycle-associated eye injuries can lead to permanent visual deficits, the prevalence of additional injury types and outcomes of motorcycle-related ocular injuries are not well understood. One way to possibly lower the risk of ocular injuries is through the use of protective equipment such as visors, goggles, and windscreens. However, the use of protective equipment may not be widespread. The most recent report on the subject demonstrated that in 73% of motorcycle accidents, the rider wore no eye protection, implying that foreign bodies or the effect of wind caused impaired vision that consequently delayed the detection of possible hazards. In addition, there is a possible elevated risk of direct ocular injuries resulting from the crashes themselves.

To better understand the injury types and descriptive characteristics of patients experiencing motorcycle-associated eye injuries, we sought to review the literature on the subject. Using our findings, we hope to fill a significant gap in the literature and combine all existing knowledge of motorcycle- and moped-associated eye injuries. To our knowledge, such a literature review has not been performed. We hope this study raises provider awareness of motorcycle-related eye injuries and care, particularly in acute trauma settings.

Materials and Methods

Literature Search

The research team utilized the following databases: PubMed, EMBASE, and Web of Science, and the following search terms for each database: (Motorcycle OR motorbike OR mini bikes OR pocket bikes OR mopeds OR motorized-bike OR motorized bike OR motorized cycle OR motorized-cycle OR scooter) AND (eye OR optic OR ophthalmic OR ophthalmologic OR ophthalmological OR globe OR orbit OR ophthalmology OR eyeball OR ocular OR orbital). Among our search terms, we included the term “scooter” because it can be used as a colloquial term for mopeds. However, we did not include kick scooters or recreational electric scooters in our analysis. The search was conducted from July 1st to July 4th, 2022, and our searches were not restricted by date.

Selection of Studies

The abstract and title and full-text screenings were conducted by two independent reviewers (EK and AG) using Covidence (Covidence systematic review software, Veritas Health Innovation, Melbourne, Australia). Both reviewers had to concur on a study’s eligibility to progress to the next stage of the literature screening process. Any conflicts were mediated through meetings and discussions.

All English articles from peer-reviewed journals that provided some patient data regarding eye injury due to motorcycle or moped accidents or usage were included in our analysis. Studies were only eligible if the described eye injuries were incurred while operating a motorcycle or riding a motorcycle as a passenger. For example, studies reporting eye injuries incurred by pedestrians being struck by a motorcyclist did not fit our inclusion criteria. We also excluded abstracts, conference proceedings, and studies that utilized previously published data.

Risk of Bias Assessment

For non-randomized studies, we utilized Cochrane’s ROBINS-I tools to assess whether a study had a low, moderate, serious, or critical risk of bias. All domains provided by the ROBINS-I tools were considered when determining bias ratings for each study. Two reviewers (EK and AG) independently determined the risk of bias scores for each study, and any discrepancies in ratings were resolved through discussion.

Results

Search Results

The details of the narrative review literature screening process can be found in our flowchart (Figure 1). From the three queried databases, we identified a total of 1529 total studies to be screened, 65 of which were included in our qualitative synthesis.
General Characteristics of Studies

Table 1 provides an overview of the 65 studies that met our inclusion criteria. A total of 65 studies provided data regarding eye injuries that could be attributed to motorcycle usage and/or accidents.\textsuperscript{19–83} Of these studies, 40 (61.5\%) were case reports, 20 (30.8\%) retrospective case series, and five (7.69\%) were observational prospective studies.\textsuperscript{19–83} Among the 25 retrospective and prospective studies, 12 (48.0\%) of these studies primarily focused on motorcycle-associated injuries. The other 13 (52.0\%) studies primarily focused on describing the epidemiology of a given type of injury (ie orbital fractures) or a specific etiology (ie motor vehicle accidents in general) and secondarily provided brief data regarding motorcycle-associated eye injuries. These 65 studies described a wide variety of motorcycle-associated eye injuries, including but not limited to orbital fractures and associated sequelae, foreign bodies, vitreoretinal trauma, neuro-ophthalmic trauma, corneal injuries, open globe injuries, lacerations, and globe avulsions. Many of these articles were conducted by authors from the United States (14/65, 21.5\%). Thirty-seven (56.7\%) of these studies were published between 2012–2022. Fifteen (15/25, 60.0\%) studies were rated as having low bias, eight (8/25, 32.0\%) moderate, and two (2/25, 8.00\%) high risk of bias.

