



QUALITY IN SPORT

eISSN 2450-3118 · Open Access · Peer-reviewed

apcz.umk.pl/QS Nicolaus Copernicus University in Toruń



JAROSZ, Agnieszka Maria, CZERNECKA, Katarzyna, MAZELANIK, Łukasz, DRANIKOWSKI, Kacper, MARKIEWICZ, Aaron, KAZIMIERCZUK, Kacper, KANADYS, Szymon, STRZEMKOWSKA, Martyna, OKNIŃSKA-ZIAREK, Aleksandra, and SMĘDOWSKI, Igor. Ocular Injuries in Sport and the Effectiveness of Eye Protection: A Narrative Review of Epidemiology by Discipline, Injury Mechanisms, Types of Eye Protectors and Current Preventive Recommendations. *Quality in Sport*. 2026;73:75274. <https://doi.org/10.12775/QS.2026.73.75274>

ARTICLE TIMELINE

Received: 12.08.2026. Revised: 30.08.2026. Accepted: 06.09.2026. Published: 15.09.2026.

The journal has been awarded 20 points in the parametric evaluation by the Polish Ministry of Higher Education and Science (Annex to the announcement of 05.01.2024, No. 32553). Unique Journal Identifier: 201398. Scientific disciplines assigned: Economics and Finance (Field of Social Sciences); Management and Quality Sciences (Field of Social Sciences).

Punkty Ministerialne z 2019 – aktualny rok 20 punktów. Załącznik do komunikatu Ministra Szkolnictwa Wyższego i Nauki z dnia 05.01.2024 Lp. 32553. Posiada Unikatowy Identyfikator Czasopisma: 201398. Przypisane dyscypliny naukowe: Ekonomia i finanse (Dziedzina nauk społecznych); Nauki o zarządzaniu i jakości (Dziedzina nauk społecznych). © The Authors 2026.

OPEN ACCESS · CC BY-NC-SA 4.0 This article is published with open access under the License Open Journal Systems of Nicolaus Copernicus University in Toruń, Poland, and is distributed under the terms of the Creative Commons Attribution Non-commercial Share Alike License (<http://creativecommons.org/licenses/by-nc-sa/4.0/>), which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the work is properly cited. The authors declare no conflict of interest regarding the publication of this paper.

Ocular Injuries in Sport and the Effectiveness of Eye Protection: A Narrative Review of Epidemiology by Discipline, Injury Mechanisms, Types of Eye Protectors and Current Preventive Recommendations

Agnieszka Maria Jarosz

Faculty of Medicine, Akademia Śląska w Katowicach ul. Rolna 43, 40-555, Katowice, Poland

jarosz-agnieszka725@wp.pl

<https://orcid.org/0009-0002-9049-2637>

Katarzyna Czernecka

Pomeranian Medical University in Szczecin

kasia.czerne.19@tlen.pl

<https://orcid.org/0009-0009-0403-1190>

Łukasz Mazelanik

Independent Researcher

lukasz.mazelanik@gmail.com

<https://orcid.org/0009-0002-6205-1113>

Kacper Dranikowski

Uniwersytet Medyczny im. Karola Marcinkowskiego w Poznaniu

k.dranikowski@gmail.com

<https://orcid.org/0009-0007-4614-1916>

Aaron Markiewicz

Poznan University of Medical Sciences

aaron.markiewicz@icloud.com

<https://orcid.org/0009-0004-0309-525X>

Kacper Kazimierczuk

Uniwersytet Opolski

kkazimierczuk01@gmail.com

<https://orcid.org/0009-0007-6262-5195>

Szymon Kanadys

Medical University of Lublin

szymonkanadys@gmail.com

<https://orcid.org/0009-0001-1723-233X>

Martyna Strzemkowska

Uniwersytet Medyczny im. Karola Marcinkowskiego w Poznaniu

martynastrzemkowska@gmail.com

<https://orcid.org/0009-0006-6424-8381>

Aleksandra Oknińska-Ziarek

Independent Researcher

ola1okninska@gmail.com

<https://orcid.org/0009-0000-5584-9843>

Igor Smędowski

Independent Researcher

igor.smedowski@gmail.com

<https://orcid.org/0009-0003-3910-8035>

Abstract

Background: Sports-related ocular trauma is a substantial yet largely preventable cause of visual morbidity, accounting for about 10–20% of all eye injuries and representing a leading cause of monocular blindness in young, predominantly male participants; in the United States alone some 600,000 sports eye injuries occur annually, about 13,500 causing permanent sight loss.

Aim: To synthesise and critically compare current evidence on the epidemiology of sports eye injuries by discipline (racket, team and combat sports), their biomechanical mechanisms, the types and standards of ocular protectors, and current preventive recommendations.

Material and methods: Narrative review of peer-reviewed epidemiological studies, hospital and registry series, clinical case series, finite-element analyses, a scoping review and international consensus guidance.

Results: Risk concentrates in fast-projectile racket sports (squash, badminton, tennis, pickleball), popular team ball sports (soccer, basketball, baseball, handball, floorball, field hockey, cricket) and full-contact combat sports (boxing, mixed martial arts). Blunt closed-globe injury dominates, producing hyphema, angle recession, secondary glaucoma, commotio retinae, retinal dialysis and detachment, orbital blow-out fracture and, less often, globe rupture; finite-element models explain the anterior- and posterior-segment stress distribution involved. About 90% of injuries are preventable, and polycarbonate eyewear meeting recognised standards, visors and face masks markedly reduce incidence and severity, whereas ordinary spectacles and contact lenses give no protection.

Conclusions: Effective prevention requires mandatory, standardised eye protection in high-risk disciplines, rule modification, pre-participation and periodic ophthalmic screening (especially for functionally one-eyed, highly myopic and post-surgical athletes), and coordinated education of athletes, coaches and parents.

Keywords: sports-related eye injuries, ocular trauma, protective eyewear, polycarbonate, hyphema, retinal detachment, combat sports, racket sports, injury prevention

1. Introduction

Vision is central to athletic performance; in sport, nearly 80% of perceptual input is visual, and eye health and sports medicine are therefore closely intertwined fields of considerable importance to athletes [1]. The physical nature of sporting activity renders participants more prone to ocular injury than the general population, and ocular trauma can leave lifelong sequelae that require careful follow-up and management [1]. Although musculoskeletal injuries are by far the most common type of injury in sport, ocular trauma is an important and clinically distinct problem, because even a single event can permanently compromise the vision of a young, otherwise healthy person and alter their career and socioeconomic trajectory for the rest of their life [2,3].

The magnitude of the problem is considerable. Sports-related eye injuries are estimated to account for between roughly 8% and 27% of all ocular trauma, and are consistently reported to represent about 10–20% of eye injuries in young people [2–5]. In the United States, more than 600,000 sports- and recreation-related eye injuries are estimated to occur each year, of which approximately 42,000 are severe enough to require emergency-department attention and around 13,500 result in permanent loss of sight [2,4]. Emergency departments in the United States have historically treated a sports-related ocular injury roughly every 13 minutes [2,4]. The overwhelming majority of those injured are male, with male-to-female ratios ranging from about 4:1 up to 15:1 depending on the population and disciplines studied, and most are children, adolescents or young adults, typically clustering between about 10 and 30 years of age [4–10]. Approximately 80% of perceptual demands in sport are visual, and given that most sports eye injuries are monocular, the loss of one eye or a substantial reduction in binocular field represents a disproportionate handicap for a young athlete [1,11,12].

A recurring and clinically decisive message across the literature is that the majority of these injuries are avoidable. It is repeatedly estimated that up to about 90% of sports-related eye injuries are preventable with adequate eye protection and well-designed safety procedures [2–4,7,11,13]. Despite this, the actual use of protective eyewear remains low across most disciplines: in a large cohort of athletes only about 12% used any eye protection, and in racket sports the median proportion of injured players wearing no eyewear at the time of injury has been reported to be as high as 93% [4,5,7]. This gap between preventability and practice, together with the pronounced heterogeneity of injury patterns between sports, provides the central motivation for the present review.

The epidemiology, mechanisms and severity of sports eye injuries differ markedly between disciplines, and this heterogeneity has both geographical and cultural dimensions, reflecting the varying popularity of individual sports across the world. Squash and soccer have dominated series from the United Kingdom and continental Europe, soccer in Portugal, Norway and Israel, basketball and baseball in the United States, floorball in Finland and Sweden, handball, soccer and diving in China, and badminton in much of South and Southeast Asia [2–5,7,9,14,15]. Because many studies report the most frequently encountered sports as absolute numbers rather than as rates per unit of exposure, a sport that is simply popular in a given country will inevitably appear to cause the most injuries there; this is an important interpretive caveat when comparing series across regions [1,5].

The clinical and socioeconomic stakes extend well beyond the sports arena. Ocular trauma is a leading cause of unilateral blindness worldwide, and its consequences – emotional distress in the aftermath, fear of social stigma, difficulties in daily living, and the threat of further deterioration of the remaining vision – fall disproportionately on young people in their productive years, who may initially be unaware of the lifelong impact on career and socioeconomic well-being [12]. Because the eye is protected against many objects by the bony orbit and by reflex closure yet remains vulnerable to small, fast projectiles, and because a single unprotected moment can suffice to cause irreversible damage, sports ophthalmology sits at the intersection of high preventability and high consequence – precisely the combination that justifies concerted preventive effort [1,12].

The aim of this narrative review is to bring together and critically compare the current evidence on ocular injuries in sport, with a deliberate emphasis on the medical dimensions of the problem. The review is organised around four linked questions: the epidemiology of sports eye injuries by discipline category (racket sports, team sports and combat sports, together with selected projectile and recreational activities); the biomechanical mechanisms that translate a moving projectile, implement or body part into a specific pattern of ocular tissue damage; the types, materials and technical standards of eye protectors and the evidence for their effectiveness; and the contemporary preventive recommendations that follow, including rule modification, screening and education. Throughout, the intention is to move beyond a simple catalogue of findings towards a comparative, critical synthesis that highlights both the consistencies and the genuine discrepancies in the evidence base.

2. Materials and Methods

This article was prepared as a narrative review of the scientific literature on ocular injuries in sport and on the effectiveness of eye protection. The synthesis draws on peer-reviewed epidemiological studies (including large registry- and emergency-department-based analyses and single- and multi-centre hospital series), clinical case series and individual case reports illustrating characteristic or severe injuries, finite-element biomechanical simulation studies, a scoping review, narrative and literature reviews published in the sports-medicine and ophthalmology literature, and international consensus guidance, principally the International Olympic Committee (IOC) consensus paper on sports-related ophthalmology issues in elite sport [1].

Consistent with the approach adopted by comparable narrative reviews with elements of a systematic search in this field, priority was given to large epidemiological studies, systematic and narrative reviews, and consensus documents describing the incidence, mechanisms and prevention of sports-related ocular trauma [3,13,16,17]. Studies were grouped thematically into four domains: (i) overall epidemiology and demographics; (ii) mechanisms and pathophysiology, including biomechanical modelling; (iii) discipline-specific patterns, subdivided into racket, team and combat sports and selected projectile or recreational activities; and (iv) protective equipment and preventive strategies. Because the source material was previously published, anonymised or aggregated data, no ethical approval or informed consent was required for this review.

Two methodological caveats apply throughout and are discussed further in the Discussion. First, much of the available epidemiology is retrospective and hospital- or emergency-department-based, which tends to capture the more severe injuries and to under-represent minor trauma that does not present to specialist care [1,8]. Second, definitions of eye injury, injury severity, denominators (exposures versus participants) and follow-up duration differ substantially between studies, which limits direct quantitative comparison and means that most cross-study statements in this review are necessarily qualitative rather than pooled.

3. Overall epidemiology and demographics

Across settings and study designs, the demographic signature of sports-related ocular trauma is remarkably consistent: the typical patient is a young male. In a casualty-department survey from the west of Scotland, 246 sport-associated eye injuries had a mean age of about 25 years and a male-to-female ratio of roughly 6.5:1, with football (association football) responsible for

44.7% of cases, followed by rugby, squash, badminton and skiing [7]. A five-year retrospective study at the largest tertiary eye hospital in Australia identified 1,793 sports-related ocular injuries, of which 80.4% occurred in males, with a mean age of about 29 years and almost 60% of patients younger than 30; soccer, Australian rules football and basketball together accounted for nearly half of all cases [6]. A cross-sectional study of 1,413 athletes in Tianjin, China, reported an eye-injury incidence of 10.7%, with handball, water polo and diving carrying the highest incidences and with younger age, lower family income and training for more than four hours per day emerging as independent risk factors [4].

