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REVIEW

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

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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.[13–15] 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.[16,17]

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.[18] 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.

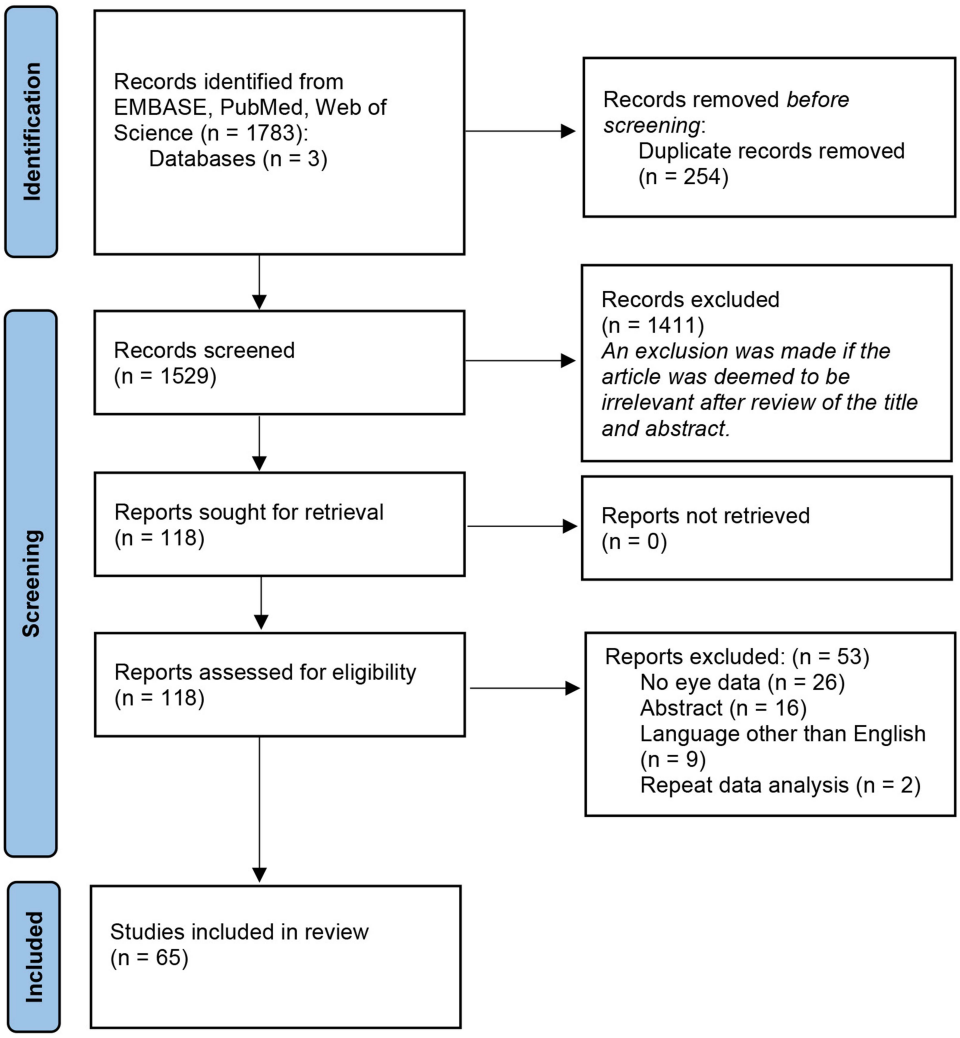

Figure 1 The initial search of three total databases yielded a total of 1529 results after 254 duplicates were removed by Covidence. A total of 118 full texts were assessed, 65 of which were eligible for qualitative synthesis. Adapted from Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*. 2021;372:n71. doi: 10.1136/bmj.n.

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.[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.[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 1 General Characteristics of Studies That Include Motorcycle-Related Eye Injury Data