It is important to note that the relative distribution of male and female patients, data regarding age and long-term sequelae could not be determined in many of the retrospective and prospective studies because of how the aggregate data were reported (Tables 2–8). As aforementioned above, many of these retrospective and prospective studies did not
<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>Country</th>
<th>Risk of Bias</th>
<th>Study Design</th>
<th>Data Source, Years(s) if Available</th>
<th>Primary OBJECTIVE of STUDY</th>
<th>Focused on Motorcycle Injury? (1) Yes (2) No</th>
<th>Injury Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kal et al</td>
<td>2015</td>
<td>Turkey</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To present a case of right abducens nerve palsy with ipsilateral Horner syndrome after motorcycle accident.</td>
<td>Yes</td>
<td>Neuro Ophthalmic</td>
</tr>
<tr>
<td>Baldwin et al</td>
<td>1988</td>
<td>United States</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To present a case of Brown’s Syndrome due to motorcycle accident-induced orbital fracture.</td>
<td>Yes</td>
<td>Orbital Fractures</td>
</tr>
<tr>
<td>Ellis et al</td>
<td>1985</td>
<td>Scotland</td>
<td>Moderate</td>
<td>Retrospective Case Series</td>
<td>Canniesburn Hospital, 1974–1983</td>
<td>To describe the epidemiology of zygomatico-orbital fractures seen at a single center during a 10 year period.</td>
<td>No</td>
<td>Orbital Fractures</td>
</tr>
<tr>
<td>Naik et al</td>
<td>2011</td>
<td>India</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To present a case in which a motorbike handle presenting as a bilateral foreign body.</td>
<td>Yes</td>
<td>Foreign Body</td>
</tr>
<tr>
<td>Das et al</td>
<td>2021</td>
<td>India</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To present a case in which a motorcycle handle was embedded in left orbit after a motorcycle accident.</td>
<td>Yes</td>
<td>Foreign Body</td>
</tr>
<tr>
<td>Johnson et al</td>
<td>2000</td>
<td>United States</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To present a case of bacterial keratitis secondary to a motorcycle accident that led to a corneal perforation.</td>
<td>Yes</td>
<td>Corneal</td>
</tr>
<tr>
<td>Nowroozzadeh et al</td>
<td>2009</td>
<td>India</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To present a case with a brake lever as foreign body after a motorcycle accident.</td>
<td>Yes</td>
<td>Foreign Body</td>
</tr>
<tr>
<td>Himori et al</td>
<td>2009</td>
<td>Japan</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To present a case of central retinal artery occlusion secondary to motorcycle-associated orbital fracture.</td>
<td>Yes</td>
<td>Orbital Fractures</td>
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<tbody>
<tr>
<td>Lin et al</td>
<td>2019</td>
<td>Taiwan</td>
<td>Low</td>
<td>Retrospective Case Series</td>
<td>Taichung Veterans General Hospital, 2009–2018</td>
<td>To describe the epidemiology of canalicular lacerations and surgical outcomes with Mini-Monoka insertions at a single center during a 10 year period.</td>
<td>No</td>
<td>Other - Canalicular Lacerations</td>
</tr>
<tr>
<td>Day et al</td>
<td>2018</td>
<td>United States</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To describe management of failed reduction of complex orbital fracture after motorcycle accident.</td>
<td>Yes</td>
<td>Orbital Fractures</td>
</tr>
<tr>
<td>Sinawat et al</td>
<td>2006</td>
<td>Thailand</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To present a case of blindness OU after a motorcycle accident.</td>
<td>Yes</td>
<td>Neuro Ophthalmic</td>
</tr>
<tr>
<td>Hegde et al</td>
<td>2005</td>
<td>United Kingdom</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To present a case with a visor as foreign body that also caused carotid artery laceration.</td>
<td>Yes</td>
<td>Foreign Body</td>
</tr>
<tr>
<td>Johnson et al</td>
<td>1995</td>
<td>United States</td>
<td>Moderate</td>
<td>Retrospective Case Series</td>
<td>Regional Level I trauma center, 4-year study period</td>
<td>To analyze the impacts of wearing a motorcycle helmet and other factors on the type, severity, and incidence of facial injuries.</td>
<td>Yes</td>
<td>Orbital Fractures</td>
</tr>
<tr>
<td>Chen et al</td>
<td>2016</td>
<td>Taiwan</td>
<td>Moderate</td>
<td>Retrospective Case Series</td>
<td>Chang Gung Memorial Hospital, 2000–2011</td>
<td>To evaluate outcomes of those who developed enophthalmos after orbital fracture repair.</td>
<td>No</td>
<td>Orbital Fractures</td>
</tr>
<tr>
<td>Kraus et al</td>
<td>2003</td>
<td>United States</td>
<td>Moderate</td>
<td>Retrospective Case Series</td>
<td>28 California hospitals, 1991–1993</td>
<td>To describe the epidemiology of facial injuries observed in motorcyclists after an accident.</td>
<td>Yes</td>
<td>Orbital Fractures</td>
</tr>
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**Table 1** (Continued)
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<th>Focused on Motorcycle Injury? (1) Yes (2) No</th>
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<tr>
<td>Norazah et al</td>
<td>2011</td>
<td>Malaysia</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To present a case of globe avulsion after a motorcycle accident.</td>
<td>Yes</td>
<td>Other - globe avulsion</td>
</tr>
<tr>
<td>Ahmad Fauzi et al</td>
<td>2021</td>
<td>Malaysia</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To present a case of bitemporal hemianopia after a motorcycle accident.</td>
<td>Yes</td>
<td>Neuro Ophthalmic</td>
</tr>
<tr>
<td>Zhang-Nunes et al</td>
<td>2012</td>
<td>United States</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To present a case of globe prolapse into maxillary sinus after motorcycle-associated trauma.</td>
<td>Yes</td>
<td>Orbital Fractures</td>
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<tr>
<td>Potapov et al</td>
<td>1996</td>
<td>Russia</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To present a case of a wooden foreign body after a motorcycle accident.</td>
<td>Yes</td>
<td>Foreign Body</td>
</tr>
<tr>
<td>Ueki et al</td>
<td>2020</td>
<td>Japan</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To present a case of plate infection that occurred 1 year after motorcycle-induced orbital fracture.</td>
<td>Yes</td>
<td>Orbital Fractures</td>
</tr>
<tr>
<td>Chen et al</td>
<td>2012</td>
<td>Taiwan</td>
<td>Low</td>
<td>Retrospective Case Series</td>
<td>Chang Gung Memorial Hospital, 1999–2009</td>
<td>To describe the epidemiology of traumatic retrobulbar hematomas at a single center</td>
<td>No</td>
<td>Orbital Fractures</td>
</tr>
<tr>
<td>Haug et al</td>
<td>2000</td>
<td>United States</td>
<td>Low</td>
<td>Retrospective Case Series</td>
<td>Level I Kentucky Trauma Center, 1992–1998</td>
<td>To describe the epidemiology and management of the trochlea of the superior oblique muscle when repairing orbital roof trauma at a single center.</td>
<td>No</td>
<td>Orbital Fractures</td>
</tr>
<tr>
<td>Sherman et al</td>
<td>1997</td>
<td>United States</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To describe the management of traumatic optic neuropathy secondary to motorcycle accidents.</td>
<td>Yes</td>
<td>Neuro Ophthalmic</td>
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<tbody>
<tr>
<td>Jabaut et al(^\text{43})</td>
<td>2017</td>
<td>United States</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To present a case of mandibular degloving and other associated facial trauma after a motorcycle accident.</td>
<td>Yes</td>
<td>Other-eyelid lacerations and periorbital edema</td>
</tr>
<tr>
<td>Khadamy et al(^\text{44})</td>
<td>2017</td>
<td>Iran</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To present a case of traumatic enucleation after a motorcycle accident.</td>
<td>Yes</td>
<td>Other-traumatic enucleation</td>
</tr>
<tr>
<td>Ruslin et al(^\text{45})</td>
<td>2019</td>
<td>European multicenter</td>
<td>Low</td>
<td>Prospective</td>
<td>12 European departments of oral and maxillofacial surgery, 2012–2013</td>
<td>To describe the epidemiology of facial fractures due to motor vehicle accidents in multiple centers.</td>
<td>No</td>
<td>Orbital Fractures</td>
</tr>
<tr>
<td>Hsieh et al(^\text{46})</td>
<td>2017</td>
<td>Taiwan</td>
<td>Low</td>
<td>Retrospective Case Series</td>
<td>Kaohsiung Chang Gung Memorial Hospital, 2009–2013</td>
<td>To describe the epidemiology of motorcycle-associated injuries among the elderly at a single center.</td>
<td>Yes</td>
<td>Orbital Fractures</td>
</tr>
<tr>
<td>Keane et al(^\text{47})</td>
<td>1989</td>
<td>United States</td>
<td>Moderate</td>
<td>Retrospective Case Series</td>
<td>2 California centers, 18-year period</td>
<td>To describe neuro-ophthalmic complications associated with motorcycle accidents observed in two centers.</td>
<td>Yes</td>
<td>Neuro Ophthalmic</td>
</tr>
<tr>
<td>Tamilarsan et al(^\text{48})</td>
<td>2022</td>
<td>Malaysia</td>
<td>Low</td>
<td>Retrospective Case Series</td>
<td>Hospital University Sains Malaysia</td>
<td>To describe 4 different cases of ocular injuries associated with insects entering the eye while operating a motorcycle.</td>
<td>Yes</td>
<td>Corneal</td>
</tr>
<tr>
<td>Upaphong et al(^\text{49})</td>
<td>2021</td>
<td>Thailand</td>
<td>Low</td>
<td>Retrospective Case Series</td>
<td>Chiang Mai University Hospital, 2006–2016</td>
<td>To describe epidemiology of traffic accident-associated open globe injuries in a single center.</td>
<td>No</td>
<td>Open Globe Injury</td>
</tr>
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<th>Primary OBJECTIVE of STUDY</th>
<th>Focused on Motorcycle Injury? (1) Yes (2) No</th>
<th>Injury Category</th>
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</thead>
<tbody>
<tr>
<td>Orr et al&lt;sup&gt;50&lt;/sup&gt;</td>
<td>2015</td>
<td>United States</td>
<td>Low</td>
<td>Retrospective Case Series</td>
<td>Single center, 2000–2012</td>
<td>To describe epidemiology of motor vehicle accident-associated open globe injuries in a single center.</td>
<td>No</td>
<td>Open Globe Injury</td>
</tr>
<tr>
<td>Wang et al&lt;sup&gt;51&lt;/sup&gt;</td>
<td>2013</td>
<td>China</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To present a case with a large foreign body after a motorcycle accident.</td>
<td>Yes</td>
<td>Foreign Body</td>
</tr>
<tr>
<td>Huang et al&lt;sup&gt;52&lt;/sup&gt;</td>
<td>2010</td>
<td>Taiwan</td>
<td>Low</td>
<td>Retrospective Case Series</td>
<td>National Cheng Kung University Hospital</td>
<td>To describe the management of 4 cases of ocular injury from a beetle entering the eye while operating a motorcycle.</td>
<td>Yes</td>
<td>Corneal</td>
</tr>
<tr>
<td>Arunkumar et al&lt;sup&gt;53&lt;/sup&gt;</td>
<td>1999</td>
<td>India</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To describe a twig foreign body after a motorcycle accident.</td>
<td>Yes</td>
<td>Foreign Body</td>
</tr>
<tr>
<td>Nakaishi et al&lt;sup&gt;54&lt;/sup&gt;</td>
<td>1997</td>
<td>Japan</td>
<td>Low</td>
<td>Retrospective Case Series</td>
<td>Tokyo Metropolitan Police Department</td>
<td>To describe the prevalence of pterygia and pingueculae in policemen who regularly use motorcycles.</td>
<td>Yes</td>
<td>Other - pterygium</td>
</tr>
<tr>
<td>Agarwal et al&lt;sup&gt;55&lt;/sup&gt;</td>
<td>2002</td>
<td>Australia</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To describe the management of pneumatization of the intraorbital optic nerve after a motorcycle accident.</td>
<td>Yes</td>
<td>Orbital Fractures</td>
</tr>
<tr>
<td>Neves et al&lt;sup&gt;56&lt;/sup&gt;</td>
<td>1998</td>
<td>United States</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To describe a case of orbital cyst after repair of orbital fracture associated with motorcycle accident.</td>
<td>Yes</td>
<td>Orbital Fractures</td>
</tr>
<tr>
<td>Achigbu et al&lt;sup&gt;57&lt;/sup&gt;</td>
<td>2014</td>
<td>Nigeria</td>
<td>High</td>
<td>Prospective</td>
<td>Recruited motorcyclists from Nigeria</td>
<td>To determine prevalence of pterygium among motorcyclists in Enugu State.</td>
<td>Yes</td>
<td>Other - pterygium</td>
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<th>Focused on Motorcycle Injury? (1)</th>
<th>Study OBJECTIVE of Injury Category</th>
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<tr>
<td>Ukponmwan et al\textsuperscript{58}</td>
<td>2007</td>
<td>Nigeria</td>
<td>High</td>
<td>Prospective</td>
<td>Recruited motorcyclists from Benin City</td>
<td>To determine prevalence and risk factors for pterygium and pinguecula in Nigerian motorcyclists.</td>
<td>Yes</td>
<td>Other - pterygium</td>
</tr>
<tr>
<td>do O silva et al\textsuperscript{59}</td>
<td>2017</td>
<td>Brazil</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To assess the effectiveness of prototyping for the treatment of orbital fracture secondary to a motorcycle accident in a single patient.</td>
<td>Yes</td>
<td>Orbital Fractures</td>
</tr>
<tr>
<td>Gotfried et al\textsuperscript{60}</td>
<td>2021</td>
<td>United States</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To report a case of third nerve palsy after a motorcycle accident.</td>
<td>Yes</td>
<td>Neuro Ophthalmic</td>
</tr>
<tr>
<td>Tatlipinar et al\textsuperscript{61}</td>
<td>2007</td>
<td>Turkey</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To report a case of Purtscher’s retinopathy after severe head trauma in a motorcycle accident.</td>
<td>Yes</td>
<td>Vitreoretinal</td>
</tr>
<tr>
<td>Pessoa Neto et al\textsuperscript{62}</td>
<td>2019</td>
<td>Brazil</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To describe the management of a foreign body injury after a motorcycle accident.</td>
<td>Yes</td>
<td>Orbital Fractures</td>
</tr>
<tr>
<td>Kapoor et al\textsuperscript{63}</td>
<td>2020</td>
<td>India</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To describe the clinical course of a retained intraorbital foreign body in a patient after a motorcycle crash.</td>
<td>Yes</td>
<td>Foreign Body</td>
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<tr>
<td>Levin et al\textsuperscript{64}</td>
<td>1991</td>
<td>United States</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To describe a case of parafoveal retinal pigment epithelial tear after motorcycle accident.</td>
<td>Yes</td>
<td>Vitreoretinal</td>
</tr>
<tr>
<td>Vien et al\textsuperscript{65}</td>
<td>2017</td>
<td>United States</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To describe a case of retrograde degeneration of retinal ganglion cells after motorcycle-associated head trauma.</td>
<td>Yes</td>
<td>Neuro Ophthalmic</td>
</tr>
</tbody>
</table>

