Eye and Orbital Injuries in Sports

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KEYWORDS

- Eye injuries • Sports • Globe rupture • Eye protection

KEY POINTS

- Eye protection prevents serious eye injuries in sports.
- Certain findings on history or physical examination warrant urgent referral to an ophthalmologist.
- Irreversible blindness may occur after sports-related trauma.

Although sports-related eye injuries are completely preventable they continue to occur, with serious consequences. Prevention is the most effective way to eliminate the significant morbidity and costs associated with sports-related eye injuries.[1,2] However, for various reasons, including noncompliance with regulations, the lack of enforcement, or suboptimal legislation, these injuries continue to occur regularly.[3–5] Eye trauma has significant consequences not only to the individual but also to society. There is a tremendous cost to care for and treat individuals who have sustained a sports-related injury and many experience permanent vision loss, which has profound effects on their lives.[6] This article discusses the mechanisms, classification, and specific sports-related injuries that may occur to the eye and orbit. It ends with a brief discussion on eye protection and ocular motor function in concussion.

MECHANISM OF INJURY

Trauma to the eye may occur by blunt, penetrating, or perforating mechanisms. Blunt injuries refer to contusions or forces that strike an intact globe. Penetrating injuries occur when there is a single laceration to the eye causing an open globe, and perforating injuries occur when 2 full-thickness lacerations (entrance and exit) are present and are usually caused by a sharp object or missile.

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The severity of an eye injury is correlated with the total impact force, the force onset rate, and the kinetic energy of an object.[7] Experimental studies performed on human, monkey, and porcine eyes show that, after impact, the sclera expands equatorially, producing corneoscleral stress that can cause rupture of the eye.[8,9] Computational models of the eye have been used to simulate a variety of impacts and analyze injury potential. An example of this is the Virginia Tech–Wake Forest University (VT-WFU) eye model, which is a finite element model that has been validated to predict globe rupture for blunt eye impacts.[10] This model has shown that stresses in the corneoscleral shell exceeding 23 MPa and local dynamic pressures exceeding 2.1 MPa result in globe rupture.[10] Other studies have shown that spherical projectiles (baseballs, BB pellets, paintballs, airsoft pellets) result in higher stresses and pressures in the eye compared with cylindrical projectiles (blunt impactor, aluminum, foam) and that peak stresses are located at the apex of the cornea, the limbus, or the equator of the globe.[11] Models such as this can be used as predictive aids to reduce the burden and better understand the mechanisms of eye injury.

CLASSIFICATION OF INJURIES

Sports-related eye injuries can be classified using the Birmingham Eye Trauma Terminology (**Fig. 1**).[12] This classification system uses the entire globe as the tissue of reference and has been endorsed by various societies of ocular trauma. In this system, an eye injury is first classified as either a closed globe injury or an open globe injury. Closed globe injuries can be further subdivided as either contusions (meaning there is no scleral or corneal wound) or lamellar lacerations (partial-thickness wounds of the eye wall). Open globe injuries are further divided into ruptures (full-thickness wound caused by blunt object) or lacerations (full-thickness wound of the eye wall caused by a sharp object). Lacerations can be penetrating, perforating, or involve an intraocular foreign body, which is a retained foreign body causing an entrance laceration.

ANATOMY OF THE EYE AND ORBIT

The eye or globe is not a true sphere. The radius of curvature of the cornea (8 mm) is smaller than that of the sclera (12 mm), giving it the shape of an oblate spheroid.[13] The anteroposterior diameter of the globe is usually between 23 and 25 mm, with myopes (near-sighted individuals) generally having longer eyes than hyperopes (far-sighted individuals). The eye is divided into 3 main compartments: the anterior chamber, the