Study	Year	Country	Risk of Bias	Study Design	Data Source, Years(s) if Available	Primary OBJECTIVE of STUDY	Focused on Motorcycle Injury? (1) Yes (2) No	Injury Category
Kal et al[19]	2015	Turkey	N/A	Case Report	N/A	To present a case of right abducens nerve palsy with ipsilateral Horner syndrome after motorcycle accident.	Yes	Neuro Ophthalmic
Baldwin et al[20]	1988	United States	N/A	Case Report	N/A	To present a case of Brown's Syndrome due to motorcycle accident-induced orbital fracture.	Yes	Orbital Fractures
Ellis et al[21]	1985	Scotland	Moderate	Retrospective Case Series	Canniesburn Hospital, 1974–1983	To describe the epidemiology of zygomatico-orbital fractures seen at a single center during a 10 year period.	No	Orbital Fractures
Naik et al[22]	2011	India	N/A	Case Report	N/A	To present a case in which a motorbike handle presenting as a bilateral foreign body.	Yes	Foreign Body
Das et al[23]	2021	India	N/A	Case Report	N/A	To present a case in which a motorcycle handle was embedded in left orbit after a motorcycle accident.	Yes	Foreign Body
Johnson et al[24]	2000	United States	N/A	Case Report	N/A	To present a case of bacterial keratitis secondary to a motorcycle accident that led to a corneal perforation.	Yes	Corneal
Nowroozzadeh et al[25]	2009	India	N/A	Case Report	N/A	To present a case with a brake lever as foreign body after a motorcycle accident.	Yes	Foreign Body
Himori et al[26]	2009	Japan	N/A	Case Report	N/A	To present a case of central retinal artery occlusion secondary to motorcycle-associated orbital fracture.	Yes	Orbital Fractures

(*Continued*)

Table 1 (Continued).

Study	Year	Country	Risk of Bias	Study Design	Data Source, Years(s) if Available	Primary OBJECTIVE of STUDY	Focused on Motorcycle Injury? (1) Yes (2) No	Injury Category
Lin et al[27]	2019	Taiwan	Low	Retrospective Case Series	Taichung Veterans General Hospital, 2009–2018	To describe the epidemiology of canalicular lacerations and surgical outcomes with Mini-Monoka insertions at a single center during a 10 year period.	No	Other - Canalicular Lacerations
Day et al[28]	2018	United States	N/A	Case Report	N/A	To describe management of failed reduction of complex orbital fracture after motorcycle accident.	Yes	Orbital Fractures
Sinawat et al[29]	2006	Thailand	N/A	Case Report	N/A	To present a case of blindness OU after a motorcycle accident.	Yes	Neuro Ophthalmic
Hegde et al[30]	2005	United Kingdom	N/A	Case Report	N/A	To present a case with a visor as foreign body that also caused carotid artery laceration.	Yes	Foreign Body
Johnson et al[31]	1995	United States	Moderate	Retrospective Case Series	Regional Level I trauma center, 4-year study period	To analyze the impacts of wearing a motorcycle helmet and other factors on the type, severity, and incidence of facial injuries.	Yes	Orbital Fractures
Gopalakrishna et al[32]	1998	United States	Low	Retrospective Case Series	9 California hospitals, 1991–1993	To describe the epidemiology of facial injuries among motorcyclists.	Yes	Orbital Fractures
Chen et al[33]	2016	Taiwan	Moderate	Retrospective Case Series	Chang Gung Memorial Hospital, 2000–2011	To evaluate outcomes of those who developed enophthalmos after orbital fracture repair.	No	Orbital Fractures
Kraus et al[34]	2003	United States	Moderate	Retrospective Case Series	28 California hospitals, 1991–1993	To describe the epidemiology of facial injuries observed in motorcyclists after an accident.	Yes	Orbital Fractures

(*Continued*)

Table 1 (Continued).

Study	Year	Country	Risk of Bias	Study Design	Data Source, Years(s) if Available	Primary OBJECTIVE of STUDY	Focused on Motorcycle Injury? (1) Yes (2) No	Injury Category
Norazah et al[35]	2011	Malaysia	N/A	Case Report	N/A	To present a case of globe avulsion after a motorcycle accident.	Yes	Other - globe avulsion
Ahmad Fauzi et al[36]	2021	Malaysia	N/A	Case Report	N/A	To present a case of bitemporal hemianopia after a motorcycle accident.	Yes	Neuro Ophthalmic
Zhang-Nunes et al[37]	2012	United States	N/A	Case Report	N/A	To present a case of globe prolapse into maxillary sinus after motorcycle-associated trauma.	Yes	Orbital Fractures
Potapov et al[38]	1996	Russia	N/A	Case Report	N/A	To present a case of a wooden foreign body after a motorcycle accident.	Yes	Foreign Body
Ueki et al[39]	2020	Japan	N/A	Case Report	N/A	To present a case of plate infection that occurred 1 year after motorcycle-induced orbital fracture.	Yes	Orbital Fractures
Chen et al[40]	2012	Taiwan	Low	Retrospective Case Series	Chang Gung Memorial Hospital, 1999–2009	To describe the epidemiology of traumatic retrobulbar hematomas at a single center	No	Orbital Fractures
Haug et al[41]	2000	United States	Low	Retrospective Case Series	Level I Kentucky Trauma Center, 1992–1998	To describe the epidemiology and management of the trochlea of the superior oblique muscle when repairing orbital roof trauma at a single center.	No	Orbital Fractures
Sherman et al[42]	1997	United States	N/A	Case Report	N/A	To describe the management of traumatic optic neuropathy secondary to motorcycle accidents.	Yes	Neuro Ophthalmic

(*Continued*)

Table 1 (Continued).