(Continued)
Table 1 (Continued).

<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>Country</th>
<th>Risk of Bias</th>
<th>Study Design</th>
<th>Data Source, Years(s) if Available</th>
<th>Primary OBJECTIVE of STUDY</th>
<th>Focused on Motorcycle Injury? (1)</th>
<th>Yes (2) No</th>
<th>Injury Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calderoni et al&lt;sup&gt;66&lt;/sup&gt;</td>
<td>2011</td>
<td>Brazil</td>
<td>Moderate</td>
<td>Retrospective Case Series</td>
<td>State University of Campinas-Unicamp, 2001–2008</td>
<td>To analyze the epidemiological characteristics of patients with orbitozygomatic complex fractures who underwent surgical treatment</td>
<td>No</td>
<td>Orbital Fractures</td>
<td></td>
</tr>
<tr>
<td>Arif et al&lt;sup&gt;67&lt;/sup&gt;</td>
<td>2019</td>
<td>India</td>
<td>Low</td>
<td>Prospective</td>
<td>4 different centers, 2015–2017</td>
<td>To analyze the incidence and pattern of patients with soft tissue facial injuries caused by motorcycle accidents</td>
<td>Yes</td>
<td>Other-orbital abrasions, lacerations, contusions</td>
<td></td>
</tr>
<tr>
<td>Cappello et al&lt;sup&gt;68&lt;/sup&gt;</td>
<td>2021</td>
<td>Italy</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To report a case of a patient with bilateral vision loss after motorcycle accident</td>
<td>Yes</td>
<td>Vitreoretinal</td>
<td></td>
</tr>
<tr>
<td>Ausayakhun et al&lt;sup&gt;69&lt;/sup&gt;</td>
<td>2005</td>
<td>Thailand</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To report a case of keratitis, caused by insect hair penetrating of the cornea, caused while riding a motorcycle</td>
<td>Yes</td>
<td>Corneal</td>
<td></td>
</tr>
<tr>
<td>Pereira et al&lt;sup&gt;70&lt;/sup&gt;</td>
<td>2020</td>
<td>Brazil</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To report a case of severe facial trauma and orbital extrusion caused by a frontal collision during a motorcycle crash</td>
<td>Yes</td>
<td>Orbital Fractures</td>
<td></td>
</tr>
<tr>
<td>Yu et al&lt;sup&gt;71&lt;/sup&gt;</td>
<td>2015</td>
<td>Malaysia</td>
<td>Low</td>
<td>Retrospective Case Series</td>
<td>Chang Gung Memorial Hospital, 2003–2014</td>
<td>To determine effects of timing of surgery on outcomes of orbital fracture repair.</td>
<td>No</td>
<td>Orbital Fractures</td>
<td></td>
</tr>
<tr>
<td>Alderazi et al&lt;sup&gt;72&lt;/sup&gt;</td>
<td>2014</td>
<td>United States</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To present a case of bulging right eye and blindness 6 weeks after a motorcycle crash and traumatic brain injury</td>
<td>Yes</td>
<td>Neuro Ophthalmic</td>
<td></td>
</tr>
</tbody>
</table>