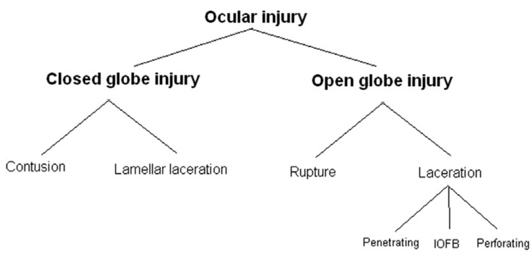

Fig. 1. Classification of sports-related eye injuries. IOFB, intraocular foreign body. (*Courtesy of* Birmingham Eye Trauma Terminology; *adapted from* Kuhn F, Morris R, Witherspoon CD, et al. A standardized classification of ocular trauma. Graefes Arch Clin Exp Ophthalmol 1996;234(6):399–403; with permission.)

posterior chamber, and the vitreous cavity. The anterior chamber refers to the space between the front surface of the eye (cornea) and the iris, whereas the posterior chamber refers to the space between the posterior portion of the iris and the anterior vitreous face. The vitreous cavity occupies that largest volume of the eye (5–6 mL).

There are some important anatomic features of the eye relevant to sports-related injuries that should be highlighted. The sclera, which is the white, outer layer of the eye, is thinnest (0.3 mm) just posterior to the insertion of the rectus muscles and therefore globe rupture is most likely to occur at this location, at the equator of the globe, and at the corneal limbus (junction of the cornea and sclera). The limbus serves as a source of stem cells whose division serves to maintain the corneal epithelium and replace lost cells from corneal abrasions.[14] The aqueous humor is the fluid that fills the anterior chamber and is made by the ciliary body and circulates in this space until it drains in the trabecular meshwork, which is located at the junction of the iris and the cornea. Contusions to the eye may result in the dispersion of blood (hyphema) or pigment that may decrease the outflow at the trabecular meshwork and result in an increased intraocular pressure.

The eye lies within the orbit, which has a volume of about 30 cm^3.[13] Each orbit is composed of 7 different bones that form a roof, floor, and medial and lateral wall. The lateral orbital wall is the thickest and strongest of the walls and is formed from 2 bones: the zygomatic and greater wing of the sphenoid. The medial orbital wall is the thinnest because it is composed of the lamina papyracea, a thin covering of the ethmoidal sinuses. The shortest of the orbital walls is the orbital floor, which does not extend to the orbital apex, but instead ends at the pterygopalatine fossa. The infraorbital canal located 4 mm below the inferior orbital margin transmits the infraorbital nerve, which is a branch of V_2 (maxillary division of the trigeminal nerve). Sports-related trauma to the orbit may result in injury or fracture to the bones, nerve, or vascular supply located within this space.

FIRST RESPONSE TO A POTENTIAL EYE INJURY

Evaluation of an athlete who sustained a potential eye injury on the sidelines begins with reviewing the mechanism of injury. This review may include interviewing the patient, spectators, or teammates, or reviewing film footage at a later date. A review of the symptoms the athlete has experienced is critical to developing a differential diagnosis and deciding on the need for and timing of referral to an ophthalmologist. It is also important to note whether the athlete was wearing glasses or contact lenses because rigid contact lenses have the potential to cause corneal abrasions or lacerations given their design with sharp edges.

Symptoms that warrant referral to an ophthalmologist are summarized in **Table 1**. A physical examination on the sidelines should begin with testing visual acuity 1 eye at a time. An examination of the pupils with a penlight and assessment of extraocular movements should follow. Assessment of the adnexa and the globe should then be performed with a penlight and using fluorescein eye drops with a cobalt blue light to assess the surface of the cornea if necessary. It is also important to have cotton swabs and eye-irrigating fluids available in case an ocular foreign body is detected. Some physical examination signs that warrant urgent referral to an ophthalmologist are summarized in **Table 2**.