Study	Year	Country	Risk of Bias	Study Design	Data Source, Years(s) if Available	Primary OBJECTIVE of STUDY	Focused on Motorcycle Injury? (1) Yes (2) No	Injury Category
Jabaut et al[43]	2017	United States	N/A	Case Report	N/A	To present a case of mandibular degloving and other associated facial trauma after a motorcycle accident.	Yes	Other-eyelid lacerations and periorbital edema
Khadamy et al[44]	2017	Iran	N/A	Case Report	N/A	To present a case of traumatic enucleation after a motorcycle accident.	Yes	Other-traumatic enucleation
Ruslin et al[45]	2019	European multicenter	Low	Prospective	12 European departments of oral and maxillofacial surgery, 2012–2013	To describe the epidemiology of facial fractures due to motor vehicle accidents in multiple centers.	No	Orbital Fractures
Hsieh et al[46]	2017	Taiwan	Low	Retrospective Case Series	Kaohsiung Chang Gung Memorial Hospital, 2009–2013	To describe the epidemiology of motorcycle-associated injuries among the elderly at a single center.	Yes	Orbital Fractures
Keane et al[47]	1989	United States	Moderate	Retrospective Case Series	2 California centers, 18-year period	To describe neuro-ophthalmic complications associated with motorcycle accidents observed in two centers.	Yes	Neuro Ophthalmic
Tamilarsan et al[48]	2022	Malaysia	Low	Retrospective Case Series	Hospital University Sains Malaysia	To describe 4 different cases of ocular injuries associated with insects entering the eye while operating a motorcycle.	Yes	Corneal
Upaphong et al[49]	2021	Thailand	Low	Retrospective Case Series	Chiang Mai University Hospital, 2006–2016	To describe epidemiology of traffic accident-associated open globe injuries in a single center.	No	Open Globe Injury

(*Continued*)

Table 1 (Continued).

Study	Year	Country	Risk of Bias	Study Design	Data Source, Years(s) if Available	Primary OBJECTIVE of STUDY	Focused on Motorcycle Injury? (1) Yes (2) No	Injury Category
Orr et al[50]	2015	United States	Low	Retrospective Case Series	Single center, 2000–2012	To describe epidemiology of motor vehicle accident-associated open globe injuries in a single center.	No	Open Globe Injury
Wang et al[51]	2013	China	N/A	Case Report	N/A	To present a case with a large foreign body after a motorcycle accident.	Yes	Foreign Body
Huang et al[52]	2010	Taiwan	Low	Retrospective Case Series	National Cheng Kung University Hospital	To describe the management of 4 cases of ocular injury from a beetle entering the eye while operating a motorcycle.	Yes	Corneal
Arunkumar et al[53]	1999	India	N/A	Case Report	N/A	To describe a twig foreign body after a motorcycle accident.	Yes	Foreign Body
Nakaishi et al[54]	1997	Japan	Low	Retrospective Case Series	Tokyo Metropolitan Police Department	To describe the prevalence of pterygia and pingueculae in policemen who regularly use motorcycles.	Yes	Other - pterygium
Agarwal et al[55]	2002	Australia	N/A	Case Report	N/A	To describe the management of pneumatization of the intraorbital optic nerve after a motorcycle accident.	Yes	Orbital Fractures
Neves et al[56]	1998	United States	N/A	Case Report	N/A	To describe a case of orbital cyst after repair of orbital fracture associated with motorcycle accident.	Yes	Orbital Fractures
Achigbu et al[57]	2014	Nigeria	High	Prospective	Recruited motorcyclists from Nigeria	To determine prevalence of pterygium among motorcyclists in Enugu State.	Yes	Other - pterygium

(*Continued*)

Table 1 (Continued).