Population-scale data reinforce this picture while adding nuance. A multi-centre Chinese inpatient series of 377 injured eyes found a male-to-female ratio of 15.4:1 and a mean age of 22.5 years, with soccer (46.8%), basketball (27.1%) and badminton (16.8%) the leading causes, and ball strikes responsible for about three-quarters of injuries [5]. In United States high-school and collegiate athletes, eye-injury rates varied markedly by sport, sex and competition level: the highest combined rates per 100,000 athlete-exposures were in women's basketball, women's field hockey, men's basketball and men's wrestling, rates were substantially higher at collegiate than high-school level, and injuries were significantly more frequent in competition than in practice [8]. Most such injuries were minor – contusions and abrasions predominated and only a small percentage resulted in time loss exceeding three weeks – yet severe, potentially blinding injuries did occur, underscoring that a low average severity does not eliminate the risk of catastrophic individual outcomes [8].

Paediatric series merit separate attention because children bear a disproportionate share of sports eye trauma and because injury patterns are age-dependent. In a decade-long analysis of pediatric sports ocular trauma from two Indianapolis tertiary centres, baseball (38.8%), basketball (17%) and soccer (14.9%) were the most common causes; contusion and hyphema together comprised about 90% of injuries; orbital fracture was the most frequent diagnosis requiring surgery, with baseball responsible for two-thirds of these fractures; and archery and golf, although rare, produced the worst presenting visual acuity [9]. Baseball- and softball-related injuries were significantly associated with younger children (aged 3–11 years), whereas soccer and (American) football were associated with older children (12–18 years) [9]. A statewide analysis of pediatric ocular trauma in California confirmed the male predominance (64.9%), a bimodal age distribution with peaks in early childhood and adolescence, and a significant seasonal pattern, and further documented health disparities, with the highest incidence among Black and Hispanic/Latino children [10].

The visual consequences of sports eye injuries are generally favourable on average but heterogeneous, and the proportion of severe outcomes is far from negligible. Contemporary estimates suggest that around 10–13% of sports eye injuries result in long-term visual impairment [3–5,11]. In the Chinese inpatient series, presenting visual acuity was the strongest determinant of final visual acuity, and final low vision ($\leq 4/200$) persisted in 10.6% of eyes, including three eyes that were removed [5]. This dependence of prognosis on presenting acuity – and, by extension, on the specific sport and mechanism that determine the initial injury – is a recurring theme and provides a clinically actionable rationale for prevention, since preventing the initial insult is far more effective than treating its consequences [5,18].

The global burden is difficult to quantify precisely because reporting is fragmented, but converging estimates place sports at the origin of roughly 8–27% of all eye injuries and identify sport as one of the leading causes of monocular blindness in young people [4,5]. In some series a substantial share of post-traumatic enucleations is sport-related, and bilateral ocular trauma, though uncommon, occurs in a minority of sports injuries [5]. These figures, together with the youth of the typical patient, mean that the aggregate loss measured in vision-years is considerable even where individual injuries are frequently minor, and they justify treating sports eye injury as a public-health rather than a purely clinical problem [3–5].

Historical casualty-department data remain informative about severity. In MacEwen's Glasgow survey of 246 sport-associated eye injuries, although sport accounted for only about 1% of all new eye-casualty attendances, 18.7% of those injured required inpatient care, 22% had significant anterior-segment damage (hyphema or traumatic uveitis), 6.9% had retinal damage, and two eyes were ultimately lost to scleral rupture and enucleation – figures that established sport as a source of a disproportionate number of severe, sight-threatening injuries relative to its share of attendances [7]. Comparable series across decades and countries have repeatedly confirmed that, while the average sport eye injury is minor and treated as an outpatient, a substantial minority threaten sight, so that severity rather than frequency should drive preventive priority [2,7].

Temporal and seasonal patterns add further texture to the epidemiology and warn against interpreting raw counts uncritically. A statewide analysis of pediatric ocular trauma in California found that, although the absolute incidence of eye-trauma emergency visits declined over 2016–2021, the proportion of ocular-trauma visits relative to all emergency visits rose, and a clear seasonal pattern emerged, with the highest incidence in May and the lowest in January – a pattern attributed to school schedules and outdoor and recreational activity [10]. The COVID-19 pandemic produced a distinctive natural experiment: basketball-related eye

injuries in United States emergency departments fell by 47% between 2019 and 2020, a decline largely attributed to reduced sports participation during lockdowns, superimposed on a longer-term downward trend that may also reflect awareness campaigns and greater use of urgent care [10,19].

The Australian tertiary-hospital series is valuable because it moves beyond frequency to relative risk. Using Australian rules football as the reference, multivariate analysis identified the greatest risk of globe rupture or penetration with martial arts (odds ratio [OR] 16.22) and golf (OR 10.43); of orbital blow-out fracture with skiing (OR 14.42), hockey (OR 4.39) and cricket (OR 2.35); of hyphema with squash (OR 4.18), badminton (OR 3.87) and cricket (OR 2.39); and of retinal tears with foam-dart projectiles (OR 5.59) [6]. Strikingly, paintball – classified as high risk but the sport for which a face shield is mandatory in Australia – caused the fewest injuries (0.33% of cases), a real-world illustration of the protective value of enforced eyewear that mirrors the experimental evidence discussed later [6]. The most common mechanisms overall were projectile impact (54.4%) and incidental body contact (28.2%), and traumatic hyphema with anterior uveitis was the most frequent diagnosis [6].

The multi-centre Chinese inpatient study is instructive because it links causative sport to injury zone and prognosis. Close-globe injury accounted for 95.1% of eyes and contusion for the overwhelming majority; open-globe injury, although only 4.9% overall, occurred more often in basketball (8.3%) and in injuries from physical collision (12.8%) or racket/equipment strikes (11.8%) than from ball strikes (2.1%), and almost all penetrating injuries were caused by broken spectacle lenses worn during play [5]. Injury zone tracked mechanism: badminton produced the most zone II (limbal–ciliary) injuries (69.8%), whereas soccer and basketball produced more zone III (posterior-segment) injuries; hyphema was most frequent in badminton (85.7%) and retinal breaks in soccer and basketball [5]. Final visual acuity correlated positively with presenting acuity ($r = 0.421$), and although badminton caused poor initial vision through anterior-segment media opacity, its zone II injuries were relatively treatable, so badminton achieved the highest proportion of good final acuity, whereas the destruction associated with basketball and physical collision produced worse outcomes [5].

Table 1 summarises the widely used classification of sports according to eye-injury risk, which underpins many of the discipline-specific recommendations discussed below.

Risk category	Defining characteristics	Representative sports
High / very high risk	Small, fast projectiles; intermittent or constant close contact; use of a bat, stick or racket; or intentional head/eye contact; little or no eye protection customary	Squash, racquetball, badminton, tennis, baseball/softball, cricket, ice and field hockey, lacrosse, boxing and full-contact martial arts, paintball, airsoft
Moderate risk	Larger or slower ball; frequent body contact; blunt ocular trauma or accidental impact possible	Soccer, basketball, handball, American football, volleyball, golf
Low risk / eye-safe	No thrown or struck ball, stick, bat or racket; no aggressive body contact	Swimming, cycling, rowing, running, gymnastics, track and field

Adapted from data reported in references [1,4,14,20]. Risk categories are approximate and depend on the level of play, use of protection and individual ocular history.

4. Mechanisms and pathophysiology of ocular trauma in sport

The mechanisms by which sport injures the eye can usefully be divided into five broad categories: impact by a ball or similar projectile; impact by a racket, bat or stick; impact by an opponent's body part (finger, elbow, knee, head or fist); introduction of a foreign body; and injury sustained during a fall or high-speed deceleration [7]. Across most series, direct ball or projectile impact is the single dominant mechanism, followed by accidental body contact; in the multi-centre Chinese inpatient data, ball strikes accounted for 74.7% of injuries, physical collision for 13.8% and racket or equipment strikes for 9.0% [5]. The relative frequency of these mechanisms varies systematically with discipline, and it is this variation that drives the discipline-specific injury profiles discussed in Section 5.

The great majority of sports eye injuries are closed-globe (blunt) injuries; open-globe injuries are comparatively uncommon but disproportionately serious [2,5,14]. In blunt trauma, a projectile smaller than the orbital aperture causes rapid antero-posterior compression of the globe with compensatory equatorial expansion, transmitting force to internal structures; the anterior segment is the region most frequently damaged, and hyphema is the most common

clinical presentation [2,4]. A blunt object larger than the orbital opening (greater than about 5 cm in diameter) instead loads the orbital rim and walls, and may fracture the thin orbital floor or medial wall – a “pressure-release” mechanism that can protect the globe from rupture but carries a high incidence of occult intraocular injury [2,12]. Open-globe injury is favoured by small, hard, high-velocity projectiles (golf balls, paintballs) and by secondary mechanisms such as shattered spectacle lenses, which convert a blunt insult into a penetrating one [5,14].

The determinants of injury severity are well characterised and reflect the physics of the impacting object: its size relative to the orbital aperture, its mass, velocity and kinetic energy, its hardness or elasticity, and the depth to which it can enter the orbit [5]. Larger, softer, slower balls disperse energy across the orbital rim and face, whereas small, hard, fast objects concentrate energy on the globe; the area-normalised kinetic energy therefore predicts globe rupture better than any single variable [5]. There is more energy in a squash ball than in a 0.22 calibre bullet by virtue of its mass, a hockey puck can travel at 90–100 mph, and a badminton shuttlecock has been clocked at extreme speeds, illustrating why apparently trivial recreational implements can inflict blinding injury [4]. Instructively, a softer ball is not necessarily safer: computational and experimental work shows that a soccer ball, although slow and deformable, remains in contact with the eye for roughly 10 ms – some 2.5 to 10 times longer than a harder ball – and moulds to the orbital aperture, generating a suction effect on rebound that distorts the globe and stresses internal structures [5,21].

Finite-element analysis (FEA) has substantially advanced understanding of these mechanisms by quantifying the spatial and temporal distribution of stress and intraocular pressure that in-vivo experiments cannot capture. In a soccer-ball simulation, impact generated a pressure wave that travelled linearly from the anterior to the posterior pole in under 0.1 ms, producing transient pockets of high and negative pressure in the vitreous adjacent to the posterior pole (ranging from about +39.6 to –30.9 kPa) and localising retinal stress to the posterior pole and vasculature; anterior-segment injuries such as hyphema and angle recession were attributed to direct force transmission at the point of contact, while posterior-segment lesions arose from the compressive and tractional forces of the propagating pressure wave [21]. Comparison of this linear-force mechanism with the repetitive, multidirectional angular forces of abusive head trauma helped explain the more localised injury profile and lower retinal-haemorrhage incidence of soccer-ball trauma, a distinction with medico-legal as well as clinical relevance [21].

A badminton shuttlecock simulation reproduced the clinical observation that the head of the shuttlecock is similar in size to the eye and therefore transfers force directly to the globe without

the cushioning of the orbit; frontal impact at 80 mph produced a very brief (<1 ms) spike in anterior-chamber pressure of about 5.7 MPa that distributed radially towards the trabecular meshwork (1.25 MPa), posterior lens displacement of up to 1.5 mm with zonular strain of 52%, and peak stresses at the limbus, ciliary body, ora serrata and optic nerve head that approached or exceeded the mechanical limits of these tissues [22]. These values provide a mechanistic basis for the characteristic badminton complications – hyphema, traumatic mydriasis, angle recession, secondary glaucoma, lens subluxation and retinal dialysis – and underline why racket sports concentrate injury in zone II of the globe [5,22]. A comparable pickleball model showed that the rigid, hard-plastic ball concentrates stress at the limbus and anterior sclera at velocities above 30 mph, applies zonular stresses as high as 0.37 MPa (greatest at the equatorial zonules and on the more exposed temporal side), and produces high retinal shear at the ora serrata and posterior pole, consistent with clinical reports of lens subluxation, hyphema, angle recession and retinal tears [23].