OPEN GLOBE INJURIES

If an open globe injury is suspected, it requires urgent attention by the medical staff on a sports team and an urgent referral to an ophthalmologist. These injuries may occur

Table 1
Ocular symptoms in athletes that warrant an urgent referral to an ophthalmologist

Symptom	Potential Problem
1. Loss of vision	Various (nonspecific complaint)
2. Diplopia (double vision)	Extraocular muscle entrapment in orbital fracture Cranial nerve injury
3. Photophobia	Anterior chamber inflammation (traumatic iritis, microhyphema)
4. Flashes ± floaters	Vitreous detachment Retinal tear
5. Visual field defect	Retinal detachment
6. Ocular pain with foreign-body sensation	Corneal abrasion
7. Ocular pain with nausea/vomiting	Increased intraocular pressure

with severe blunt injuries or by penetrating or perforating mechanisms. Athletes with open globe injuries complain of severe pain and reduced vision. Physical examination may reveal dramatic findings, such as a deformed globe or extrusion of intraocular contents, or more subtle findings, such as an irregular pupil or a small corneal laceration (Fig. 2). If an open globe injury is suspected, no pressure should be placed on the eye and a shield should be placed to prevent any further accidental contact with the eye. An urgent evaluation is then required by an ophthalmologist.

Open globe injuries require urgent surgical repair to ensure that the globe is closed. Depending on the mechanism of injury, a computed tomography (CT) scan of the orbits may be required to ensure that there is no intraocular foreign body. An open globe with an intraocular foreign body requires a different surgical approach. Timely closure of the open wound is required in the operating room to reduce the risk of infection and permanent loss of vision. Previous studies have shown that factors associated with a poor prognosis are younger age, poor initial visual acuity, and posterior segment involvement.[15] After surgical intervention, patients must be closely monitored because

Table 2
Physical examination findings in athletes that warrant an urgent referral to an ophthalmologist

Examination Finding	Potential Problem
1. Unequal visual acuity in one eye compared with the other	Various (nonspecific problem)
2. Unequal pupils	Traumatic mydriasis Anterior chamber inflammation
3. Restricted extraocular movements	Extraocular muscle entrapment in orbital fracture Cranial nerve injury
4. Photophobia with penlight examination	Anterior chamber inflammation (traumatic iritis, microhyphema)
5. Iris not visualized in detail	Anterior chamber inflammation (traumatic iritis, microhyphema) Corneal injury Increased intraocular pressure

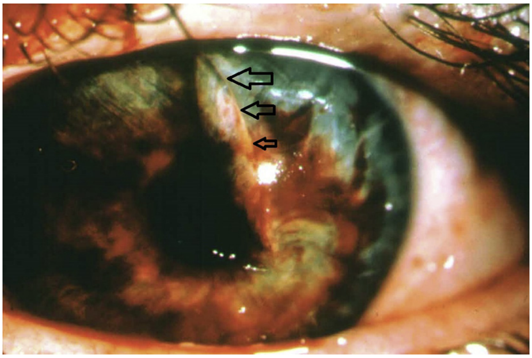

Fig. 2. External view of the eye revealing a corneal laceration. Iris can be seen in the corneal wounds (*arrows*). This patient requires urgent surgical management to close the corneal wound.

they may develop other ocular conditions, such as retinal detachment or glaucoma, in the future.

CLOSED GLOBE INJURIES

Nonpenetrating trauma can result in a wide variety of tissue damage to the cornea, iris, lens, vitreous, choroid, and retina. The expansion of the eyeball perpendicular to the direction of impact has been proposed to be responsible for the injuries that occur from blunt trauma.[1] The large stresses cause a significant amount of distortion in the anatomy of the eye and result in tearing of structures such as the cornea, pupillary sphincter, ciliary body, trabecular meshwork, lens zonules, and peripheral retina. These injuries are discussed in further detail later.