(Continued)
<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>Country</th>
<th>Risk of Bias</th>
<th>Study Design</th>
<th>Data Source, Years(s) if Available</th>
<th>Primary OBJECTIVE of STUDY</th>
<th>Focused on Motorcycle Injury? (1) Yes (2) No</th>
<th>Injury Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Christian et al 73</td>
<td>2014</td>
<td>United States</td>
<td>Low</td>
<td>Retrospective Case Series</td>
<td>Elvis Presley Memorial Trauma Center, 2001–2010</td>
<td>To analyze patterns of bony and soft tissue injuries in helmeted versus non helmeted motorcycle crash patients</td>
<td>Yes</td>
<td>Orbital Fractures</td>
</tr>
<tr>
<td>Manana et al 74</td>
<td>2017</td>
<td>Kenya</td>
<td>Moderate</td>
<td>Prospective</td>
<td>Dental Hospital and Kenyatta National Referral Hospital, June 2014-December 2014</td>
<td>To analyze the patterns of orbital fractures among patients</td>
<td>No</td>
<td>Orbital Fractures</td>
</tr>
<tr>
<td>Okamoto et al 75</td>
<td>2019</td>
<td>Japan</td>
<td>Low</td>
<td>Retrospective Case Series</td>
<td>Japan Clinical Retina Study Hospitals</td>
<td>To analyze the characteristics and outcomes of patients with traffic accident-related open globe injuries</td>
<td>No</td>
<td>Open Globe Injury</td>
</tr>
<tr>
<td>Meena et al 76</td>
<td>2020</td>
<td>India</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To report a case of complete globe extrusion with optic nerve avulsion following a motorcycle accident</td>
<td>Yes</td>
<td>Neuro Ophthalmic</td>
</tr>
<tr>
<td>Saka et al 77</td>
<td>2017</td>
<td>Nigeria</td>
<td>Moderate</td>
<td>Retrospective Case Series</td>
<td>Federal Medical Center Birnin Kebbi, 2013–2014</td>
<td>To analyze epidemiological patterns and outcomes of traumatic corneal lacerations</td>
<td>No</td>
<td>Cornea</td>
</tr>
<tr>
<td>Tuncbilek et al 78</td>
<td>2008</td>
<td>Turkey</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To report a case globe enucleation and facial fractures following a motorcycle accident</td>
<td>Yes</td>
<td>Other-glove enucleation</td>
</tr>
<tr>
<td>Kastelan et al 79</td>
<td>2018</td>
<td>Croatia</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To report a case of traumatic optic neuropathy after a motorcycle accident.</td>
<td>Yes</td>
<td>Neuro Ophthalmic</td>
</tr>
<tr>
<td>Bhat et al 80</td>
<td>2022</td>
<td>India</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To report a case of optic neuropathy following a motorcycle accident</td>
<td>Yes</td>
<td>Neuro Ophthalmic</td>
</tr>
</tbody>
</table>

(Continued)
### Table 1 (Continued).

<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>Country</th>
<th>Risk of Bias</th>
<th>Study Design</th>
<th>Data Source, Years(s) if Available</th>
<th>Primary OBJECTIVE of STUDY</th>
<th>Focused on Motorcycle Injury?</th>
<th>Injury Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ham et al</td>
<td>2015</td>
<td>United States</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To report a case of patient with vision loss following a motorcycle accident</td>
<td>Yes</td>
<td>Neuro Ophthalmic</td>
</tr>
<tr>
<td>Roybal et al</td>
<td>2016</td>
<td>United States</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To present a case of retinal complications following a motorcycle crash</td>
<td>Yes</td>
<td>Vitreoretinal</td>
</tr>
<tr>
<td>Ioannidis et al</td>
<td>2004</td>
<td>UK</td>
<td>N/A</td>
<td>Case Report</td>
<td>N/A</td>
<td>To report a case of transient maculopathy following use of a motorcycle</td>
<td>Yes</td>
<td>Vitreoretinal</td>
</tr>
</tbody>
</table>

### Table 2 Characteristics of Patients with Motorcycle-Associated Orbital Fractures

<table>
<thead>
<tr>
<th>Study</th>
<th>Number of Individuals with Injury</th>
<th>Age (Years)</th>
<th>Type of Orbital Fracture</th>
<th>Resolution of Visual Acuity?/Full Recovery?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ellis et al</td>
<td>Male: Cannot be Determined</td>
<td>Cannot be Determined</td>
<td>Tripod Fractures</td>
<td>Cannot be Determined</td>
</tr>
<tr>
<td></td>
<td>Female: Cannot be Determined</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total: 18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Johnson et al</td>
<td>Male: Cannot be Determined</td>
<td>Cannot be Determined</td>
<td>Non-specified orbital fracture</td>
<td>Cannot be Determined</td>
</tr>
<tr>
<td></td>
<td>Female: Cannot be Determined</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total: 26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gopalakrishna et al</td>
<td>Male: Cannot be Determined</td>
<td>Cannot be Determined</td>
<td>Non-specified orbital fracture</td>
<td>Cannot be Determined</td>
</tr>
<tr>
<td></td>
<td>Female: Cannot be Determined</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total: 109</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chen et al</td>
<td>Male: Cannot be Determined</td>
<td>Cannot be Determined</td>
<td>Orbital fracture with enophthalmos</td>
<td>Cannot be Determined</td>
</tr>
<tr>
<td></td>
<td>Female: Cannot be Determined</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total: 209</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kraus et al</td>
<td>Male: Cannot be Determined</td>
<td>Cannot be Determined</td>
<td>Non-specified orbital fracture</td>
<td>Cannot be Determined</td>
</tr>
<tr>
<td></td>
<td>Female: Cannot be Determined</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total: 111</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chen et al</td>
<td>Male: 6</td>
<td>2x 13 y.o.</td>
<td>Orbital fracture with retrobulbar hematoma</td>
<td>Cannot be Determined</td>
</tr>
<tr>
<td></td>
<td>Female: 1</td>
<td>1x 18 y.o.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total: 7</td>
<td>1x 20 y.o.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1x 23 y.o.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2x.43 y.o.</td>
<td></td>
<td></td>
</tr>
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</table>

(Continued)
Table 2 (Continued).