Study	Year	Country	Risk of Bias	Study Design	Data Source, Years(s) if Available	Primary OBJECTIVE of STUDY	Focused on Motorcycle Injury? (1) Yes (2) No	Injury Category
Ukponmwan et al[58]	2007	Nigeria	High	Prospective	Recruited motorcyclists from Benin City	To determine prevalence and risk factors for pterygium and pinguecula in Nigerian motorcyclists.	Yes	Other - pterygium
do O silva et al[59]	2017	Brazil	N/A	Case Report	N/A	To assess the effectiveness of prototyping for the treatment of orbital fracture secondary to a motorcycle accident in a single patient.	Yes	Orbital Fractures
Gotfried et al[60]	2021	United States	N/A	Case Report	N/A	To report a case of third nerve palsy after a motorcycle accident.	Yes	Neuro Ophthalmic
Tatlipinar et al[61]	2007	Turkey	N/A	Case Report	N/A	To report a case of Purtscher's retinopathy after severe head trauma in a motorcycle accident.	Yes	Vitreoretinal
Pessoa Neto et al[62]	2019	Brazil	N/A	Case Report	N/A	To describe the management of a foreign body injury after a motorcycle accident.	Yes	Orbital Fractures
Kapoor et al[63]	2020	India	N/A	Case Report	N/A	To describe the clinical course of a retained intraorbital foreign body in a patient after a motorcycle crash.	Yes	Foreign Body
Levin et al[64]	1991	United States	N/A	Case Report	N//A	To describe a case of parafoveal retinal pigment epithelial tear after motorcycle accident.	Yes	Vitreoretinal
Vien et al[65]	2017	United States	N/A	Case Report	N/A	To describe a case of retrograde degeneration of retinal ganglion cells after motorcycle-associated head trauma.	Yes	Neuro Ophthalmic

(*Continued*)

Table 1 (Continued).

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

(*Continued*)

Table 1 (Continued).

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

(*Continued*)

Table 1 (Continued).

Study	Year	Country	Risk of Bias	Study Design	Data Source, Years(s) if Available	Primary OBJECTIVE of STUDY	Focused on Motorcycle Injury? (1) Yes (2) No	Injury Category
Ham et al[81]	2015	United States	N/A	Case Report	N/A	To report a case of patient with vision loss following a motorcycle accident	Yes	Neuro Ophthalmic
Roybal et al[82]	2016	United States	N/A	Case Report	N/A	To present a case of retinal complications following a motorcycle crash	Yes	Vitreoretinal
Ioannidis et al[83]	2004	UK	N/A	Case Report	N/A	To report a case of transient maculopathy following use of a motorcycle	Yes	Vitreoretinal

Table 2 Characteristics of Patients with Motorcycle-Associated Orbital Fractures

Study	Number of Individuals with Injury	Age (Years)	Type of Orbital Fracture	Resolution of Visual Acuity?/Full Recovery?
Retrospective and Prospective Studies				
Ellis et al[21]	Male: Cannot be Determined Female: Cannot be Determined Total: 18	Cannot be Determined	Tripod Fractures	Cannot be Determined
Johnson et al[31]	Male: Cannot be Determined Female: Cannot be Determined Total: 26	Cannot be Determined	Non-specified orbital fracture	Cannot be Determined
Gopalakrishna et al[32]	Male: Cannot be Determined Female: Cannot be Determined Total: 109	Cannot be Determined	Non-specified orbital fracture	Cannot be Determined
Chen et al[33]	Male: Cannot be Determined Female: Cannot be Determined Total: 209	Cannot be Determined	Orbital fracture with enophthalmos	Cannot be Determined
Kraus et al[34]	Male: Cannot be Determined Female: Cannot be Determined Total: 111	Cannot be Determined	Non-specified orbital fracture	Cannot be Determined
Chen et al[40]	Male: 6 Female: 1 Total: 7	2x 13 y.o. 1x 18 y.o. 1x. 20 y.o. 1x 23 y.o 2x.43 y.o.	Orbital fracture with retrobulbar hematoma	Cannot be Determined

(*Continued*)

Table 2 (Continued).