Corneal and Conjunctival Injuries

The cornea is a transparent, avascular tissue that measures approximately 11 to 12 mm in horizontal diameter and provides most of the refractive power of the eye. The cornea has one of the highest densities of nerve endings in the body, receiving its innervation from the ophthalmic branch of the trigeminal nerve.[16] The cornea is composed of 5 major layers from the superficial epithelium, Bowman layer, stroma, Descemet membrane, and the endothelium.[17] The aqueous humor provides the glucose and the tear film provides the oxygen for the cornea's nutritional needs. The conjunctiva is a thin, transparent mucous membrane that covers the sclera and inner linings of the eyelid. The conjunctiva may become red after a direct injury or as a secondary reaction to an injury or disease process elsewhere in the eye.

Corneal abrasion

Among the most frequent sports-related injuries is the corneal abrasion, which is a defect of the superficial epithelium that almost always occurs secondary to trauma in sports-related settings. Corneal abrasions account for more than 10% of the ocular injuries in the National Basketball Association and more than 20% of soccer ball–related injuries in young amateur athletes.[18,19] Abrasions are also frequently seen in wrestling, martial arts, boxing, and rugby and occur when either a finger or ball comes into contact with the cornea.[20] Once the corneal epithelium is traumatically removed, immediate pain, foreign-body sensation, and tearing may be experienced by the athlete. Given the intense and immediate pain, corneal abrasions require prompt attention to assess the eye and rule out any associated injuries.

External examination of the cornea can be performed with a penlight and should begin with an assessment of the position and action of the eyelids and overall assessment of the globe. Because a corneal abrasion is a superficial injury, the pain from this injury resolves with an application of topical anesthetic such as proparacaine hydrochloride or tetracaine. Topical fluorescein is a nontoxic, water-soluble dye that makes corneal abrasions more evident because it detects disruption of intercellular junctions and stains areas of absent epithelium fluorescent green in the presence of cobalt blue light (**Fig. 3**).[21] Examination of the cornea can be performed in greater detail with slit-lamp biomicroscopy, but is not usually available on the sidelines. This tool allows an assessment of the cornea in greater detail and provides a cross-sectional view that enables the depth of a corneal defect to be determined.

Corneal abrasions are usually managed with topical antibiotics (drops or ointment) to prevent infection.[21,22] Topical nonsteroidal antiinflammatory agents (ketorolac tromethamine [Acular], nepafenac [Nevanac], or diclofenac sodium [Voltaren]) may also be used for the first 24 to 48 hours for pain relief in selected patients; however, they should be used with caution because they can cause local toxicity. Therapeutic contact lenses and patching may also be used in larger abrasions with significant pain, but should be used in conjunction with an ophthalmologist.

Corneal injuries after refractive surgery

Refractive surgery, including radial keratotomy (RK) and laser in situ keratomileusis (LASIK), have been used for the treatment of myopia (nearsightedness) and hyperopia (farsightedness). RK involves making deep radial corneal incisions with a diamond knife to flatten the central cornea for mild to moderate myopia.[23] However, this procedure is now considered obsolete, primarily because of the continuing long-term instability of the procedure.[23] RK also weakens the cornea to a great extent. An eye that has had RK ruptures through the RK incisions with about half the force required to rupture an unincised eye.[24] Previous studies have shown that RK incisions become the weakest point in the eye, leading to an increased risk of globe rupture after blunt trauma.[25] Consequently, protective polycarbonate eyewear is of the utmost importance in patients who have undergone RK.

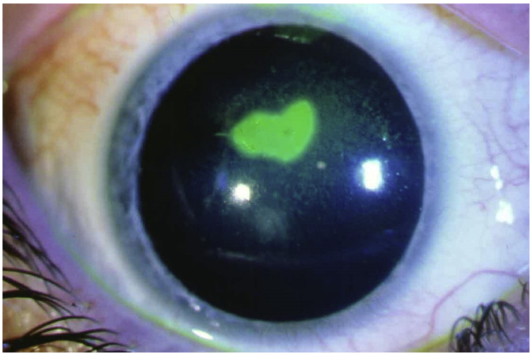

Fig. 3. External view of the eye revealing a corneal abrasion highlighted with topical fluorescein. The fluorescein dye stains the de-epithelialized area when examined with cobalt blue light.