<table>
<thead>
<tr>
<th>Study</th>
<th>Number of Individuals with Injury</th>
<th>Age (Years)</th>
<th>Type of Orbital Fracture</th>
<th>Resolution of Visual Acuity?/Full Recovery?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haug et al⁴¹</td>
<td>Male: 3</td>
<td>1x 25 y.o.</td>
<td>Orbital Roof Trauma</td>
<td>Full recovery in all patients</td>
</tr>
<tr>
<td></td>
<td>Female: 0</td>
<td>1x 29 y.o.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total: 3</td>
<td>1x 43 y.o.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ruslin et al⁴⁵ *</td>
<td>Male: Cannot be Determined</td>
<td>Cannot be</td>
<td>Nonspecific orbital fractures and complex naso-orbitoethmoid fractures</td>
<td>Cannot be Determined</td>
</tr>
<tr>
<td></td>
<td>Female: Cannot be Determined</td>
<td>Determined</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total: 4–9</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Hsieh et al⁴⁶</td>
<td>Male: Cannot be Determined</td>
<td>151x adults</td>
<td>Nonspecific orbital fractures</td>
<td>Cannot be Determined</td>
</tr>
<tr>
<td></td>
<td>Female: Cannot be Determined</td>
<td>9x elderly</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total: 160</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calderoni et al⁵⁶</td>
<td>Male: 29</td>
<td>Cannot be</td>
<td>Orbito-zygomatic fractures</td>
<td>Cannot be Determined</td>
</tr>
<tr>
<td></td>
<td>Female: 3</td>
<td>Determined</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total: 31</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yu et al⁷¹</td>
<td>Male: Cannot be Determined</td>
<td>Cannot be</td>
<td>98x 1 wall fracture</td>
<td>Cannot be Determined</td>
</tr>
<tr>
<td></td>
<td>Female: Cannot be Determined</td>
<td>Determined</td>
<td>39x 2 wall fracture</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total: 173</td>
<td></td>
<td>36x 3–4 wall fracture</td>
<td></td>
</tr>
<tr>
<td>Christian et al⁷³</td>
<td>Male: Cannot be Determined</td>
<td>Cannot be</td>
<td>Nonspecific orbital fractures</td>
<td>Cannot be Determined</td>
</tr>
<tr>
<td></td>
<td>Female: Cannot be Determined</td>
<td>Determined</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Total: 38</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manana et al⁷⁴</td>
<td>Male: Cannot be Determined</td>
<td>Cannot be</td>
<td>Nonspecific orbital fractures</td>
<td>Cannot be Determined</td>
</tr>
<tr>
<td></td>
<td>Female: Cannot be Determined</td>
<td>Determined</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total: 19</td>
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<td></td>
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<tr>
<td><strong>Case Reports</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baldwin et al⁵⁰</td>
<td>Male</td>
<td>31</td>
<td>Orbital roof fracture</td>
<td>Cannot be Determined</td>
</tr>
<tr>
<td>Himori et al⁵¹</td>
<td>Female</td>
<td>20</td>
<td>Blow-out fracture followed by central retinal vein occlusion</td>
<td>Unilateral loss of VA</td>
</tr>
<tr>
<td>Day et al⁷⁸</td>
<td>Male</td>
<td>50</td>
<td>Complex left orbital fracture</td>
<td>Full recovery of VA</td>
</tr>
<tr>
<td>Zhang-Nunes et al⁷⁷</td>
<td>Male</td>
<td>20</td>
<td>Right orbital floor and medial wall fracture with globe displacement</td>
<td>Full recovery of VA</td>
</tr>
<tr>
<td>Ueki et al⁷⁹</td>
<td>Male</td>
<td>19</td>
<td>Orbital floor fracture (infection of resorbable plates)</td>
<td>Full recovery of VA</td>
</tr>
<tr>
<td>Agarwal et al⁶⁵</td>
<td>Male</td>
<td>22</td>
<td>Bilateral orbital roof and medial wall fractures with pneumatization of intraorbital portion of the optic nerve sheath</td>
<td>N/A, in coma</td>
</tr>
<tr>
<td>Neves et al⁶⁶</td>
<td>Male</td>
<td>71</td>
<td>Orbital floor fracture (pneumo-orbital cysts after orbital fracture repair)</td>
<td>Full recovery of VA</td>
</tr>
<tr>
<td>do O silva et al⁵⁹</td>
<td>Male</td>
<td>27</td>
<td>Zygomatic-orbital complex fracture</td>
<td>Full recovery of VA</td>
</tr>
</tbody>
</table>

(Continued)
Table 2 (Continued).

<table>
<thead>
<tr>
<th>Study</th>
<th>Number of Individuals with Injury</th>
<th>Age (Years)</th>
<th>Type of Orbital Fracture</th>
<th>Resolution of Visual Acuity?/Full Recovery?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pessoa Neto et al52</td>
<td>Male</td>
<td>32</td>
<td>Orbital-zygomaticomaxillary complex fracture</td>
<td>Blindness Unilateral, ophthalmology</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>performed evisceration of eye</td>
</tr>
<tr>
<td>Pereira et al70</td>
<td>Male</td>
<td>21</td>
<td>Orbital roof fracture</td>
<td>Full recovery of VA</td>
</tr>
</tbody>
</table>

**Notes:** *A range was provided because the total number of motorcycle-associated orbital fractures was determined from a bar chart and it was not possible to ascertain the exact number of motorcycle-associated orbital fractures from this chart. Therefore, a range was provided.

Table 3 Characteristics of Patients with Motorcycle-Associated Foreign Body Injuries

<table>
<thead>
<tr>
<th>Study</th>
<th>Number of Individuals with Injury</th>
<th>Age (Years)</th>
<th>Type of Foreign Body and Location of Foreign Body</th>
<th>Resolution of Visual Acuity?/Full Recovery?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naik et al22</td>
<td>Male</td>
<td>30</td>
<td>7-cm-long motorbike handle lodged in the retrobulbar space of both orbits</td>
<td>Unilateral loss of VA</td>
</tr>
<tr>
<td>Das et al23</td>
<td>Male</td>
<td>29</td>
<td>Motorcycle handle was seen lodged in his left orbit (10.3 cm in length and 2 cm in diameter)</td>
<td>Full recovery of VA</td>
</tr>
<tr>
<td>Nowroozzadeh et al25</td>
<td>Male</td>
<td>25</td>
<td>Two pieces of metal</td>
<td>Unilateral blindness</td>
</tr>
<tr>
<td>Hegde et al30</td>
<td>Male</td>
<td>37</td>
<td>Impacted visor in the left orbit with breached orbital roof</td>
<td>Unilateral blindness</td>
</tr>
<tr>
<td>Potapov et al38</td>
<td>Male</td>
<td>26</td>
<td>Small wooden foreign body in left naso orbital zone</td>
<td>Unilateral blindness</td>
</tr>
<tr>
<td>Wang et al31</td>
<td>Male</td>
<td>30</td>
<td>Large plant foreign body penetrating the nasal orbit through the left upper eyelid</td>
<td>Unilateral blindness</td>
</tr>
<tr>
<td>Arunkumar et al53</td>
<td>Male</td>
<td>27</td>
<td>Wooden stick 15 cm long that emerged from below the right medial canthus</td>
<td>Death</td>
</tr>
<tr>
<td>Kapoor et al63</td>
<td>Male</td>
<td>36</td>
<td>Wooden foreign body (30×6mm) between the medial rectus and optic nerve</td>
<td>Full recovery of VA</td>
</tr>
</tbody>
</table>

Table 4 Characteristics of Patients with Motorcycle-Associated Vitreoretinal Trauma

<table>
<thead>
<tr>
<th>Study</th>
<th>Number of Individuals with Injury</th>
<th>Age (Years)</th>
<th>Type of Injury</th>
<th>Resolution of Visual Acuity?/Full Recovery?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tatlipinar et al61</td>
<td>Male</td>
<td>22</td>
<td>Purtscher’s Retinopathy</td>
<td>Loss of Visual Acuity Bilaterally</td>
</tr>
<tr>
<td>Levin et al64</td>
<td>Male</td>
<td>28</td>
<td>Purtscher’s Retinopathy</td>
<td>Full recovery of VA</td>
</tr>
<tr>
<td>Cappello et al68</td>
<td>Male</td>
<td>51</td>
<td>Whiplash maculopathy</td>
<td>Full recovery of VA</td>
</tr>
<tr>
<td>Roybal et al82</td>
<td>Male</td>
<td>26</td>
<td>Blurred vision and diplopia due to macular edema</td>
<td>Full recovery of VA</td>
</tr>
<tr>
<td>Ioannidis et al83</td>
<td>Male</td>
<td>14</td>
<td>Valsalva retinopathy</td>
<td>Full recovery of VA</td>
</tr>
</tbody>
</table>
primarily focus on motorcycle-associated injury, and therefore data regarding motorcycles were inconsistently reported among the studies. In addition, several studies reported aggregate, mixed data in a manner that precluded the reviewers from parsing out any motorcycle-specific data and made it impossible to determine whether reported eye injuries were indeed caused by motorcycles. Therefore, these studies were excluded from our analysis.