Standardised terminology underpins meaningful comparison of these injuries. The Birmingham Eye Trauma Terminology and the Ocular Trauma Classification distinguish closed-globe injury (contusion and lamellar laceration, with no full-thickness wound of the eye wall) from open-globe injury, and within the latter separate rupture – caused by a blunt object through an inside-out mechanism – from penetration by a sharp object through an outside-in mechanism [1,5]. Zones describe the anteroposterior location of the wound or the involved tissues, and the classic notion of the seven rings of trauma conceptualises the concentric structures at risk from blunt injury [5]. This framework matters clinically because prognosis is strongly zone-dependent: posterior-segment involvement (vitreous, retina, choroid, optic nerve) predicts poor visual outcome, whereas many anterior-segment lesions are recoverable [5].

Computational thresholds help explain why globe rupture is uncommon in most ball sports despite very high transient pressures. Models of blunt eye impact suggest that rupture requires corneoscleral stresses exceeding roughly 23 MPa and local dynamic pressures above about 2.1 MPa, occurring at sites of peak stress such as the corneal apex, limbus and equator, or at pre-existing weaknesses from prior surgery or trauma [5]. In the soccer simulation, the peak vitreous pressure of about 2.3 MPa (some 17,000 mmHg) recorded transiently at the point of contact would exceed the reported dynamic rupture threshold of roughly 0.91–0.97 MPa, yet globe rupture is rarely reported after soccer trauma because this pressure is sharply localised at the anterior segment and dissipates to below 50 kPa before propagating through the vitreous, so the globe as a whole is never uniformly over-pressurised [21]. This reconciles the apparent

paradox between extreme peak pressures and the rarity of rupture, and highlights that it is the interaction of magnitude, localisation and object hardness – captured by area-normalised kinetic energy – that determines whether the globe fails [5,21].

The pickleball and shuttlecock simulations add mechanistic specificity to well-known clinical sequelae. In the pickleball model, stress concentrated at the iridocorneal angle and trabecular-meshwork region (about 0.35 MPa), with a secondary tensile peak during the rebound phase as the faster-recoiling anterior structures pulled on the lagging lens and strained the zonules; equatorial zonules sustained the greatest stress, and the more exposed temporal side experienced 34% higher stress than the nasal side because of greater scleral bending, mechanistically explaining lens subluxation, angle recession and the trabecular residual stresses that may drive secondary glaucoma [23]. In the shuttlecock model, force transmitted through the stiff sclera reached the optic nerve head faster than through the vitreous, producing compressive stress of nearly 6 MPa at the lamina cribrosa and posterior optic-nerve-head displacement of 2.6 mm (about 10% of axial length), consistent with reported cases of optic nerve avulsion, while zonular strain of 52% approached the roughly 80% threshold for irreversible zonular damage – a margin that would be exceeded at professional shuttlecock speeds [22]. These models collectively convert clinical observations into quantitative, testable mechanisms and provide a rational basis for the design and evaluation of protective eyewear [21–23].

It is clinically useful to distinguish the primary compression phase of blunt trauma from the secondary rebound phase, because each imparts distinct forces. During compression, the projectile rapidly deforms the globe, raising intraocular pressure and loading the cornea, sclera, iris, ciliary body and, through the propagating pressure wave, the posterior segment, potentially causing corneal abrasion, iridodialysis, sphincter tears, hyphema, and vitreous and retinal displacement [23]. During rebound, as the globe recoils and intraocular pressure transiently falls below baseline, the faster recovery of the sclera and anterior structures relative to the lens strains the zonules and can extend tears initiated during compression, exacerbate lens subluxation, and increase traction on the retina, so that some of the most damaging events occur after the object has already begun to leave the eye [23]. This two-phase model, quantified by finite-element analysis, explains why maximum zonular and posterior stresses often occur during rebound rather than at peak compression, and why apparently minor initial injuries can evolve [22,23].

The natural protective structures of the eye also shape the injury pattern. The bony orbit absorbs much of the energy of larger objects, and modelling suggests that the eyelid, while it does not

substantially reduce retinal stress from a large ball, distributes force over the cornea and, when closure is timely, may reduce the frequency of corneal abrasion relative to deeper injury [21]. Anatomical variation matters: a more prominent or recessed globe, as in proptosis or in certain refractive states, alters exposure and therefore risk, and the more exposed temporal aspect of the eye is preferentially injured in several models [21,23]. These observations reinforce that protection must be matched to the geometry of the threat, and that reliance on natural defences alone is insufficient in high-energy sports [21].

Taken together, the biomechanical evidence converges on a coherent scheme. Anterior-segment lesions (corneal abrasion, hyphema, iridodialysis, sphincter tears, angle recession, lens subluxation) reflect direct compression and pressure transmission through the aqueous, together with the equatorial expansion that stretches the zonules and iridocorneal angle; posterior-segment lesions (commotio retinae, retinal dialysis and tears, macular hole, vitreous and retinal haemorrhage, choroidal rupture) reflect the propagation and reflection of a vitreous pressure wave and the tractional forces exerted at the vitreoretinal interface, particularly at sites of firm adhesion [5,21,22,24]. Ageing amplifies these risks: stiffening of soft tissues, progressive lens hardening and vitreous liquefaction reduce the eye's capacity to absorb mechanical shock and increase susceptibility at the vitreoretinal interface – a consideration of growing importance as older adults take up dynamic sports such as pickleball [23].

5. Epidemiology and injury patterns by discipline

5.1. Racket sports (squash, badminton, tennis, racquetball, pickleball)

Racket sports occupy a special place in the history of sports ophthalmology because the combination of a small, fast projectile, an implement swung in a confined space, and the close proximity of opponents produces a high proportion of severe, potentially blinding injuries [7,14]. The close relationship between the diameter of a squash ball and the orbital aperture has long focused attention on squash as a cause of serious ocular trauma, and squash has repeatedly been identified as a leading or the leading cause of sports-related ocular injury in British series [7,14,24]. Squash injuries include retinal haemorrhage, open-globe injury, vitreous haemorrhage and macular lesions, and a substantial minority result in permanent visual loss; importantly, the odds of injury bear no relation to player experience, so skill offers no protection [24]. Retinal detachment from squash-ball accidents is well documented, frequently associated with large retinal tears near the ora and with avulsion of the vitreous base [24].

Badminton is the paradigmatic example of a widely underestimated but dangerous racket sport, particularly in South and Southeast Asia. In Malaysia, badminton accounts for nearly two-thirds of all sport-related eye trauma, and a United Kingdom series attributed 14.3% of sport-associated eye injuries to badminton [25,26]. The shuttlecock is the dominant causative agent: its small, rigid base is similar in size to the eyeball and generates significant blunt force, causing sudden antero-posterior compression and equatorial expansion, while its sharp feathered edges can cause penetrating trauma [25,27]. A clinical audit of 23 eyes in a Malaysian tertiary centre found that shuttlecock hits caused all injuries, 96% of patients wore no protective eyewear, hyphema was the commonest presentation, angle recession was detected in 17 of 23 eyes as early as one week after injury, and commotio retinae and vitreous haemorrhage were the common posterior-segment findings; although visual acuity improved significantly overall, three eyes retained poor final vision [25]. A more recent single-centre case series of seven badminton injuries spanned the full spectrum from subconjunctival haemorrhage, traumatic uveitis and hyphema to commotio retinae and an open-globe corneoscleral laceration from shattered spectacles, with the penetrating injury carrying the poorest prognosis [27].

Two features of badminton trauma deserve emphasis because they carry direct preventive implications. First, contrary to intuition, several series report that the doubles game and, more specifically, the smash shot from one's own partner – struck from close range while the front player turns to look back – is a frequent and especially dangerous mechanism, precisely because the short inter-player distance leaves almost no time to react [26,27]. Two well-documented cases of this “doubles trouble” mechanism resulted in coup–countercoup injuries with subluxated lens, cyclodialysis, secondary glaucoma and Berlin's oedema, and both eyes ended blind (vision <3/60) despite prompt surgery [26]. Second, prescription spectacles are hazardous in racket sports because they can shatter on impact and convert a blunt injury into a penetrating one, so glass spectacles should never be worn during play and refractive correction should be incorporated into polycarbonate protective eyewear [26].

Tennis and cricket, which are often grouped with racket and bat-and-ball sports, produce a similar closed-globe spectrum. A three-year prospective Indian series of 76 eyes injured by tennis or cricket balls while playing cricket found that most injuries were closed-globe, with sphincter tears, retinal detachment, angle recession, choroidal rupture and Berlin's oedema among the most frequent significant findings; posterior-segment involvement predicted poor presenting and final vision, and final visual outcome depended chiefly on presenting acuity, time to presentation and the type of intervention [18]. Cricket specifically endangers the eye when the ball rises, and severe injuries including retinal detachment and globe rupture have

been reported, prompting recommendations for face protection for batsmen facing fast bowling and for close fielders [28]. A narrative review of tennis and the visual system additionally stresses the sport's dual character: the fast-moving ball drives adaptive enhancement of dynamic visual acuity, contrast sensitivity and visuomotor coordination, yet also carries risks of corneal abrasion, intraocular haemorrhage and retinal detachment from ball or racket impact, as well as foreign bodies and cumulative visual fatigue, for which impact-resistant polycarbonate glasses, UV-filtering sunglasses and regular eye examinations are recommended [29].

The history of racquetball is a cautionary tale about incomplete protection. Early eye guards were open frames without lenses, and injuries continued to occur because the flexible ball could deform through the gap between the rims, while shattering of hard resin lenses added a second mechanism of harm; only after clubs mandated eyewear with impact-resistant lenses conforming to the ASTM F803 standard did racquetball eye injuries fall dramatically, and no injury has since been reported in a player wearing F803-compliant protection [24]. The largest badminton series, comprising 85 eyes, confirmed the distinctive epidemiology of the sport: 86% of injuries occurred in doubles matches and 61% were caused by the patient's own partner rather than an opponent, reinforcing the specific danger of the close-range partner smash and the case for protective eyewear even in recreational play [24,27].

Tennis illustrates that even a sport with a comparatively large, soft ball produces significant vitreoretinal trauma. A classic series of ten eyes injured by tennis balls found vitreous haemorrhage in every eye, with retinal tears and dialysis, and half requiring surgery, while a later series of 28 retinal detachments from tennis-ball injury found that a third had more than one break, most breaks were infratemporal, and 10% were associated with a full-thickness macular hole; other reported tennis injuries include choroidal rupture and post-traumatic choroidal neovascularisation [24]. A review of more than 15,000 United States emergency-department visits for tennis-related ocular injury reported open-globe injury in 1.5%, retinal detachment in 0.9% and posterior vitreous detachment in 0.2%, with injury most frequent in those under 20 years and a modest decline over two decades [24].

Pickleball, the fastest-growing sport in the United States, is an instructive contemporary case because its rapid uptake – particularly among older adults, of whom nearly 20% of players are aged 65 or over – is generating a new stream of ocular injuries in a population with age-related ocular vulnerability [23]. Reported pickleball injuries include corneal abrasion, iritis, hyphema, retinal tears, vitreous haemorrhage, traumatic lens subluxation and dislocation, and posterior vitreous detachment, mechanistically similar to other racket sports because the eye is exposed

to high-energy impact at close range [23]. The rigid hard-plastic ball, which stores little elastic energy, transfers most of its kinetic energy directly to the eye, and the short ball-transit time at the non-volley line leaves little opportunity to avoid a strike [23]. Protective polycarbonate eyewear is very rarely worn, and expert bodies now advocate its routine use, especially for those at elevated risk of retinal detachment (family history, high myopia, pseudophakia, or age 60–70 years) [23].

The socioeconomic dimension of pickleball injury is substantial and growing: total medical costs of pickleball-related injuries were estimated at between USD 250 and 500 million in 2023 alone, encompassing emergency visits, outpatient care, surgery and hospitalisation, a burden that preventive measures such as polycarbonate glasses could materially reduce [23]. Documented case reports span the clinical spectrum and the demographic profile of the sport – a 47-year-old man with hyphema and raised intraocular pressure, a 66-year-old man with posterior vitreous detachment and retinal tear, a 77-year-old man with intraocular-lens dislocation, and a case series of traumatic lens subluxation – corroborating the finite-element prediction that the equatorial zonules and the iridocorneal angle are especially vulnerable in this sport [23].

5.2. Team and ball sports (soccer, basketball, baseball, handball, floorball, field hockey, cricket, volleyball)

Team ball sports account for the largest absolute numbers of sports eye injuries in most countries, reflecting their popularity, and are characterised biomechanically by fast-moving balls or pucks and frequent collisions with players and equipment [3]. Epidemiological syntheses consistently place basketball, baseball/softball, soccer, handball, American football and hockey among the most frequently implicated team sports, with the dominant mechanism being ball or object impact together with accidental blows from a hand, elbow or head [3,5,8]. From a medical standpoint, blunt ocular trauma and hyphema predominate, sometimes accompanied by raised intraocular pressure and retinal detachment requiring surgery; most injuries do not cause severe permanent loss of acuity, but the proportion with permanent visual impairment is estimated at about 10–13% [3].