The LASIK procedure is performed with a microkeratome or femtosecond laser to create a corneal flap approximately 15% to 35% of the corneal thickness.[26] After the flap is lifted, an excimer laser is used to ablate the remaining corneal bed in the visual axis to correct myopia, hyperopia, or astigmatism. Traumatic dislocation of the LASIK flap has been reported many months or even years following surgery.[27] Sports-related traumatic dislocations and amputations of the LASIK flap may also occur and requires immediate attention by an ophthalmologist.[27,28] Flap loss is a serious complication because severe and unpredictable refractive error may occur, emphasizing the importance of using polycarbonate protective eyewear in these athletes.

Subconjunctival hemorrhage

Subconjunctival hemorrhage is a common condition that occurs when a blood vessel ruptures and blood accumulates in the subconjunctival space. Common causes include trauma, hypertension, anticoagulant therapy, and increased venous pressure (Valsalva, coughing, vomiting).[29] Sports-related blunt trauma is a common cause of subconjunctival hemorrhage and may occur in almost all settings.[30] This condition does not cause pain or vision changes and is mainly a cosmetic issue. It manifests as diffuse areas of redness that contrasts sharply with the underlying adjacent white sclera (**Fig. 4**). No treatment is necessary because the blood resorbs spontaneously and there are no sequelae. Small hemorrhages usually take 2 to 3 days to resolve, whereas large hemorrhages may take up to 2 weeks. However, large amounts of 360° of subconjunctival hemorrhage may be harbingers of a more severe underlying penetrating injury and must be referred urgently to an ophthalmologist if this is suspected.

Anterior and Posterior Segment Injuries

Important anatomic structures in the anterior segment (located between the cornea and iris) and posterior segment (located between the lens and anterior vitreous face) are the iris, lens, and trabecular meshwork. The iris is composed of the blood vessels, connective tissue, melanocytes, and pigment cells that are responsible for its distinctive color. The mobility of the iris allows the pupil to change size and respond to changes in light. The lens is an important biconvex structure that contributes focusing power to the eye. It is held in place by a system of zonular fibers that are made of fibrillin fibers that may weaken or rupture because of trauma.

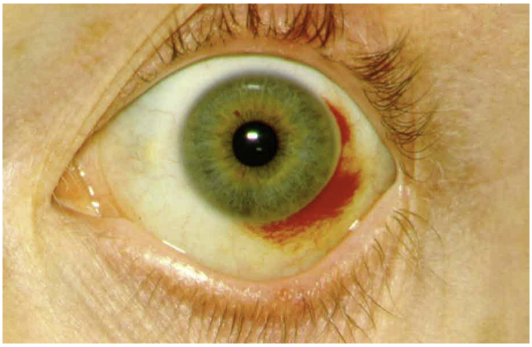

Fig. 4. Subconjunctival hemorrhage seen in the temporal part of the eye from blunt trauma. The hemorrhage appears dark red in contrast with the adjacent white sclera.

Traumatic hyphema

A traumatic hyphema is the entry of blood in the anterior chamber and may be seen with a penlight as layering of blood at the inferior part of the cornea. Trauma causes scleral expansion in the equatorial zone and disruption of the major iris arterial circle and arterial branches of the ciliary body, which results in blood in the anterior chamber. Hyphemas are common injuries in sports in both children and adults and occur with blunt trauma.[31,32] They have been reported to occur more often in male participants (approximately 3:1) and in sports such as baseball, basketball, soccer, racquet sports, and combat.[31,33,34] A hyphema requires urgent referral to an ophthalmologist for evaluation.