### Table 5 Characteristics of Patients with Motorcycle-Associated Neuro-Ophthalmic Trauma

<table>
<thead>
<tr>
<th>Study</th>
<th>Number of Individuals with Injury</th>
<th>Age (Years)</th>
<th>Types of Injury</th>
<th>Resolution of Visual Acuity?/Full Recovery?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keane et al</td>
<td>Male: 89 Female: 7 Total: 96</td>
<td>Range: 15–52 Mean: 25.5</td>
<td>Optic nerve injuries (n = 18) Homonymous hemianopia (n = 4) Papilledema (n = 6) Third-nerve palsy (n = 27) Fourth-nerve palsy (n = 19) Sixth-nerve palsy (n = 25) Seventh-nerve palsy (n = 10) Pectal syndrome (n = 6) Internuclear ophthalmoplegic (n = 3) Skew deviation (n = 1) Gaze palsy (n = 1) Nystagmus (n = 14) Other involuntary eye movements (n = 3) Orbital muscle palsy (n = 3) Orbital apex syndrome (n = 2) Carotic-cavernous fistula (n = 1) Horner’s syndrome (n = 5) Isolated, fixed, dilated pupil (n = 5).</td>
<td>It was found that no individuals with optic nerve injury recovered to their baseline visual acuity, and those with ocular motor manifestations had variable recovery.</td>
</tr>
<tr>
<td>Kal et al</td>
<td>Male</td>
<td>22</td>
<td>Abducens nerve palsy and Horner Syndrome</td>
<td>Cannot be Determined</td>
</tr>
<tr>
<td>Sinawat et al</td>
<td>Male</td>
<td>47</td>
<td>Cortical blindness</td>
<td>Bilateral loss of visual acuity</td>
</tr>
<tr>
<td>Ahmad Fauzi et al</td>
<td>Male</td>
<td>20</td>
<td>Bitemporal hemianopia secondary to traumatic chiasmal syndrome</td>
<td>Unilateral loss of visual acuity</td>
</tr>
<tr>
<td>Sherman et al</td>
<td>Male</td>
<td>31</td>
<td>Traumatic optic neuropathy</td>
<td>Bilateral loss of visual acuity</td>
</tr>
<tr>
<td>Gotfried et al</td>
<td>Female</td>
<td>45</td>
<td>Ptosis caused by complete third nerve palsy</td>
<td>Cannot be Determined</td>
</tr>
<tr>
<td>Vien et al</td>
<td>Male</td>
<td>25</td>
<td>Transsynaptic retrograde degeneration and homonymous hemianopia</td>
<td>Full recovery of VA</td>
</tr>
<tr>
<td>Alderazi et al</td>
<td>Male</td>
<td>45</td>
<td>Right carotic-cavernous fistula</td>
<td>Cannot be Determined</td>
</tr>
<tr>
<td>Meena et al</td>
<td>Male</td>
<td>41</td>
<td>Optic nerve transection</td>
<td>Unilateral blindness</td>
</tr>
<tr>
<td>Kastelan et al</td>
<td>Male</td>
<td>47</td>
<td>Traumatic optic neuropathy</td>
<td>Full recovery of VA</td>
</tr>
<tr>
<td>Bhat et al</td>
<td>Male</td>
<td>50</td>
<td>Traumatic optic neuropathy</td>
<td>Bilateral loss of visual acuity</td>
</tr>
<tr>
<td>Ham et al</td>
<td>Male</td>
<td>35</td>
<td>Bilateral optic nerve deficits</td>
<td>Cannot be Determined</td>
</tr>
</tbody>
</table>

Case Reports

<table>
<thead>
<tr>
<th>Study</th>
<th>Number of Individuals with Injury</th>
<th>Age (Years)</th>
<th>Types of Injury</th>
<th>Resolution of Visual Acuity?/Full Recovery?</th>
</tr>
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<td>Male</td>
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<td>Abducens nerve palsy and Horner Syndrome</td>
<td>Cannot be Determined</td>
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<td>Female</td>
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<td>Male</td>
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<tr>
<td>Bhat et al</td>
<td>Male</td>
<td>50</td>
<td>Traumatic optic neuropathy</td>
<td>Bilateral loss of visual acuity</td>
</tr>
<tr>
<td>Ham et al</td>
<td>Male</td>
<td>35</td>
<td>Bilateral optic nerve deficits</td>
<td>Cannot be Determined</td>
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</tbody>
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Orbital Fractures

A total of 23 studies described orbital fractures secondary to motorcycle accidents. Ten studies were case reports, 11 were retrospective case series, and two were prospective studies (Table 1)\(^{20,21,26,28,31–34,37,39–41,45,46,55,56,59,62,66,70,71,73,74}\). Overall, the findings of these studies provided detailed information regarding the types and sequelae of orbital fractures and the characteristics of those who developed motorcycle-accident associated orbital fractures (Table 2).

One study found that significantly more males were involved in motorcycle crashes and subsequently developed orbital fractures than females.\(^{66}\) Another study found that orbital fractures associated with motorcycle accidents were more common

| Table 6 Characteristics of Patients with Motorcycle-Associated Corneal Trauma |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| Study                          | Number of Individuals with Injury | Age (Years) | Types of Injury | Resolution of Visual Acuity?/Full Recovery? |
| Tamilarsan et al\(^{68}\)      | Male: 3 Female: 1 Total: 4       | 1x 18 y.o. 1x 22 y.o. 1x 23 y.o. 1x 24 y.o. | Ophthamia Nodosa | Cannot be Determined |
| Huang et al\(^{62}\)           | Male: 2 Female: 2 Total: 4       | 1x 21 y.o. 1x 35 y.o. 1x 46 y.o. 1x 56 y.o. | Keratitis       | Cannot be Determined |
| Saka et al\(^{77}\)            | Male: Cannot be Determined Female: Cannot be Determined Total: 6 | Cannot be Determined | Corneal Lacerations | 2x Full recovery 2x Cannot be Determined |
| Johnson et al\(^{24}\)         | Male                           | 43           | Corneal perforation after bacterial keratitis | Cannot be Determined |
| Ausayakhun et al\(^{59}\)      | Male                           | 68           | Insect hair deeply embedded in the corneal stroma | Full recovery of VA |

| Table 7 Characteristics of Patients with Motorcycle-Associated Open Globe Injuries |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| Study                          | Number of Individuals with Injury | Age (Years) | Types of Injury | Resolution of Visual Acuity?/Full Recovery? |
| Upaphong et al\(^{79}\)        | Male: Cannot be Determined Female: Cannot be Determined Total: 30 | Cannot be Determined | Open Globe Injury | Cannot be Determined |
| Orr et al\(^{50}\)             | Male: Cannot be Determined Female: Cannot be Determined Total: 1 | Cannot be Determined | Open Globe Injury | Cannot be Determined |
| Okamoto et al\(^{75}\)         | Male: 1 Female: Cannot be Determined Total: 1 | 30 y.o. male | Open Globe Injury | Cannot be Determined |

Orbital Fractures

A total of 23 studies described orbital fractures secondary to motorcycle accidents. Ten studies were case reports, 11 were retrospective case series, and two were prospective studies (Table 1).\(^{20,21,26,28,31–34,37,39–41,45,46,55,56,59,62,66,70,71,73,74}\) Overall, the findings of these studies provided detailed information regarding the types and sequelae of orbital fractures and the characteristics of those who developed motorcycle-accident associated orbital fractures (Table 2).