Study	Number of Individuals with Injury	Age (Years)	Type of Orbital Fracture	Resolution of Visual Acuity?/Full Recovery?
Haug et al[41]	Male: 3 Female: 0 Total: 3	1x 25 y.o. 1x 29 y.o. 1x 43 y.o.	Orbital Roof Trauma	Full recovery in all patients
Ruslin et al[45] *	Male: Cannot be Determined Female: Cannot be Determined Total: 4–9	Cannot be Determined	Nonspecific orbital fractures and complex naso-orbitoethmoid fractures	Cannot be Determined
Hsieh et al[46]	Male: Cannot be Determined Female: Cannot be Determined Total: 160	151x adults 9x elderly	Nonspecific orbital fractures	Cannot be Determined
Calderoni et al[66]	Male: 29 Female: 3 Total: 31	Cannot be Determined	Orbito-zygomatic fractures	Cannot be Determined
Yu et al[71]	Male: Cannot be Determined Female: Cannot be Determined Total: 173	Cannot be Determined	98x 1 wall fracture 39x 2 wall fracture 36x 3–4 wall fracture	Cannot be Determined
Christian et al[73]	Male: Cannot be Determined Female: Cannot be Determined Total: 38	Cannot be Determined	Nonspecific orbital fractures	Cannot be Determined
Manana et al[74]	Male: Cannot be Determined Female: Cannot be Determined Total: 19	Cannot be Determined	Nonspecific orbital fractures	Cannot be Determined
Case Reports				
Baldwin et al[20]	Male	31	Orbital roof fracture	Cannot be Determined
Himori et al[26]	Female	20	Blow-out fracture followed by central retinal vein occlusion	Unilateral loss of VA
Day et al[28]	Male	50	Complex left orbital fracture	Full recovery of VA
Zhang-Nunes et al[37]	Male	20	Right orbital floor and medial wall fracture with globe displacement	Full recovery of VA
Ueki et al[39]	Male	19	Orbital floor fracture (infection of resorbable plates)	Full recovery of VA
Agarwal et al[55]	Male	22	Bilateral orbital roof and medial wall fractures with pneumatization of intraorbital portion of the optic nerve sheath	N/A, in coma
Neves et al[56]	Male	71	Orbital floor fracture (pneumo-orbital cysts after orbital fracture repair)	Full recovery of VA
do O silva et al[59]	Male	27	Zygomatic-orbital complex fracture	Full recovery of VA

(*Continued*)

Table 2 (Continued).

Study	Number of Individuals with Injury	Age (Years)	Type of Orbital Fracture	Resolution of Visual Acuity?/Full Recovery?
Pessoa Neto et al[62]	Male	32	Orbital-zygomaticomaxillary complex fracture	Blindness Unilateral, ophthalmology performed evisceration of eye
Pereira et al[70]	Male	21	Orbital roof fracture	Full recovery of VA

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

Case Reports				
Study	**Number of Individuals with Injury**	**Age (Years)**	**Type of Foreign Body and Location of Foreign Body**	**Resolution of Visual Acuity?/Full Recovery?**
Naik et al[22]	Male	30	7-cm-long motorbike handle lodged in the retrobulbar space of both orbits	Unilateral loss of VA
Das et al[23]	Male	29	Motorcycle handle was seen lodged in his left orbit (10.3 cm in length and 2 cm in diameter)	Full recovery of VA
Nowroozzadeh et al[25]	Male	25	Two pieces of metal	Unilateral blindness
Hegde et al[30]	Male	37	Impacted visor in the left orbit with breached orbital roof	Unilateral blindness
Potapov et al[38]	Male	26	Small wooden foreign body in left naso orbital zone	Unilateral blindness
Wang et al[51]	Male	30	Large plant foreign body penetrating the nasal orbit through the left upper eyelid	Unilateral blindness
Arunkumar et al[53]	Male	27	Wooden stick 15 cm long that emerged from below the right medial canthus	Death
Kapoor et al[63]	Male	36	Wooden foreign body (30×6mm) between the medial rectus and optic nerve	Full recovery of VA

Table 4 Characteristics of Patients with Motorcycle-Associated Vitreoretinal Trauma

Case Reports				
Study	**Number of Individuals with Injury**	**Age (Years)**	**Type of Injury**	**Resolution of Visual Acuity?/ Full Recovery?**
Tatlipinar et al[61]	Male	22	Purtscher's Retinopathy	Loss of Visual Acuity Bilaterally
Levin et al[64]	Male	28	Purtscher's Retinopathy	Full recovery of VA
Cappello et al[68]	Male	51	Whiplash maculopathy	Full recovery of VA
Roybal et al[82]	Male	26	Blurred vision and diplopia due to macular edema	Full recovery of VA
Ioannidis et al[83]	Male	14	Valsalva retinopathy	Full recovery of VA