Traumatic hyphemas may be fairly asymptomatic or present with significant pain and decreased vision. The pain may be a result of associated corneal injuries or secondary to increased intraocular pressure (IOP), which occurs because of obstruction of the trabecular meshwork (aqueous drainage pathway) by red blood cells, fibrin, or other debris.[34,35] Uncontrolled IOP can lead to irreversible damage to the optic nerve and therefore must be monitored by an ophthalmologist during the course of the condition. Treatment may require topical medications or even surgery if the IOP cannot be controlled medically.[35] Another concern with hyphemas is the possibility of rebleeding, which has been reported to occur in about 18% of patients between 3 and 5 days after the injury.[36] Rebleeding is of particular concern in patients with sickle-cell disease who have been found to have enhanced fibrinolysis.[37]

Traumatic cataract

Blunt injury to the eye may also result in a cataract because of disruption of the organized lens proteins. It may involve the entire lens or be segmental (**Fig. 5**). A common pattern after trauma is a petalloid or rosette-shaped cataract in which each petal is separated by a linear suture line in the lens.[38] A traumatic cataract may be difficult to visualize in the absence of pupil dilatation because the iris covers most of the lens, especially in bright conditions. In a dark room or with dilatation, a cataract appears as a white to brown discoloration of the lens that precludes a detailed image of the fundus. In the setting of a traumatic cataract, there is a high incidence of disruption of the zonular fibers, which hold the lens in position.[39] This condition may result in lens subluxation or dislocation (**Fig. 6**). Any patients with reduced vision, including findings that suggest a traumatic cataract, require referral to an ophthalmologist.

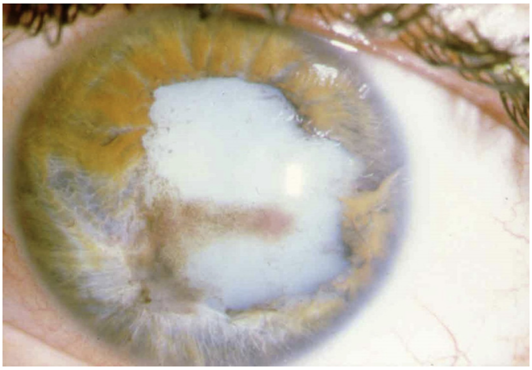

Fig. 5. Traumatic cataract that developed several weeks after blunt trauma. There is also associated iris injury.

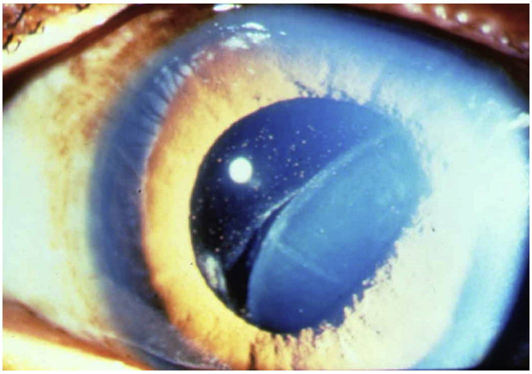

Fig. 6. Lens dislocation after blunt trauma. The edge of the lens can be seen in the center of the pupil.

Traumatic cataract may cause mild to significant loss of vision. When there is significant vision loss that interferes with the patient's quality of life, cataract surgery is indicated. This surgery involves making microincisions in the cornea, removal of the lens with high-energy ultrasonography, and insertion of an artificial intraocular lens. Because the artificial lens does not have the same accommodative ability of the natural crystalline lens, spectacle correction is usually necessary to allow for near vision.[40] If there is significant loss or disruption of the lens zonules, the intraocular lens will not center in the normal lens capsule, but may need to be fixated to the sclera or placed in the anterior chamber.[39]

Vitreous Cavity Injuries

The vitreous occupies approximately 80% of the volume of the eye. It is a clear matrix composed mainly of water and hyaluronic acid. The vitreous is firmly attached to the vitreous base (an area in the peripheral retina), retinal vessels, macula, and optic nerve. With increasing age, pockets of liquefaction develop and the vitreous gel eventually starts to shrink, putting parts of the retina under traction.[41] This traction can lead to spontaneous breaks in the retina, which can be visualized as horseshoe tears or operculated holes in the fundus (**Fig. 7**). These breaks permit the movement of