One study found that significantly more males were involved in motorcycle crashes and subsequently developed orbital fractures than females.\(^{66}\) Another study found that orbital fractures associated with motorcycle accidents were more common
Analyzing these studies in aggregate, we found that motorcycle accidents can lead to the following types of orbital fractures: orbital roof, orbital floor, blow-out fractures, tripod fractures, orbito-zygomatic fractures, naso-orbito fractures, maxilla-orbital fractures, and complex naso-orbito-ethmoid fractures. In addition, several studies noted that at a given center, the most common etiology for orbital fractures and facial fractures involving the orbit was motorcycle accidents. For example, Ellis et al found that at a single center, motorcycle accidents not only commonly caused zygomatico-orbital fracture, but were the most frequent cause of bilateral orbital fractures and were associated with more major trauma than any other etiology. Studies also found that the presence of orbital fractures can be a strong indicator for other injuries or clinical outcomes such as neurological deficits. For example, Kraus et al found that the presence of orbital fracture in the setting of motorcycle accidents was a strong predictor of traumatic brain injury, while Yu et al found that certain

### Table 8 Characteristics of Patients with Other Types of Motorcycle-Associated Eye Injuries

<table>
<thead>
<tr>
<th>Study</th>
<th>Number of Individuals with Injury</th>
<th>Age (Years)</th>
<th>Types of Injury</th>
<th>Resolution of Visual Acuity/Full Recovery?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lin et al57</td>
<td>Male: Cannot be Determined Female: Cannot be Determined Total: 20</td>
<td>Cannot be Determined</td>
<td>Canalicular lacerations</td>
<td>Cannot be Determined</td>
</tr>
<tr>
<td>Nakaishi et al54</td>
<td>Male: 600 Female: 0 Total: 600</td>
<td>Mean: 34.5 years Median 32.4 years</td>
<td>590x pinguecula, 10x pterygia</td>
<td>Cannot be Determined</td>
</tr>
<tr>
<td>Achigbu et al57</td>
<td>Male: 635 Female: 0 Total: 635</td>
<td>Cannot be Determined</td>
<td>269x Pinguecula 206x Pterygia 160x Hyperemia and subconjunctival hemorrhages</td>
<td>Cannot be Determined</td>
</tr>
<tr>
<td>Ukpongwan et al58</td>
<td>Male: 55 Female: 0 Total: 55</td>
<td>Cannot be Determined</td>
<td>37x pinguecula 18x pterygium</td>
<td>Cannot be Determined</td>
</tr>
<tr>
<td>Arif et al59</td>
<td>Male: Cannot be Determined Female: Cannot be Determined Total: Cannot be Determined</td>
<td>Cannot be Determined</td>
<td>173x Orbital abrasion 93x orbital laceration 83x orbital contusions</td>
<td>Cannot be Determined</td>
</tr>
</tbody>
</table>

**Case Reports**

<table>
<thead>
<tr>
<th>Study</th>
<th>Number of Individuals with Injury</th>
<th>Age (Years)</th>
<th>Types of Injury</th>
<th>Resolution of Visual Acuity/Full Recovery?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norazah et al55</td>
<td>Male</td>
<td>18</td>
<td>Right eye positioned outside the eyelid fissure on the malar eminence, hanging by lateral rectus muscle</td>
<td>Unilateral blindness</td>
</tr>
<tr>
<td>Jabaut et al43</td>
<td>Male</td>
<td>21</td>
<td>Periorbital edema</td>
<td>Cannot be Determined</td>
</tr>
<tr>
<td>Khadamy et al44</td>
<td>Male</td>
<td>19</td>
<td>Traumatic enucleation</td>
<td>Unilateral blindness</td>
</tr>
<tr>
<td>Tuncbilek et al78</td>
<td>Male</td>
<td>23</td>
<td>Globe avulsion</td>
<td>Unilateral blindness</td>
</tr>
</tbody>
</table>
types of orbital fractures were a predictor of a poor Glasgow Coma Score.\(^{34,71}\) Christian et al also found that motorcyclists who did not wear helmets were at higher risk of orbital fractures, and Johnson et al surprisingly found that wearing eye protection (ie motorcycle goggles) without a helmet may increase the risk of peri-orbital injury\(^{31,73}\) (Table 2).

Orbital fractures due to motorcycle accidents can potentially lead to other sequelae. For example, orbital fractures and their associated mechanical trauma can lead to enophthalmos, central retinal vein occlusions, retrobulbar hematomas, pneumatization of the intraorbital optic nerve, globe prolapse, and Brown’s syndrome after entrapment of the superior oblique muscle.\(^{20,26,33,37,40,55}\) There were also reports of complications following motorcycle-associated orbital fracture repair, such as infection and pneumo-orbital cysts\(^{39,56}\) (Table 2).

### Foreign Body Injuries

Our literature search yielded eight articles describing foreign body injuries secondary to motorcycle accidents.\(^{22,23,25,30,38,51,53,63}\) All eight articles were case reports. All eight cases of foreign body injuries involved adult males between the ages of 25–40 years old. Two cases involved a motorcycle handle being lodged in the orbit.\(^{22,23}\) Three cases involved wooden objects penetrating the orbit, while the remaining cases involved a large plant, motorcycle visor, and metal objects.\(^{25,30,38,51,53,63}\) Five (62.5%) of these foreign body cases resulted in permanent loss of visual acuity or unilateral blindness due to irreversible injury to the optic nerve\(^{22,25,30,38,51}\) (Table 3).

### Vitreoretinal Injury

Similar to knowledge regarding motorcycle-associated foreign body injuries, current knowledge of motorcycle-associated vitreoretinal trauma is limited to case reports \((n = 5)\).\(^{61,64,68,82,83}\) Only one case of vitreoretinal damage did not involve an adult.\(^{83}\) In fact, this case involved a 14-year-old who developed Valsalva retinopathy while riding a motorcycle and attempting to perform stunts, ultimately achieving a full recovery after rest and avoiding strenuous activity.\(^{83}\) Two of these vitreoretinal cases described the development of Purtscher’s Retinopathy after severe head trauma from a motorcycle accident, one case resulting in permanent loss of visual acuity bilaterally while the other fully recovered.\(^{61,64}\) Another case involved a 51-year-old who developed a whiplash maculopathy after being involved in a crash, later achieving a full recovery after one year.\(^{68}\) The final case described a 26-year-old who developed retinopathy and macular edema secondary to a carotid-cavernous fistula caused by head trauma during a motorcycle accident but eventually recovered fully\(^{82}\) (Table 4).

### Neuro-Ophthalmic Manifestations

A total of 12 studies were identified that described neuro-ophthalmic manifestations secondary to motorcycle accidents.\(^{19,28,35,36,42,47,57,60,72,76,79–81}\) Only one of these 12 studies was not a case report and described the neuro-ophthalmic complications associated with motorcycle and moped accidents observed in two centers over an 18-year period.\(^{47}\) This study described 94 motorcycle-associated neuro-ophthalmic injuries and 2 moped-associated neuro-ophthalmic injuries. Of these patients, 89 were operators and 7 were passengers, and all 96 patients also had associated head injuries.\(^{47}\) In addition, almost all of these patients were male \((89/96)\), and only four \((4/96, 4.2\%)\) were confirmed to be wearing helmets.\(^{47}\) Neuro-ophthalmic injuries included optic nerve injuries \((n = 18)\), homonymous hemianopia \((n = 4)\), papilledema \((n = 6)\), third-nerve palsy \((n = 27)\), fourth-nerve palsy \((n = 19)\), sixth-nerve palsy \((n = 25)\), seventh-nerve palsy \((n = 10)\), pretectal syndrome \((n = 6)\), internuclear ophthalmoplegia \((n = 3)\), skew deviation \((n = 1)\), gaze palsy \((n = 1)\), nystagmus \((n = 14)\), other involuntary eye movements \((n = 3)\), orbital muscle palsy \((n = 3)\), orbital apex syndrome \((n = 2)\), carotid-cavernous fistula \((n = 1)\), Horner’s syndrome \((n = 5)\), and isolated, fixed, dilated pupil \((n = 5)\).\(^{47}\) It was found that no individuals with optic nerve injury recovered to their baseline visual acuity, and those with ocular motor manifestations had variable recovery. Keane et al also described how alcohol consumption was a precipitating factor in many of these motorcycle accidents, although the exact number was unspecified\(^{17}\) (Table 5).