Soccer, the most played sport in the world, is the single most common cause of sports-related eye injury in Europe and a leading cause elsewhere, and although classed as only moderate risk it accounts for a high share of complex ocular trauma with severe consequences [14,16,30]. Roughly 80% of soccer eye injuries occur in men under 25 and result from high-velocity blunt trauma from a kicked ball [30]. The apparent paradox that a large, soft ball can cause serious

posterior-segment injury is resolved by the biomechanics described above: prolonged contact and a suction effect distort the globe and localise a pressure wave to the posterior pole and superior temporal quadrant, producing retinal dialysis, giant retinal tear, macular hole and retinal detachment [21,30]. A published case of an 18-year-old professional soccer player struck in the eye by the ball illustrates how a seemingly innocuous training incident produced a complex injury – traumatic mydriasis, zonular damage, retinal tear, macular oedema progressing towards a full-thickness macular hole, and extensive commotio – that nonetheless resolved with emergency vitreoretinal surgery and allowed return to competitive play within eight weeks, demonstrating both the seriousness of soccer trauma and the value of prompt specialist intervention [30].

Basketball is the leading cause of sports eye injury in the United States, principally because of frequent contact with other players; the most common mechanism is player contact (a finger or elbow to the eye) rather than the ball, and the most common diagnosis is corneal abrasion [19]. A ten-year analysis of United States emergency-department visits estimated approximately 46,800 basketball-related eye injuries, most affecting males and children, with a significant decline over the study period that was largely driven by reduced participation during the COVID-19 pandemic and possibly by awareness campaigns [19]. Although vitreoretinal injuries are relatively uncommon in basketball because of the ball's low velocity and large size, retinal detachment does occur, particularly in myopic players, and there are no eye-protection requirements at any level of United States basketball despite the fact that most injured players wear none at the time of injury [19,24].

Baseball and softball are consistently among the leading causes of ocular trauma, especially in children, and are notable for a high proportion of orbital fractures and severe injuries because of the hardness, size and velocity of the ball; baseball was the single most common cause of injuries requiring surgery, and of orbital fractures, in a large pediatric series [9]. Field hockey provides one of the clearest historical demonstrations that rule changes and protective equipment matter: a mid-1980s report described a disturbing cluster of perforating eye injuries from hockey sticks after the rule penalising raising the stick above shoulder height was relaxed, drawing an explicit parallel with the dramatic reduction of eye injuries in Canadian ice hockey after the introduction of the high-sticks rule and mandatory face protection [31]. Mandatory protective eyewear in United States high-school field hockey was subsequently associated with a 52% reduction in the eye-injury rate [8]. Floorball, a fast indoor stick-and-ball sport, has been a particular concern in the Nordic countries – in a Finnish series it caused 45% of all sports eye

injuries – which led the Finnish Floorball Federation to mandate protective eyewear in junior floorball [1].

Several discipline-specific mechanistic and policy details reinforce this pattern. Experimental work using artificial orbits showed that although a soccer ball penetrates the orbit less deeply than smaller balls, it remains in contact with the globe for far longer and exerts a suction effect on rebound, explaining the disproportionately high rate of serious posterior-segment injury from an ostensibly soft ball [21,24]. In professional basketball, the National Basketball Association reported 59 eye injuries in the 1992–1993 season and 18 in 2018–2019, none involving the posterior segment, reflecting the predominance of anterior contact injury; where retinal detachment does occur in basketball it is concentrated in myopic players, in whom the relatively protruding, elongated globe is more exposed [24]. In baseball, orbital floor fractures dominate the surgical caseload, particularly in children, and although batting helmets approved by the National Operating Committee on Standards for Athletic Equipment are mandatory in youth leagues, eye protection itself is not required, and catcher masks have wide orbital openings that the American Society for Testing and Materials advises against – a regulatory gap for a sport the American Academy of Ophthalmology classifies as high risk [9].

Cricket injuries are characteristically caused by a rising ball, and the hook shot places the dominant-side eye at particular risk; a classic series of five severe cricket eye injuries – including retinal detachment and globe rupture – all involved a rising ball, prompting recommendations for face protection for batsmen facing fast bowling and for close fielders [28]. In a three-year Indian series, cricket injuries occurred overwhelmingly in recreational players using tennis or rubber balls rather than the hard leather ball, with batsmen most often affected, underscoring that even softer improvised balls cause vision-threatening closed-globe injury [18]. Beyond the classic ball sports, the Tianjin athlete cohort highlighted less obvious hazards: handball carried the highest eye-injury incidence (38.5%), followed by water polo (36.4%) and diving (26.7%), and in artistic gymnastics injuries arose from accidental eyelid poking by ribbons – a reminder that eye-injury risk is not confined to fast-ball sports [4].

Other team sports complete the picture. American football and ice hockey, although associated with frequent head impact, have comparatively low eye-injury rates where full facial or eye protection is standard, illustrating again the protective effect of mandated equipment; in United States high-school and collegiate surveillance no eye injuries were recorded in ice hockey during the study period, consistent with universal face protection [8]. Lacrosse provides a natural experiment: mandatory protective eyewear in women's lacrosse reduced eye injuries without an increase in head or facial injuries, countering the concern that protection encourages

rougher play [8]. Volleyball, handball and basketball injuries are dominated by ball or player contact to the anterior segment and are usually minor, but occasionally include orbital fracture and retinal injury, so polycarbonate goggles remain advisable for predisposed players [5,8]. Across team sports, competition carries a higher per-exposure risk than practice, and collegiate athletes have higher rates than high-school athletes, patterns that should inform where preventive resources and supervision are concentrated [8].

Table 2 summarises the dominant injury mechanisms and characteristic lesions across the principal team and racket disciplines, and illustrates the systematic relationship between the physics of each sport and its clinical injury signature.

Discipline	Dominant mechanism	Characteristic lesions
Soccer	Kicked-ball blunt impact; head/elbow contact	Hyphema, commotio retinae, retinal dialysis/tear, macular hole, retinal detachment
Basketball	Finger/elbow (player) contact; occasional ball	Corneal abrasion, contusion, subconjunctival haemorrhage; rarely retinal detachment
Baseball/softball	Hard-ball impact; bat	Orbital (floor) fracture, hyphema, contusion, posterior-segment injury
Squash / racquetball	Small fast ball; racket	Hyphema, angle recession, vitreous/retinal haemorrhage, retinal detachment, open globe
Badminton	Shuttlecock (zone II); racket; shattered spectacles	Hyphema, angle recession, secondary glaucoma, lens subluxation, commotio, retinal dialysis
Cricket	Rising hard ball; ricochet off bat	Hyphema, orbital fracture, retinal detachment, choroidal rupture, globe rupture
Field/ice hockey	Stick, puck, ball	Perforating injury, orbital fracture, contusion; markedly reduced by face protection

Boxing / MMA	Punches, elbows, knees, kicks; finger (eye poke)	Eyebrow/eyelid laceration, orbital haematoma and fracture, corneal abrasion, angle recession, retinal changes
Paintball	High-velocity projectile	Hyphema, iridodialysis, traumatic cataract, retinal detachment, secondary glaucoma, globe rupture
Golf	Ball (adults); club (children)	Globe rupture, orbital fracture, blindness/enucleation

Compiled from references [2,5,9,14,18,19,21–25,28,30–34]. MMA – mixed martial arts.

5.3. Combat sports (boxing, mixed martial arts, Muay Thai, kickboxing, martial arts)

Combat sports create an especially high-risk environment for ocular trauma because they involve deliberate strikes to the head and face, close physical contact and, in full-contact formats, rules that permit powerful blows to the orbital region [15,16,35]. In these disciplines the head and face account for the majority of all injuries – between roughly 29.5% and 75.9% depending on the sport and series – with a predominance of soft-tissue damage and facial fractures, and the eye and periocular region constitute a substantial share of this burden [15,16,35]. Systematic reviews of mixed martial arts (MMA) confirm that 66.8–78% of injuries involve the head, frequently the orbital-eyelid region [15,16].

The most detailed discipline-specific data come from a retrospective case–control analysis of professional and amateur combat-sports bouts in Texas, which recorded ophthalmic injury incidences of 9.7 per 100 bouts in boxing and 12.2 per 100 bouts in MMA; ophthalmic injuries represented 37.9% of all boxing injuries and 28% of all MMA injuries [35]. The most common ocular injuries in both sports were eyebrow and eyelid lacerations, followed by orbital and eyelid haematomas and corneal abrasions, with MMA showing a greater variety of injury types (including “eye poke”, pupil injuries and orbital haematomas) than boxing, reflecting the wider range of striking tools – hands, elbows, knees and feet – and the smaller, thinner gloves used in MMA [35]. A key clinical–competitive finding was that ocular injury was significantly associated with losing the bout in boxing but not in MMA, plausibly because sustained blows to the face that cause eye injury also impair vision, defence and reaction time [35].

A large series from the Nevada State Athletic Commission covering nearly two decades of professional MMA found that 73.3% of events had at least one eye injury; among 369 eye injuries, eyebrow and eyelid lacerations (43%), lacerations around the eye (27%) and orbital fractures (17%) predominated, most were right-sided, and the majority of fighters who sustained an eye injury lost their bout [15]. Orbital fractures accounted for a larger share of eye injuries in fighters who lost, and were the most common reason for a recommendation of ophthalmological follow-up and for mandated no-contact periods [15]. These findings, echoed by earlier boxing studies reporting a high prevalence of vision-threatening injuries and retinal tears in professional boxers, establish that combat-sports ocular trauma is frequent, clinically significant and probably underestimated by injury-surveillance systems that record only broad body regions rather than specific organs [15,35].

Beyond acute globe and orbital injury, combat sports raise two additional concerns. First, repeated head acceleration–deceleration during knockouts and knockdowns generates shearing forces within the retina and choroid that may promote asymptomatic peripheral retinal changes; boxers and other collision-sport athletes are more likely than non-collision athletes to harbour such lesions, which may increase the risk of severe complications after a subsequent injury [16,32]. Second, in most professional MMA and boxing formats no equipment directly protects the orbital region and standard gloves neither prevent globe trauma nor stop eye-poke incidents, so protection depends chiefly on rules, refereeing and medical supervision rather than on personal protective equipment [16,35]. The combat-sports literature also highlights the value of experience from military ocular trauma, where shorter time to surgical intervention improves visual prognosis – a principle directly relevant to the management of severe combat-sport eye injuries [16].

Combat sports also exemplify the concept of cumulative, subclinical ocular injury. Retinal screening of elite athletes found asymptomatic peripheral retinal lesions in 40% of boxers, a prevalence comparable to rugby and far above that in non-collision athletes, attributable to repetitive head acceleration–deceleration and shearing at the vitreoretinal interface [32]. Even without overt eye trauma, combat-sport athletes exhibit vestibulo-oculomotor dysfunction – impaired saccades, smooth pursuit and gaze stabilisation – linked to repeated head impacts, and isolated reports of infectious complications such as herpes gladiatorum with ocular involvement highlight the additional risks of close skin-to-skin contact [16]. Because most combat-sport injury surveillance records broad body regions rather than specific ophthalmic categories, and because prospective studies with full pre- and post-bout ophthalmic

examination are lacking, the true incidence of retinal microtrauma and minor haemorrhage in these athletes remains unknown and is probably underestimated [16,35].

Two additional strands of combat-sports evidence deserve emphasis. First, the mechanical difference between disciplines is quantifiable: MMA fighters wear 4–6 ounce fingerless gloves that, in kinetic testing, produced four to five times greater peak force than traditional boxing gloves, with a faster load rate, helping to explain both the higher overall injury incidence in MMA (estimated at 22.9–28.6 per 100 athlete-exposures) and its greater diversity of ocular injury types [15,35]. Second, older ophthalmological studies of boxers established a high prevalence of vision-threatening posterior-segment pathology: one series found a 58% prevalence of vision-threatening injuries and retinal tears among professional boxers compared with 7% in controls, and an Italian study reported conjunctival, corneal, lenticular, vitreal and retinal problems in 40.9% of boxers versus 3.1% of controls [15]. Data from the Nevada State Athletic Commission indicate that about 14% of all boxing injuries involve the eye region [16,35]. Together these findings argue that the ophthalmic burden of combat sports is both mechanically explicable and clinically serious, and that experience from military ocular trauma – where reduced time to surgical repair improves visual outcome and lowers the risk of enucleation – should inform the organisation of ringside and post-bout ophthalmic care [16,35].