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

Retrospective and Prospective Studies				
Study	**Number of Individuals with Injury**	**Age (Years)**	**Types of Injury**	**Resolution of Visual Acuity?/Full Recovery?**
Keane et al[47]	Male: 89 Female: 7 Total: 96	Range: 15–52 Mean: 25.5	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) Isolated, fixed, dilated pupil (n = 5).	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.
Case Reports				
Kal et al[19]	Male	22	Abducens nerve palsy and Horner Syndrome	Cannot be Determined
Sinawat et al[29]	Male	47	Cortical blindness	Bilateral loss of visual acuity
Ahmad Fauzi et al[36]	Male	20	Bitemporal hemianopia secondary to traumatic chiasmal syndrome	Unilateral loss of visual acuity
Sherman et al[42]	Male	31	Traumatic optic neuropathy	Bilateral loss of visual acuity
Gotfried et al[60]	Female	45	Ptosis caused by complete third nerve palsy	Cannot be Determined
Vien et al[65]	Male	25	Transsynaptic retrograde degeneration and homonymous hemianopsia	Full recovery of VA
Alderazi et al[72]	Male	45	Right carotid-cavernous fistula	Cannot be Determined
Meena et al[76]	Male	41	Optic nerve transection	Unilateral blindness
Kastelan et al[79]	Male	47	Traumatic optic neuropathy	Full recovery of VA
Bhat et al[80]	Male	50	Traumatic optic neuropathy	Bilateral loss of visual acuity
Ham et al[81]	Male	35	Bilateral optic nerve deficits	Cannot be Determined

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.[84,85] Therefore, these studies were excluded from our analysis.

Table 6 Characteristics of Patients with Motorcycle-Associated Corneal Trauma

Retrospective and Prospective Studies				
Study	**Number of Individuals with Injury**	**Age (Years)**	**Types of Injury**	**Resolution of Visual Acuity?/ Full Recovery?**
Tamilarsan et al[48]	Male: 3 Female: 1 Total: 4	1x 18 y.o. 1x 22 y.o. 1x 23 y.o. 1x 24 y.o.	Ophthalmia Nodosa	Cannot be Determined
Huang et al[52]	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
Case Reports				
Johnson et al[24]	Male	43	Corneal perforation after bacterial keratitis	Cannot be Determined
Ausayakhun et al[69]	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

Retrospective and Prospective Studies				
Study	**Number of Individuals with Injury**	**Age (Years)**	**Types of Injury**	**Resolution of Visual Acuity?/Full Recovery?**
Upaphong et al[49]	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

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

Retrospective and Prospective Studies				
Study	**Number of Individuals with Injury**	**Age (Years)**	**Types of Injury**	**Resolution of Visual Acuity?/Full Recovery?**
Lin et al[27]	Male: Cannot be Determined Female: Cannot be Determined Total: 20	Cannot be Determined	Canalicular lacerations	Cannot be Determined
Nakaishi et al[54]	Male: 600 Female: 0 Total: 600	Mean: 34.5 years Median 32.4 years	590x pinguecula, 10x pterygia	Cannot be Determined
Achigbu et al[57]	Male: 635 Female: 0 Total: 635	Cannot be Determined	269x Pinguecula 206x Pterygia 160x Hyperemia and subconjunctival hemorrhages	Cannot be Determined
Ukponmwan et al[58]	Male: 55 Female: 0 Total: 55	Cannot be Determined	37x pinguecula 18x pterygium	Cannot be Determined
Arif et al[67]	Male: Cannot be Determined Female: Cannot be Determined Total: Cannot be Determined	Cannot be Determined	173x Orbital abrasion 93x orbital laceration 83x orbital contusions	Cannot be Determined
Case Reports				
Norazah et al[35]	Male	18	Right eye positioned outside the eyelid fissure on the malar eminence, hanging by lateral rectus muscle	Unilateral blindness
Jabaut et al[43]	Male	21	Periorbital edema	Cannot be Determined
Khadamy et al[44]	Male	19	Traumatic enucleation	Unilateral blindness
Tuncbilek et al[78]	Male	23	Globe avulsion	Unilateral blindness

in adults than in the elderly.[46] 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.[21,41,45,66,71] 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.[66,74] 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.[21] 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

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 periorbital 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.[19,29,36,42,47,60,65,72,76,79–81] 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 unspecfied[47] (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.[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.[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.[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.[48] In all four patients, the insect penetrated the cornea and the resulting insect hairs or spines caused anterior chamber reactions.[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.[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[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.[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.[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%).[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.[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.[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.[87] The most recent study that investigated the role of eye protection in preventing motorcycle crashes was the Hurt Report of 1981.[16,17] 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).[30] 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.[31] 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.[47] 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.

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