Four of the remaining 11 case reports describing neuro-ophthalmic injuries also described the same types of injuries observed by Keane et al.\(^{19,60,72,81}\) The other seven case reports described other neuro-ophthalmic manifestations secondary to motorcycle accidents, including bitemporal hemianopia secondary to traumatic chiasmal syndrome, permanent cortical blindness, traumatic optic neuropathy, optic nerve transection, and retrograde degeneration of retinal
ganglion cells.\textsuperscript{29,36,42,65,76,79,80} All but one of these case reports involved males, and all cases of neuro-ophthalmic injury were observed in adults (Table 5).

**Corneal Injuries**
A total of six studies that described corneal manifestations due to motorcycle accidents were identified, two of which were case reports and the remaining three were retrospective case series.\textsuperscript{24,48,52,69,77,79} Males constituted most of the reported cases of corneal injuries. Again, across all six studies, almost all patients were adults (Table 6).

From these six studies, two retrospective case series and one case report described corneal injuries, such as ophthalmia nodosa and keratitis, that resulted from insects entering the motorcyclists’ eye.\textsuperscript{48,52,69} For example, Tamilarasan et al described how four patients presented with ocular irritation after an insect entered their eye while operating a motorcycle.\textsuperscript{48} In all four patients, the insect penetrated the cornea and the resulting insect hairs or spines caused anterior chamber reactions.\textsuperscript{48} Tamilarasan et al, in this case, emphasized the importance of eye protection in preventing injuries such as ophthalmia nodosa when operating a motorcycle. Motorcycle accidents were also shown to cause corneal lacerations.\textsuperscript{77} One study found that after a motorcycle crash significant secondary trauma and systemic infection, a patient developed bacterial keratitis and subsequently a corneal perforation\textsuperscript{24} (Table 6).

**Open Globe Injuries**
We identified three retrospective cases series that provided some data that showed motorcycle accidents could lead to open globe injuries.\textsuperscript{49,50,75} Unfortunately, all three studies focused on traffic accident-related open globe injuries and secondarily reported data regarding motorcycles. Therefore, there was less available data from these studies regarding motorcycle-associated open globe injuries. Due to how the aggregate data was reported in all three studies, we could not determine information regarding the stratification by age and sex from any of these studies nor could we determine any of the long-term sequelae associated with motorcycle-associated open globe injuries (Table 7).

**Other**
There were nine identified studies that provided data on other ocular manifestations that can occur secondary to motorcycle accidents and usage, such as pinguecula, pterygia, canalicular lacerations, orbital abrasions, subconjunctival hemorrhages, lacerations, and contusions, and globe avulsions.\textsuperscript{27,35,43,44,54,57,58,67,78} Four of these studies were case reports, two were retrospective case series, and three were prospective studies. Among the three studies that investigated the prevalence of pterygia and pinguecula among motorcyclists, the reported prevalence across studies varied widely for both pterygia (12.5 – 33.5\%) and pinguecula (37.7 – 43.7\%).\textsuperscript{54,57,58} Among all of these studies, nearly all patients were adult males (Table 8).

**Discussion**
The objectives of this study were to characterize the literature regarding motorcycle-associated eye injuries, provide an all-encompassing review of the types of motorcycle-associated ocular injuries, and classify descriptive characteristics of those most afflicted. Unfortunately, we could not discern the relative distribution of males and females in many of the non-case report studies. However, most studies that did report data regarding sex commonly found that motorcycle accidents involved males. This result is not surprising, as most motorcycle owners are males.\textsuperscript{86} It was also notable that among all ocular injuries associated with motor vehicle accidents, motorcycle accidents comprised one of the most common causes of ocular injuries, only second to car accidents.\textsuperscript{45}

We also found that overall publications regarding motorcycle related-eye injuries are lacking, consisting mostly of case reports and retrospective studies that are not focused specifically on motorcycle eye injuries. In fact, out of the 65 studies that reported at least some data regarding motorcycle-associated eye injuries, 40 (61.5\%) were case reports. In addition, among the 25 retrospective and prospective studies identified in our literature search, only 12 (48.0\%) studies were exclusively focused on motorcycle-associated injuries and 15 (60.0\%) were considered to have a low risk of bias. There is also less knowledge regarding certain types of motorcycle-associated ocular injuries. For example, motorcycle-associated foreign body injuries are limited to case reports. This review highlights existing gaps in knowledge and will hopefully encourage future studies to address these gaps.
From the results of this review, motorcycle eye injuries can at times lead to permanent loss of visual acuity and, in severe cases, blindness. However, the role of eye protection, such as helmet visors and goggles, in preventing eye injuries is poorly characterized in the medical literature. Eye protection presumably serves two functions: firstly, to reduce the risk of motorcycle accidents by preventing vision obstruction caused by foreign objects and wind; secondly, to reduce or even possibly prevent eye injuries in the event of a motorcycle accident. The most recent study that investigated the role of eye protection in preventing motorcycle crashes was the Hurt Report of 1981. They found that in 73% of motorcycle accidents, the operator was not wearing eye protection, likely causing wind and foreign bodies to impair vision on unprotected eyes and subsequently reduce awareness of potential surrounding hazards. According to the present study, while it is clear that there were instances in which the use of eye protection could have directly prevented eye injury (ie ophthalmia nodosa), it is unclear how many eye injuries caused by the motorcycle accident themselves could have been prevented with eye protection, as reporting concerning the use of eye protection was severely limited. It is also important to note that there were instances in which the eye protection device was the primary modality of eye injury (ie impacted visor in left orbit). In addition, it was notable that Johnson et al found that wearing eye protection (ie motorcycle goggles) without a helmet can surprisingly increase the risk of periorbital injury, indicating that helmet use in tandem with eye protection may be indicated. In fact, helmet use could also possibly attenuate or even prevent certain motorcycle-associated eye injuries, as Keane et al found that all cases of neuro-ophthalmic trauma were associated with head trauma. Further studies need to be conducted to better characterize the roles of eye protection in preventing crashes and eye injuries in the event of an accident. This research should include case-control studies to investigate more quantitatively the associations with protective and risk factors.

There were several limitations to this narrative review of the literature. Firstly, for many studies, we were unable to determine the nature of the motorcycle accidents (ie fall from a motorcycle, crash into another vehicle), which could play a role in the type and severity of eye injury incurred by the motorcyclist. In addition, due to inconsistent reporting, we could not ascertain whether an injured motorcyclist was wearing some form of eye protection and/or a helmet at the time of the accident for many studies, preventing us from conducting a more insightful analysis. In addition, the decision to exclude languages other than English could have led to language bias. Finally, the decision to exclude grey literature could have led to publication bias, as it is understood that published studies are more likely to report positive results.

**Conclusion**

The current state of the literature indicates that knowledge regarding the ocular manifestations of motorcycle accidents is limited to mostly case reports and few retrospective cohort studies focused specifically on motorcycle-associated eye injuries. However, it is evident that the types of motorcycle-associated eye injuries are legion and predominantly seen in adult males, potentially leading to severe injuries and loss of vision and blindness. Future research needs to be conducted in order to better characterize the epidemiology of certain types of motorcycle-associated eye injuries (ie foreign body injuries) and to better understand the roles of eye protection in reducing eye injuries, both through its prevention of visual interruptions that cause crashes and through the attenuation of eye injury severity in the event of an accident.

**Data Sharing Statement**

All data for the research reported herein is available upon reasonable request from the corresponding author (EJK).

**Disclosure**

The authors report no conflicts of interest in this work.

**References**


48. Kim et al
61. Kim et al
64. Kim et al