5.4. Projectile, recreational and other sports (paintball, airsoft, golf, skiing, motocross, rugby)

Paintball is among the most dangerous recreational activities for the eye. The projectile is small, relatively massive and travels at 80–130 m/s or more, producing a sharply localised impact that transfers most of its energy to the globe and frequently causes severe injury [33,36]. Reported injuries include hyphema, iridodialysis, traumatic cataract, lens subluxation, scleral rupture, retinal detachment and secondary (often delayed) glaucoma, with a high rate of surgery and of permanent visual loss [33,36]. A recurring and preventable pattern is that many injuries occur when players remove eye protection prematurely – after they believe the game has ended, or because of fogging – while others continue shooting; in one series all victims had used eye protection during play but were injured after removing it [33]. Traumatic glaucoma following paintball injury may not manifest until years after the initial trauma, underscoring the need for prolonged follow-up [36]. Crucially, no ocular injuries have been reported in players wearing eye protection compliant with the relevant American Society for Testing and Materials (ASTM) standard, and the consistent recommendation is that ASTM-approved protectors be worn at all times while any player remains on the field [24,33].

Golf produces infrequent but characteristically devastating eye injuries. A scoping review of golf-related ocular injury found high rates of enucleation or evisceration (about one-third of reported cases) and of blindness in at least one eye (about 38%), with adults typically injured by golf balls and children by golf clubs, often away from the course and without supervision [34]. These findings support constant adult supervision of children using golf equipment, education in course etiquette and safety, and consideration of protective eyewear, particularly for beginners [34]. Skiing and snowboarding, by contrast, cause facial and craniofacial trauma more often than isolated globe injury; a decade-long analysis of skiing-related facial trauma in adults found that concussions predominated, that nasal and cervical-spine fractures were the most common fractures, and that males sustained the majority of injuries, while also drawing attention to ultraviolet (snow-blindness) risk and to the limited evidence that helmets protect the face [37].

Rugby illustrates the danger of intentional or reckless injury in contact sports. A report of giant retinal tears resulting from deliberate eye gouging during a rugby tackle demonstrates that the eye is particularly vulnerable to punching or gouging, and that such foul play can cause sight-threatening retinal detachment; the authors emphasise that any athlete complaining of persistent floaters after a blow to the eye or head should be examined by an ophthalmologist within 24 hours [38]. Older series similarly identified combat sports, motocross and “modern” health-club and adventure sports (squash, capoeira, paintball, motocross, new forms of soccer, bungee jumping) as emerging causes of severe ocular trauma, with a consistent finding that most injuries could have been prevented by adequate, correctly used eye protection [2].

The literature on emerging and mixed activities reinforces the theme that no dynamic sport is inherently eye-safe. A ten-year series of ocular injuries from modern health-club, adventure and war-game sports found that health-club activities collectively formed the largest share (41.6%), squash alone accounting for 29.2%, followed by paintball, motocross and new forms of soccer; three-quarters of these injuries were severe, and no patient was wearing adequate protection at the time of impact [2]. Instructive individual mechanisms in that series included paintball players struck after removing eye protection, motocross riders in whom a dislodged stone broke a non-impact-resistant lens that was driven into the eye, and retinal haemorrhage from the abrupt rise in intravascular pressure during bungee jumping – each pointing to a distinct, addressable failure of protection or regulation [2]. Airsoft and paintball together illustrate the projectile-sport paradigm, in which full-face protection worn continuously is the decisive preventive measure [2,33].

Discipline-specific detail sharpens these conclusions. In golf, historical injuries from the caustic liquid centres of older golf balls have been superseded by blunt and rupture injuries from modern balls and clubs; adults are typically struck by balls during play, children by clubs away from the course, and about 9% of injuries occur in spectators, so safety measures must extend to bystanders and to driving-range design [34]. In skiing, the paradox that helmet use has risen sharply yet facial and eye protection remains rare is compounded by risk compensation – helmeted, and especially occasional-helmet-using, skiers take greater risks – and by the high frequency of cervical-spine fractures, which co-occur with facial trauma and carry life-threatening potential [37]. In paintball, detailed case series document that severe injuries frequently follow removal of eye protection once players believe the game has ended, and that non-standard protectors fail when the ball enters beneath or displaces the mask; traumatic glaucoma may present years later, so both strict, continuous use of ASTM-compliant protection and prolonged follow-up are essential [33,36].

6. Clinically important ocular sequelae and their comparative frequency

The clinical spectrum of sports eye injury spans the entire globe and orbit, and the same lesions recur across disciplines but with markedly different frequencies, reflecting the underlying mechanism. This section compares the principal sequelae and their determinants.

Hyphema – blood in the anterior chamber – is the single most common clinically significant presentation of blunt ocular trauma across virtually all ball and racket sports, and is reported in a high proportion of racket-sport injuries in particular (up to about 85–96% in badminton series) [5,25]. It results from shearing of iris and ciliary vessels during compression and equatorial expansion, and is important not only in itself but as a marker of more severe underlying injury and as a cause of secondary complications, including raised intraocular pressure and, over the longer term, angle-recession glaucoma [5,18,25]. Angle recession, detectable on gonioscopy, is frequently associated with hyphema and can lead to traumatic glaucoma years or decades later through progressive trabecular dysfunction; badminton audits detected angle recession in the majority of injured eyes, and traumatic angle-recession glaucoma developed in a subset over months to years [22,25]. Secondary glaucoma may also arise after hyphema, paintball injury and blunt trauma generally, and can require prolonged medical or surgical management, with visual acuity frequently failing to return to baseline [31,36].

Comotio retinae (Berlin's oedema) is a common finding after blunt sports trauma, representing transient photoreceptor outer-segment disruption manifesting as retinal whitening;

it is usually self-limiting when peripheral but is associated with poor visual outcome when it involves the macula [18,24]. Retinal dialysis (disinsertion at the ora serrata), giant retinal tears and rhegmatogenous retinal detachment form the most vision-threatening group of posterior-segment injuries and are associated particularly with soccer, squash, tennis, basketball and combat sports; they arise from equatorial expansion and vitreoretinal traction and, when they involve the macula, frequently leave permanent visual deficit despite successful reattachment [7,18,24,38]. Traumatic macular hole is comparatively uncommon and, unlike idiopathic macular hole, frequently closes spontaneously, so a period of observation may be appropriate in isolated cases, whereas complex trauma warrants earlier surgery [24,30].

Retinal detachment (RD) deserves particular emphasis as a severe, potentially blinding emergency whose risk is elevated in athletes. Its incidence in the general population is estimated at 5–20 cases per 100,000 person-years, and risk factors of specific relevance to athletes include myopia, lattice degeneration, prior ocular surgery (especially cataract surgery and vitrectomy), a family history of RD and contralateral RD [11]. Collision sports increase the likelihood of retinal injury and of peripheral retinal lesions in elite athletes; blunt trauma from sports balls can cause equatorial expansion and vitreoretinal traction culminating in retinal tears or detachment [11]. A retrospective screening study of 88 professional athletes found that peripheral retinal lesions were significantly more prevalent in collision-sport athletes – 40.5% in rugby, 40.0% in boxing and 12.5% in judo – than in non-collision athletes (6.1%), with participation in collision sport associated with an approximately twelve-fold increased adjusted odds of peripheral retinal lesions [32]. Many of these lesions were asymptomatic and detectable only on careful fundus examination; ultra-widefield imaging showed high specificity but relatively low sensitivity (about 45%) compared with dilated fundus examination, so it cannot replace a thorough dilated examination for screening in high-risk athletes [32].

Orbital blow-out fracture is a distinctive sports injury caused by a sudden explosive rise in intra-orbital pressure, most often from high-velocity ball impact, that fractures the thin orbital floor or medial wall while the rim remains intact [1,12]. In a series of pure orbital blow-out fractures, 37% were sustained during sport – soccer most commonly – and parts of an opponent's body were responsible for 70% of the sporting cases; although visual-acuity recovery was usually complete, permanent loss of binocular visual field with diplopia on certain gaze directions was almost universal, a handicap of particular importance to young athletes with high dynamic-vision demands [12]. The association between a fracture of the orbital rim itself and globe rupture, and the recognised dissociation between orbital and ocular

injury (an intact orbit does not guarantee an intact globe, and vice versa), together mandate full ophthalmic examination of every athlete with periorbital trauma [1,12]. Open-globe injury, though comparatively rare in sport, is the most serious outcome and is associated especially with small hard projectiles (golf, paintball), with shattered spectacles, and with intentional trauma; it carries a poor visual prognosis and frequently requires multiple procedures, including evisceration or enucleation [14,33,34].

Choroidal rupture and vitreous haemorrhage warrant separate mention. Choroidal rupture, a break in the choroid, Bruch's membrane and retinal pigment epithelium, is a recognised outcome of blunt sports trauma with relatively low incidence because of the higher tensile strength of choroidal tissue, but it threatens central vision when it involves the macula and can be complicated by later choroidal neovascularisation [21,24]. Vitreous haemorrhage is common after posterior-segment injury – reported in roughly a third of soccer injuries – and, by obscuring the fundus, can delay the diagnosis of underlying retinal tears or detachment, so ultrasonography and close follow-up are important [21,24]. Open-globe injury remains the worst outcome: in golf, more than half of injuries are open-globe and about a third end in enucleation or evisceration, and in paintball a quarter or more of injured eyes reach no light perception, outcomes that starkly quantify the cost of unprotected exposure to small, high-energy projectiles [33,34].

Several further sequelae complete the clinical picture. Traumatic optic neuropathy, an acute injury of the optic nerve after blunt trauma (often to the forehead), may present with severe vision loss – light perception or worse in up to 60% of cases – with an initially normal-appearing disc and later optic atrophy, and must be considered after high-energy head and orbital impacts [2]. Iridodialysis, sphincter tears, traumatic mydriasis and cyclodialysis clefts reflect direct anterior-segment disruption and may cause glare, photophobia and hypotony, while ciliary-body injury can produce prolonged hypotony and choroidal effusion [26]. Angle-recession glaucoma is a characteristically delayed complication: in badminton and other blunt-trauma cohorts, recession was detected in a high proportion of eyes within weeks, elevated intraocular pressure developed in a subset over the following months, and an estimated 10% of eyes progress to angle-recession glaucoma over about ten years, so lifelong intermittent monitoring after significant blunt trauma is warranted [22,25]. Commotio retinae reflects photoreceptor outer-segment disruption and light scatter rather than true oedema on histopathology, which explains both its transient nature and the poor prognosis when the fovea is involved [24].

Retinal detachment also carries a distinctive functional cost that is directly relevant to athletes: it is associated with longer periods of disability than retinal tears or less severe ocular injuries and is more likely to limit return to sport, so counselling athletes on realistic recovery timelines and the probability of resuming participation is an important part of management [11]. Because most rhegmatogenous detachments are idiopathic but traumatic detachment is frequently preventable, and because early diagnosis of retinal tears and regular ophthalmic review can pre-empt progression to detachment, the case for structured screening and protection in predisposed athletes is strengthened [11]. Prompt recognition is critical: any athlete reporting new floaters, flashes, a curtain or shadow across the visual field, or sudden reduction of vision after ocular or head trauma must be referred urgently, because the interval to treatment influences the visual prognosis of both retinal detachment and severe globe injury [1,11,38]. The acute management of these injuries follows from their mechanism and severity. Hyphema requires rest, head elevation and avoidance of exertion, with monitoring for raised intraocular pressure and for secondary haemorrhage, which can occur in a minority of eyes within a week of injury and worsens the prognosis; larger hyphemas and those with angle recession carry a long-term glaucoma risk that mandates follow-up [18]. A suspected open globe is an emergency in which the priority is to prevent extrusion of intraocular contents: the eye should be shielded rigidly rather than padded, pressure and manipulation avoided, antiemetics given to prevent Valsalva, broad-spectrum antibiotics and tetanus prophylaxis considered, and the patient transferred urgently to an eye centre [2]. The sports-medicine physician's role is to distinguish minor injuries from those requiring immediate referral – sudden loss of vision or visual field, a peaked or irregular pupil, an absent red reflex, marked hyphema, foreign-body sensation with a possible penetrating body, diplopia or restricted motility, and severe pain – and to initiate protective first aid without delay [1,2].

7. Eye protection: types, materials and technical standards

The single most effective countermeasure against sports eye injury is appropriate, correctly used eye protection, and the evidence that it works is both strong and consistent [1,4,13,20,24]. Effective protectors dissipate impact force over a larger area, shifting load from the eye and face to the skull without causing intracranial injury [4]. The material of choice is polycarbonate, a highly impact-resistant plastic that is roughly eight times stronger than comparable materials, capable of absorbing ultraviolet light, and available in both prescription and non-prescription forms; ordinary eyeglass lenses have only a small fraction of the impact resistance of polycarbonate of comparable thickness [4,20]. A newer impact-resistant material, Trivex,

offers similar protection [2]. Finite-element modelling of paediatric soccer injury indicates that polycarbonate protective eyewear can reduce retinal strain by roughly 47–69%, significantly decreasing the severity of eye deformation on impact [11].

Protection takes several forms matched to the demands of each sport: sports goggles or spectacles with polycarbonate lenses; faceguards or visors attached to helmets; and full-face masks or shields [1,20]. Recommended configurations include polycarbonate sports goggles for basketball, soccer, tennis and racket sports; a batter's helmet with a polycarbonate or wire face guard plus polycarbonate goggles for baseball and softball fielders; full face masks for ice-hockey goalkeepers and helmets with full-face protection for field players; polycarbonate eye shields attached to a wire face mask for American football; full-face protection for lacrosse, paintball and airsoft; and high-impact, ultraviolet-filtering eyewear or goggles for skiing [20]. A central and repeatedly emphasised point is that street wear offers no protection and may be harmful: participants using ordinary corrective glasses or sunwear are at greater risk of severe injury than those using no eyewear at all, because glass or standard plastic lenses can shatter, and hard or gas-permeable contact lenses may break on impact; contact lenses provide no protective benefit and are not appropriate protective equipment [4,20].

Technical standards are what distinguish genuine protection from a false sense of security, and their heterogeneity between regions and sports is itself a barrier to prevention [1]. Certification by recognised bodies indicates that a protector has been tested to a defined standard by an independent laboratory; the ASTM has established performance standards for eyewear in several sports (for example ASTM F803 for racket sports and, historically, sport-specific standards for baseball, basketball, women's lacrosse, field hockey and skiing), and the European Committee for Standardization publishes analogous standards [20,24]. The importance of standard-compliant equipment is demonstrated most clearly in racquetball and paintball: injuries continued to occur with early "open" eye guards that lacked lenses, because the ball could deform through the gap, whereas no injuries have been reported in players wearing ASTM F803-compliant eyewear with impact-resistant lenses [24,33]. Ophthalmologists and optometrists, together with local bodies and professional associations, are well placed to formulate and disseminate guidance on choosing the correct protector for a given activity, since low-quality or poorly fitting eyewear, or a helmet without a visor, can give a false sense of security while providing inadequate protection [13].

Two refinements of protective-eyewear science deserve mention. First, an impact-resistant alternative to polycarbonate, Trivex, offers comparable protection with improved optical quality, widening the options for prescription protective lenses [14]. Second, protection against

impact and protection against ultraviolet radiation can be combined but must be separately verified: the eye-sun protection factor (E-SPF) integrates ultraviolet transmission through the lens with ultraviolet reflected from its back surface, and predictive protection factors model real-world performance under a defined exposure geometry, showing that a small, flat or ill-fitting frame can perform poorly even with an intrinsically good lens, whereas goggles or large close-fitting frames give near-complete protection [17]. These principles argue for dual-purpose sports eyewear – impact-resistant, certified to the relevant ASTM or equivalent standard, and providing certified ultraviolet filtration up to 400 nm with adequate frame coverage – particularly for outdoor and high-reflectance sports [1,17].

8. Prevention: rules, screening, education and current recommendations

Prevention of sports eye injury is best conceived as a multi-level strategy that integrates protective equipment, rule and environment modification, systematic screening and coordinated education, consistent with established injury-prevention frameworks [1,3]. Because approximately 90% of injuries are preventable and comprehensive programmes combining eye protection, rule change and education can reduce the incidence and severity of injuries by as much as 70–100%, the case for a proactive, organised approach is compelling [3,11,13].

The strongest evidence base concerns mandatory protective-eyewear policies. The introduction of mandatory eye protection has repeatedly produced steep, durable falls in injury rates: eye injuries in the National Hockey League fell to essentially zero after visors were mandated for new players; the World Squash Federation requires appropriate eyewear for juniors in its championship competitions, after which no significant ocular injuries were reported; mandatory protective eyewear in United States high-school field hockey more than halved the eye-injury rate; and the Finnish Floorball Federation made protective eyewear mandatory in junior floorball after floorball was found to cause 45% of sports eye injuries in a national series [1,5,8]. The consistent conclusion is that the effectiveness of protection depends heavily on compliance, and that mandatory, standardised policies in high-risk disciplines are justified [1,3].

Rule modification and modification of the playing environment form a complementary pillar. Historical experience in ice hockey (the high-sticks rule and mandatory face protection) and the cautionary counter-example of relaxed high-stick rules in field hockey demonstrate that rules governing dangerous play directly affect eye-injury rates [31]. In team sports, stricter enforcement against elbowing, late tackles and dangerous play, and age-appropriate restriction

of the most hazardous techniques, can reduce the number of events leading to eye injury, analogous to concussion-prevention strategies; in combat sports, sanctions for eye pokes, glove-design modification and prompt stoppage when eye injury is suspected are rational measures [3,16,35]. Because a substantial minority of the most severe injuries result from intentional foul play – punching, gouging or high-sticking – firmer control of deliberate injury is itself a preventive intervention, and sportsmen should be aware that the sports venue confers no immunity from the law [12,38].

Screening and medical surveillance constitute a third pillar. The IOC consensus recommends periodic ophthalmic examination in high-risk athletes, including assessment of visual acuity and ocular structures, with baseline documentation and follow-up after injury, and stresses that the eyes are among the most exposed yet least protected organs in elite sport [1,16]. Pre-participation ophthalmological examination is especially important in children and adolescents, the group most at risk of injury and of its permanent consequences, and standardised screening should include questions about previous eye injury, monocular status, corrective lenses, protective equipment and participation in high-risk sport [3]. In collision-sport athletes, dedicated retinal screening for asymptomatic peripheral lesions is valuable, and dilated fundus examination remains the reference standard because ultra-widefield imaging, although fast, non-invasive and cost-effective for initial screening, has limited sensitivity for subtle peripheral lesions [32]. Certain groups warrant particular vigilance and, in some cases, mandatory protection or activity restriction: functionally one-eyed athletes, highly myopic athletes, those with peripheral retinal degeneration or a history of retinal detachment, and those who have undergone cataract, refractive or retinal surgery [1,11,20]. For patients with peripheral lattice degeneration or a history of retinal detachment, abrupt head movements can trigger detachment, so contact and high-acceleration sports (including weightlifting and roller-coasters) are generally discouraged, whereas cycling and swimming are considered safe [11]. Education and behavioural change are the fourth pillar and are essential to convert the availability of protection into its actual use. Studies of knowledge, attitudes and practices consistently show poor adoption of ocular protection even among those aware of the risk, and interventions targeting athletes, coaches, parents and organisations improve awareness and uptake [13]. A pragmatic study in India reduced eye-injury incidents by almost 70% through education directed at those at risk, and “enhanced education” packages combining individual and group sessions have improved compliance in occupational settings [11,13]. Educational reinforcement, exemplified by the World Sight Day theme “Love your eyes”, and the involvement of ophthalmologists and optometrists in formulating job- or sport-specific

guidance, are recognised routes to the behavioural change that ultimately determines whether preventable injuries are in fact prevented [13]. Because risk-taking behaviour – the “winning at all costs” attitude – itself contributes to injury, education that raises awareness of the long-term consequences of eye injury and that shapes pro-safety attitudes is an integral component of prevention rather than an optional adjunct [3].

Table 3 collates the principal recommended protectors and applicable standards by discipline, together with the groups for whom protection should be regarded as mandatory.

Sport / setting	Recommended protection	Standard / note
Racket sports (squash, racquetball, badminton, tennis)	Sports goggles with polycarbonate lenses	ASTM F803; open (lensless) guards inadequate
Basketball, soccer, handball, volleyball	Polycarbonate sports goggles/spectacles	Sport-fit frame not affecting play
Baseball / softball	Batter’s helmet with polycarbonate or wire guard; polycarbonate goggles for fielders	Helmet + face protection
Ice hockey	Helmet with full-face mask or visor; goalkeeper full mask	Mandatory in many leagues; markedly reduces injury
Field hockey / lacrosse	Protective eyewear or full-face protection	Mandatory eyewear halved injury in field hockey
Paintball / airsoft	Full-face protection worn at all times on field	ASTM-compliant; never remove on field
Skiing / snowboarding	High-impact eyewear or goggles with UV filtration	Also protects against snow-blindness
Combat sports	Rule/refereeing measures; screening; no eye protector during bouts	Protection depends on rules and supervision
Functionally one-eyed / post-eye-surgery / high myopia	Polycarbonate protection mandatory; avoid unprotected high-risk sport	Individualised counselling

Compiled from references [1,3,4,8,11,20,24,33,37]. UV – ultraviolet.

On-field and acute management, and systematic surveillance, are further components of a mature preventive system. The IOC consensus provides practical guidance for the sports-medicine physician: assess visual acuity, pupillary responses and the red reflex; recognise the signs of orbital fracture, open-globe injury and orbital compartment syndrome; avoid any pressure on a suspected ruptured globe and any ophthalmic ultrasound in that setting; protect the eye with a rigid transparent shield rather than a pad; and refer urgently when red-flag features are present [1]. The recommended field bag includes a penlight with a cobalt-blue filter, a direct ophthalmoscope, fluorescein strips, a transparent hard-shell shield and appropriate lubricating, anaesthetic and antibiotic drops, and a smartphone can serve for illumination and for photo and video documentation that conveys more information to the receiving ophthalmologist than a written description [1]. At the organisational level, systematic recording of eye injuries within sports-injury registries – ideally using standardised, organ-specific categories consistent with consensus reporting standards – is necessary to assess the effectiveness of interventions and to identify emerging risks, a need felt most acutely in combat sports, where current surveillance under-records ophthalmic trauma [3,16].

Concrete examples demonstrate that rule change works. The ban on body-checking in youth ice hockey significantly reduced concussion rates, and by analogy measures such as shorter round durations, limits on absorbed strikes and prompt stoppage when eye injury is suspected have been proposed for combat sports; reduced full-contact sparring in favour of technical training, and emphasis on blocking and evasive technique, are associated with fewer head injuries and, plausibly, fewer orbital injuries [16]. In field and ice hockey the historical sequence – rising injuries after relaxation of the high-stick rule, followed by sharp falls after mandatory face protection – provides perhaps the clearest evidence that governance of dangerous play and equipment directly determines eye-injury rates [31]. These precedents support international harmonisation of rules and of protective standards across analogous sports [3,16].

8.1. Special populations and individualised protection

Certain athletes warrant an individualised approach in which protection is mandatory and, occasionally, participation in specific sports is discouraged. Functionally one-eyed athletes – those with corrected acuity of 20/40 or worse in one eye – and athletes who are pseudophakic or have undergone refractive, cataract or retinal surgery, or who have suffered previous ocular trauma, should wear polycarbonate protection for any sport carrying eye-injury risk and should avoid disciplines in which adequate protection is unavailable, such as boxing and certain

martial arts [1,2,20]. High myopia and peripheral retinal degeneration warrant particular caution because they predispose to retinal detachment; heavy occupational or athletic lifting and rapid head acceleration (as in weightlifting and on roller-coasters) have been implicated in retinal detachment among myopes, and patients with lattice degeneration or previous detachment are generally advised to avoid contact and high-acceleration sports, whereas cycling and swimming are considered safe and beneficial [11]. Children and adolescents merit special emphasis because they sustain a disproportionate share of injuries and because early education and habit formation are decisive; decisions about eye protection should prioritise individual ocular history and retinal risk factors rather than the nominal risk category of the sport [9,11].

9. Non-traumatic ocular considerations in sport

Although mechanical trauma dominates the sports-ophthalmology literature, several non-traumatic considerations are relevant to a complete account of the athlete's eye and to the design of protective eyewear. Ultraviolet radiation (UVR) is an under-recognised hazard in outdoor and high-reflectance sports; acute high-dose exposure causes photokeratitis (snow blindness), while chronic cumulative exposure contributes to pinguecula, pterygium and cortical cataract, with a less direct and more heterogeneous association with age-related macular degeneration [1,17]. UVR effects are best understood as tissue-specific responses to a shared exposure, modified by wavelength, exposure geometry and environment; altitude, and reflection from snow, water and sand amplify ocular dose, making skiing, sailing, surfing, cycling and endurance running high-exposure activities [1,17]. Effective ocular photoprotection requires both adequate spectral filtering (certified blocking of UVA and UVB up to 400 nm) and geometric protection (frame and lens shape that limit peripheral, oblique and reflected radiation); importantly, lens tint and polarisation do not indicate ultraviolet protection, and a clear certified lens may protect better than a dark, non-certified sunglass lens [17]. These principles are directly relevant to the design of dual-purpose protective eyewear that guards against both impact and ultraviolet exposure [1,17].

The tissue-specific character of ultraviolet ocular disease follows from exposure geometry. Peripheral light focusing concentrates irradiance about 22-fold at the nasal limbus and about 8-fold at the nasal lens cortex, which explains why pinguecula and pterygium arise typically at the nasal conjunctival–limbal region and why cortical cataract often begins in the nasal lens cortex [17]. Acute high-dose exposure causes photokeratitis (snow blindness), a painful, usually bilateral keratoconjunctivitis that appears several hours after exposure and resolves

within one to three days, whereas chronic cumulative exposure drives pinguecula, pterygium and cortical cataract over years, with a more heterogeneous and indirect association with age-related macular degeneration mediated partly by short-wavelength visible light [17]. Dosimetry from outdoor competition confirms that athletes accumulate substantial exposure – in one study of school rowers the median personal ultraviolet dose in a single race exceeded the recommended daily threshold in most participants – so preventive counselling and certified, well-fitting protective eyewear should begin early, particularly in children whose clearer lenses transmit more ultraviolet and short-wavelength light to deeper ocular structures [17].

Contact lenses warrant specific comment because they are widely used by athletes for refractive correction but must not be mistaken for protection. Contact lenses provide no protective benefit against trauma and are not appropriate protective equipment; moreover, lens wear carries its own spectrum of complications relevant to active individuals, including contact-lens-induced dry eye and discomfort, giant papillary conjunctivitis, superior limbic keratoconjunctivitis, allergic or toxic conjunctivitis, superficial punctate keratitis, corneal abrasion, hypoxic corneal oedema, and, most seriously, microbial keratitis – the risk of which is increased by poor hygiene, prolonged wear and, notably, swimming in contact lenses [20]. Athletes who require refractive correction and wish to participate without spectacles or lenses may consider refractive surgery, but this is itself a risk factor for ocular-surface disease and dry eye through corneal nerve transection, which can affect up to about 30% of patients and occasionally causes persistent, severe symptoms [1]. Finally, the broader environmental context of sport – wind, dust, dry or air-conditioned indoor environments and, in electronic sports, prolonged screen use – contributes to dry-eye disease and digital eye strain, which, while not sight-threatening, can measurably impair comfort, quality of life and performance [1].

Finally, the athlete's eye is not only an organ at risk but also a determinant of performance, and this dual role has preventive relevance. Because vision supplies nearly 80% of perceptual input in sport, uncorrected refractive error, subclinical retinal or optic-nerve pathology and post-concussion visual dysfunction can degrade performance and may predispose to further injury, which is one rationale for comprehensive pre-participation visual assessment [1]. Sports vision – dynamic visual acuity, contrast sensitivity, depth perception, peripheral awareness and visuomotor coordination – can be trained and adapts with practice, as illustrated in tennis, and correcting deficits at the base of the so-called sports-vision pyramid supports both performance and safety [1,29]. Behavioural and psychological factors also modulate risk: sport psychology situates injury prevention within the broader physical-culture sciences, and personality and risk-taking dispositions influence the propensity to engage in hazardous play and to adopt or

reject protective equipment, so that education aimed at attitudes and at winning-at-all-costs behaviour is a legitimate component of an ocular-injury-prevention strategy [3,39,40].

10. Discussion

Viewed as a whole, the evidence assembled here supports several robust and mutually reinforcing conclusions, while also exposing genuine discrepancies and limitations that temper any simple synthesis. The first robust conclusion is epidemiological: sports eye injuries are common, disproportionately affect young males, cluster in a predictable set of high-risk disciplines, and, although usually of low average severity, carry a small but important risk of permanent, life-altering visual loss [2–5,8]. The second is mechanistic: the pattern of injury in any given sport is largely determined by the physics of the impacting object and the anatomy it loads, so that fast small projectiles and close-range implements concentrate high-energy, potentially penetrating trauma on the globe, whereas larger objects load the orbit and may fracture it while sparing or occultly injuring the eye [5,12,21–23]. The third, and most consequential for practice, is preventive: roughly 90% of these injuries are preventable, polycarbonate protection meeting recognised standards is highly effective, and mandatory-eyewear policies have repeatedly produced large, durable reductions in injury where they have been implemented [1,13,24,33].

The comparative dimension of this review reveals both consistency and instructive discrepancy between disciplines. There is striking cross-study consistency in the demographic profile, in the dominance of blunt closed-globe injury, in the primacy of hyphema as a presenting sign, and in the effectiveness of standard-compliant polycarbonate protection [4,5,24,25,33]. The discrepancies are equally informative. The dominant mechanism differs systematically – ball impact in soccer and squash, player contact in basketball, deliberate striking and eye pokes in combat sports, and premature removal of protection in paintball – and each discrepancy points to a different preventive lever [19,33,35]. The injury zone differs too: racket sports and small projectiles concentrate damage in zone II (limbus, ciliary body, angle, zonules) and thus in hyphema, angle recession and lens subluxation, whereas large slow balls localise a posterior pressure wave and thus retinal dialysis and detachment, a distinction now given quantitative substance by finite-element modelling [5,21,22]. Even the apparently paradoxical observation that a soft soccer ball can blind, or that badminton – an ostensibly gentle recreational game – is a leading cause of monocular blindness in parts of Asia, is resolved once mechanism rather than intuition guides interpretation [5,21,25].

Several limitations of the underlying evidence base must be acknowledged and constrain the strength of any recommendation. First, most epidemiological data are retrospective and derive from emergency departments, hospitals or specialist eye centres, which over-represent severe injuries and under-count minor trauma managed elsewhere or not at all; true population incidence is therefore poorly defined [1,8]. Second, there is substantial heterogeneity in injury definitions, severity grading, denominators and follow-up, which precludes valid quantitative pooling and means that many cross-study comparisons in this review are necessarily qualitative [3,5]. Third, because most series report absolute case numbers rather than exposure-adjusted rates, the apparent ranking of dangerous sports is confounded by local popularity, so a sport that merely has many participants will spuriously appear especially hazardous [1,5]. Fourth, the finite-element studies, although powerful, rely on simplifying assumptions and on material properties derived from ex-vivo tissue that may not fully reproduce in-vivo behaviour, and most do not yet incorporate ageing or protective eyewear [21–23]. Fifth, protective-eyewear use is frequently undocumented in clinical records, which hampers direct estimation of its real-world effectiveness and argues for routine recording of eyewear status in all sports eye-injury encounters [6]. Finally, combat-sport surveillance in particular tends to record broad body regions rather than specific ophthalmic categories, almost certainly underestimating the true burden of ocular trauma and precluding reliable estimation of retinal microtrauma; standardised, organ-specific surveillance (for example in line with consensus reporting standards) is a clear priority [15,16,35].

These limitations notwithstanding, the practical implications are clear and actionable. Effective prevention requires the integration of medical and organisational interventions: mandatory, standardised polycarbonate eye protection in high-risk disciplines; rule and environment modification to limit dangerous play; pre-participation and periodic ophthalmic screening, with particular attention to functionally one-eyed, highly myopic and post-surgical athletes and to asymptomatic peripheral retinal lesions in collision-sport athletes; unified acute-care protocols with clear criteria for red-flag symptoms, removal from play and prompt specialist referral; and sustained education of athletes, coaches and parents to change attitudes and improve compliance [1,3,11,13,16]. International harmonisation of guidelines, systematic injury surveillance within sports-injury registries, and interdisciplinary collaboration between ophthalmology, sports medicine, biomechanics, epidemiology and health education would materially strengthen both the evidence base and its translation into practice [3,16]. Future research should prioritise prospective, exposure-adjusted studies; incorporation of ageing and of protective eyewear into biomechanical models to quantify protection and inform equipment

standards; and prospective ophthalmic studies in combat sports, including routine retinal assessment before and after competition and long-term follow-up of cumulative eye and head trauma [16,23,36].

A final synthesising observation is that the epidemiological and biomechanical strands of evidence, though methodologically very different, tell a consistent story. Epidemiology identifies which sports and mechanisms injure the eye and how severely; biomechanics explains why, translating the size, speed, hardness and geometry of each impacting object into a predictable pattern of anterior- or posterior-segment damage; and the protective-equipment literature closes the loop by showing that interrupting the transfer of energy to the globe prevents the injury [5,21,22,33]. This convergence is reassuring, because it means that recommendations rest not on any single fragile dataset but on mutually reinforcing lines of evidence, and it is the strongest available justification for the mandatory, standardised, enforced protection advocated throughout this review [1,3,13].

Several priorities for future research follow directly from these gaps. Prospective, exposure-adjusted cohort studies with long-term follow-up are needed to define true incidence and the natural history of injuries such as angle recession and peripheral retinal lesions; biomechanical models should incorporate ageing and, crucially, protective eyewear so that the magnitude of protection can be quantified and used to inform equipment standards; and combat sports in particular require prospective studies with full ophthalmic examination before and after competition to capture cumulative and subclinical trauma [16,22,23]. Equally important is implementation research: identifying which combinations of mandate, education and equipment design most effectively raise and sustain protective-eyewear use, and how best to harmonise standards internationally, would translate the well-established efficacy of protection into population-level effectiveness [3,13,16].

A recurring and sobering theme is the gap between the strong evidence for protection and its weak uptake. Studies of knowledge, attitudes and practices show that even athletes who are aware of the risk frequently do not use protection, whether because of concerns about comfort, appearance or performance, a false sense of security from ordinary spectacles or from helmets without visors, or a sporting culture that normalises risk [13]. This behavioural gap means that technical solutions alone are insufficient; durable reductions in injury have been achieved chiefly where protection is mandatory and enforced, as in ice hockey, women's lacrosse, high-school field hockey and junior floorball and squash [1,8,13]. The implication for policy is clear: voluntary recommendation is necessary but not sufficient, and in high-risk disciplines mandatory, standardised, enforced protection – supported by sustained education that targets

attitudes as well as knowledge – is the intervention most likely to convert preventability into prevention [3,13].

11. Conclusions

Ocular injuries in sport are frequent, potentially severe and, above all, largely preventable. They affect predominantly young males, cluster in fast-projectile racket sports, popular team ball sports and full-contact combat sports, and produce a characteristic spectrum of blunt closed-globe injury – hyphema, angle recession and secondary glaucoma, commotio retinae, retinal dialysis and detachment, orbital blow-out fracture and, less often, globe rupture – whose distribution across the eye is now well explained by the biomechanics of each sport. Although average severity is modest, a small but clinically important minority of injuries cause permanent, often monocular, visual loss in people at the start of their productive lives.

The central and consistent message of the literature is that approximately nine in ten of these injuries could be prevented. Polycarbonate eyewear conforming to recognised standards, sport-specific visors and full-face protection markedly reduce both the incidence and the severity of injury, whereas ordinary spectacles and contact lenses offer no protection and may aggravate harm. Effective prevention therefore demands the integration of medical and organisational measures: mandatory, standardised eye protection in high-risk disciplines; rule modification and firmer control of dangerous play; pre-participation and periodic ophthalmic screening, with individualised protection for functionally one-eyed, highly myopic and post-surgical athletes; unified acute-care and referral protocols; systematic, organ-specific injury surveillance; and sustained education of athletes, coaches and parents. The combination of medical and organisational analysis should form the basis for designing effective eye-injury prevention programmes in sport, so that participation in physical activity, with all its health benefits, need not be paid for in avoidable blindness.

DISCLOSURE:

Conceptualization: Agnieszka Maria Jarosz, Katarzyna Czernecka

Methodology: Łukasz Mazelanik, Kacper Dranikowski

Investigation: Aaron Markiewicz, Kacper Kazimierzuk, Szymon Kanadys, Agnieszka Maria Jarosz, Katarzyna Czernecka, Łukasz Mazelanik, Kacper Dranikowski, Martyna Strzemkwoska, Aleksandra Oknińska-Ziarek, Igor Smędowski

Writing-rough preparation: Martyna Strzemkwoska, Igor Smędowski

Writing-review and editing: Agnieszka Maria Jarosz, Katarzyna Czernecka, Łukasz Mazelanik, Kacper Dranikowski, Aaron Markiewicz, Kacper Kazimierczuk, Szymon Kanadys, Martyna Strzemkwoska, Aleksandra Oknińska-Ziarek, Igor Smędowski

Supervision: Igor Smędowski

Project administration: Igor Smędowski

Funding statement:

This study received no external funding.

Informed consent statement:

Not applicable.

Institutional Review Board Statement:

Not applicable.

Conflict of interest:

The authors declare no conflict of interest.

Declaration of the use of generative AI and AI-assisted technologies in the writing process. In preparing this work, the authors used Claude for the purpose of checking grammar and improving readability. After using this tool, the authors have reviewed and edited the content as needed and accept full responsibility for the substantive content of the publication

References

1. Moe MC, Özmert E, Baudouin C, Binadra A, Crafoord S, Jo Y, et al. International Olympic Committee (IOC) consensus paper on sports-related ophthalmology issues in elite sports. *BMJ Open Sport Exerc Med.* 2023;9:e001644. DOI: <https://doi.org/10.1136/bmjsem-2023-001644>
2. Mishra A, Verma AK. Sports related ocular injuries. *Med J Armed Forces India.* 2012;68(3):260–266. DOI: <https://doi.org/10.1016/j.mjafi.2011.12.004>
3. Kluś M, Olszok M, Karbowski K, Makselan N, Nawrat N, Handzel K, et al. Assessment of the risk of eye injuries in team sports and the impact of safety procedures on their incidence – an interdisciplinary perspective on injury prevention. *Quality in Sport.* 2026;52:69381. DOI: <https://doi.org/10.12775/qs.2026.52.69381>

4. Zhang J, Zhu X, Sun Z, Wang J, Sun Z, Li J, et al. Epidemiology of sports-related eye injuries among athletes in Tianjin, China. *Front Med.* 2021;8:690528. DOI: <https://doi.org/10.3389/fmed.2021.690528>
5. Zhang Y, Jia H, Kang X, Yang Q, Ying J, Wu Q, et al. Discrepancy of eye injuries in mechanism, clinical features, and vision prognosis by different causative sports. *Front Public Health.* 2023;11:1182647. DOI: <https://doi.org/10.3389/fpubh.2023.1182647>
6. Ashraf G, Arslan J, Crock C, Chakrabarti R. Sports-related ocular injuries at a tertiary eye hospital in Australia: a 5-year retrospective descriptive study. *Emerg Med Australas.* 2022;34(5):794–800. DOI: <https://doi.org/10.1111/1742-6723.13982>
7. MacEwen CJ. Sport associated eye injury: a casualty department survey. *Br J Ophthalmol.* 1987;71(9):701–705. DOI: <https://doi.org/10.1136/bjo.71.9.701>
8. Boden BP, Pierpoint LA, Boden RG, Comstock RD, Kerr ZY. Eye injuries in high school and collegiate athletes. *Sports Health.* 2017;9(5):444–449. DOI: <https://doi.org/10.1177/1941738117712425>
9. Chaudhary A, Carr EW, Bogan F, Liu JX, Hajrasouliha AR. An analysis of ocular trauma resulting from pediatric sports injuries. *Clin Ophthalmol.* 2025;19:507–517. DOI: <https://doi.org/10.2147/OPTH.S493655>
10. Bishay MN, Xu A, Nesemann JM, Keenan JD, Oatts JT. Temporal and seasonal trends in pediatric eye trauma in California. *Clin Ophthalmol.* 2025;19:2107–2115. DOI: <https://doi.org/10.2147/OPTH.S523256>
11. Jurczyk-Florkiewicz W, Bajor G, Gniadek Z, Pszczółka A, Kozak J, Melka K, et al. Retinal detachment risk among athletes: incidence, predisposing factors and preventive strategies. *Quality in Sport.* 2026;51:68208. DOI: <https://doi.org/10.12775/qs.2026.51.68208>
12. Jones NP. Orbital blowout fractures in sport. *Br J Sports Med.* 1994;28(4):272–275. DOI: <https://doi.org/10.1136/bjsm.28.4.272>
13. Sinha S, Nishant P, Morya AK, Bejjani P. Commentary: The untapped potential of protective eyewear for primary prevention of ocular trauma. *Indian J Ophthalmol.* 2023;71(5):2215–2216. DOI: https://doi.org/10.4103/ijo.IJO_3376_2
14. Capão Filipe JA, Rocha-Sousa A, Falcão-Reis F, Castro-Correia J. Modern sports eye injuries. *Br J Ophthalmol.* 2003;87(11):1336–1339. DOI: <https://doi.org/10.1136/bjo.87.11.1336>

15. Fliotics MJ, Reed DS, Giles G, Altman AHH, Santamaria JA, Zafar S, et al. Prevalence, patterns, and characteristics of eye injuries in professional mixed martial arts. *Clin Ophthalmol*. 2021;15:2759–2766. DOI: <https://doi.org/10.2147/OPTH.S319025>
16. Kozdra B, Olszok M, Karbowski K, Makselan N, Nawrat N, Handzel K, et al. Eye injuries in combat sports – literature review. *Quality in Sport*. 2026;54:70126. DOI: <https://doi.org/10.12775/qs.2026.54.70126>
17. Borowska A, Kobryń P, Ocicki D, Bojarski M, Kwiatkowski M, Musielak M, et al. Ultraviolet-related ocular disease: tissue-specific effects, outdoor exposure and prevention – a literature review. *Quality in Sport*. 2026;61:72938. DOI: <https://doi.org/10.12775/qs.2026.61.72938>
18. Mahapatra SK, Malhotra K, Mendke RG. A 3-year prospective study on ocular injuries with tennis or cricket ball while playing cricket: a case series. *Indian J Ophthalmol*. 2018;66(2):256–261. DOI: https://doi.org/10.4103/ijo.IJO_458_17
19. Kim EJ, Ganga A, Rana VK, Greenberg PB. The epidemiology of basketball-associated eye injuries in the United States, 2012–2021. *Graefes Arch Clin Exp Ophthalmol*. 2023. DOI: <https://doi.org/10.1007/s00417-023-06136-8>
20. Mazurek W, Rękas B, Stradczuk M, Mazurek Ł, Czach Z, Bachurska D, et al. The most common contact lens-related complications: a brief review of the literature. *J Educ Health Sport*. 2024;74:52574. DOI: <https://doi.org/10.12775/JEHS.2024.74.52574>
21. Lam MR, Dong P, Shokrollahi Y, Gu L, Suh DW. Finite element analysis of soccer ball-related ocular and retinal trauma and comparison with abusive head trauma. *Ophthalmol Sci*. 2022;2(2):100129. DOI: <https://doi.org/10.1016/j.xops.2022.100129>
22. Hong JD, Colmenarez JA, Choi EH, Suh A, Suh A, Lam M, et al. Finite element analysis of mechanical ocular sequelae from badminton shuttlecock projectile impact. *Ophthalmol Sci*. 2025;5(1):100625. DOI: <https://doi.org/10.1016/j.xops.2024.100625>
23. Rydz C, Colmenarez JA, Shahraki K, Dong P, Gu L, Suh DW. Finite element analysis of ocular impact forces and potential complications in pickleball-related eye injuries. *Bioengineering*. 2025;12(6):570. DOI: <https://doi.org/10.3390/bioengineering12060570>
24. Rohowetz LJ, Fan J, Flynn HW Jr. Vitreoretinal injury associated with sports ball ocular trauma. *Clin Ophthalmol*. 2025;19:1931–1943. DOI: <https://doi.org/10.2147/OPTH.S507399>

25. Mohd Rasidin AH, Muhammad-Ikmal MK, Raja Omar RN, Yaakub A, Ahmad Tajudin LS. Clinical audit on badminton-related ocular injuries in a tertiary hospital in Malaysia. *Cureus*. 2022;14(10):e30769. DOI: <https://doi.org/10.7759/cureus.30769>
26. Khandelwal R, Majumdar MR, Gupta A. An unusual mechanism of ocular trauma in badminton players: two incidental cases. *BMJ Case Rep*. 2012;2012:bcr-2012-006363. DOI: <https://doi.org/10.1136/bcr-2012-006363>
27. Mat Nawati FN, Bastion MLC. Hazards of Malaysia's favorite sport: a case series of badminton-related ocular injuries at a single tertiary center. *Cureus*. 2026;18(1):e101594. DOI: <https://doi.org/10.7759/cureus.101594>
28. Jones NP, Tullo AB. Severe eye injuries in cricket. *Br J Sports Med*. 1986;20(4):178–179. DOI: <https://doi.org/10.1136/bjsm.20.4.178>
29. Rabstein D, Gościńiewicz P, Porwolik H, Porwolik A, Pabis P, Porwolik A, et al. The impact of playing tennis on the organ of vision – threats, benefits and prevention of the organ of vision. *J Educ Health Sport*. 2025;77:56836. DOI: <https://doi.org/10.12775/JEHS.2025.77.56836>
30. Lauga A, Maguire A, Muqit M. Complex ocular injury following blunt trauma in a professional adult male soccer player: a case report. *Cureus*. 2024;16(10):e71677. DOI: <https://doi.org/10.7759/cureus.71677>
31. Elliott AJ, Jones D. Major ocular trauma: a disturbing trend in field hockey injuries. *BMJ*. 1984;289:21–22. DOI: <https://doi.org/10.1136/bmj.289.6436.21-a>
32. Arej N, Treguer H, Le Cossec C, Kakona B, Mandrillon N, Vasseur V, et al. Retinal screening in high-performance athletes: a retrospective analysis of asymptomatic peripheral lesions in collision and non-collision sports. *Sports Med Open*. 2025;11:74. DOI: <https://doi.org/10.1186/s40798-025-00869-y>
33. Keles S, Ondas O, Ekinci M, Sener MT, Erhan E, Sirinkan A, et al. Paintball-related ocular trauma: paintball or painball? *Med Sci Monit*. 2014;20:564–568. DOI: <https://doi.org/10.12659/MSM.890319>
34. Jenkins E, Hawkes R, Murray A. A scoping review of the associations of golf with eye injuries in adults and children. *J Sports Med*. 2016;2016:7216325. DOI: <https://doi.org/10.1155/2016/7216325>
35. Akanno UE, Malik M, Alik M, Ashrafi R, Nguyen AX, Wu AY. Characterising ocular injuries in competitive combat sports in Texas: a retrospective case–control study.

- BMJ Open. 2025;15(10):e098197. DOI: <https://doi.org/10.1136/bmjopen-2024-098197>
36. Lee KM, Seery C, Khouri AS. Traumatic glaucoma due to paintball injuries: a case series. *J Curr Ophthalmol.* 2017;29(4):318–320. DOI: <https://doi.org/10.1016/j.joco.2017.06.006>
 37. Galgano AC, Cohn JE, Licata JJ, Othman S, Stucker FJ, Bundrick P. Slippery slopes: skiing-related facial trauma in adults. *Craniomaxillofac Trauma Reconstr.* 2022;15(2):122–127. DOI: <https://doi.org/10.1177/19433875211020933>
 38. Duguid IGM, Leaver PK. Giant retinal tears resulting from eye gouging in rugby football. *Br J Sports Med.* 2000;34(1):65–66. DOI: <https://doi.org/10.1136/bjsm.34.1.65>
 39. Piepiora P, Rauk-Kubacka A, Kubacki R. Sport psychology in the physical culture sciences. A review. *Pedagogy Psychol Sport.* 2021;7(1):61–75. DOI: <https://doi.org/10.12775/PPS.2021.07.01.003>
 40. Piepiora P. A review of personality research in sport. *Pedagogy Psychol Sport.* 2020;6(4):64–83. DOI: <https://doi.org/10.12775/PPS.2020.06.04.007>