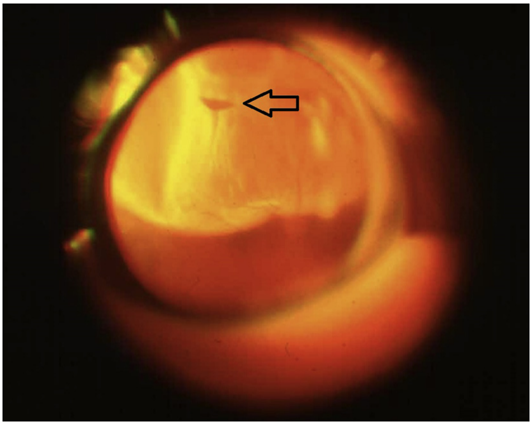

Fig. 7. Horseshoe tear in the retina seen with an indirect ophthalmoscope (*arrow*).

liquefied vitreous into the subretinal space, which can cause the retina to detach (**Fig. 8**).[41] Blunt trauma in sports may cause similar changes in the vitreous and subsequent traction on the retina. If this force is severe enough it may result in a vitreous hemorrhage, retinal tear, or retinal detachment.

The retina is the transparent film of the eye that contains photoreceptors that translate light stimuli into information that can be interpreted by the brain.[42] The retina receives its blood supply from 2 major sources: the inner half of the retina from the retinal circulation and the outer half from the choroidal circulation.[43] In a retinal detachment, the outer blood supply from the choroid is no longer able to nourish the retina, resulting in damage to the photoreceptors. This damage can be permanent if enough time passes before the retinal detachment is repaired.

Retinal detachment

In sports settings, retinal detachments may occur in isolation or in conjunction with other ocular or orbital injuries. The most common symptom elicited by patients with a retinal detachment are a history of flashes and floaters.[44] Flashes represent the retinal response to traction from the vitreous gel and floaters represent mobile condensations in the vitreous gel that project a dark shadow onto the retina. When the retina starts to detach, the patient notices a defect corresponding with the area of detached retina. Because the superior retina interprets the inferior visual field and vice versa, a superior retinal detachment manifests as an inferior visual field defect. If left untreated, this visual field progresses to involve the central vision and the entire visual field. Therefore, patients with these symptoms require urgent evaluation and treatment by an ophthalmologist.

The prognosis for retinal detachment is improved when the detached retina is localized and does not involve the macula, or central retina. These so-called macula-on detachments are considered urgent and require immediate attention to prevent further retinal involvement. When a larger part of the retina is detached and involves the macula, a macula-off detachment, the treatment is less urgent. Similar outcomes have been reported for macula-off detachments with immediate treatment and treatment within 1-week of symptom onset.[45,46] Treatment options include office-based procedures, such as pneumatic retinopexy, which involves the injection of an intraocular gas bubble and laser around the retinal break. Other surgical options include pars plana vitrectomy and scleral buckling.[45]

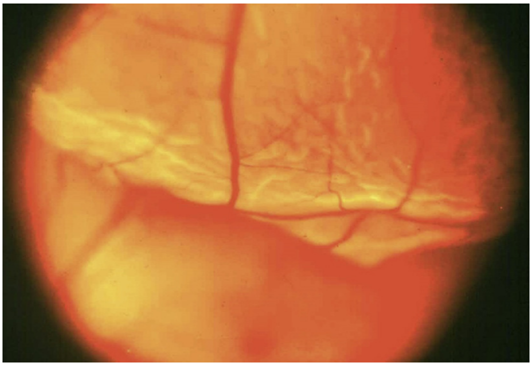

Fig. 8. Retinal detachment seen with an indirect ophthalmoscope. The elevated retina can be seen with the retinal vessels in the superior part of the image.

Vitreous hemorrhage

Blunt ocular trauma may cause vitreous traction that results in a rupture of a retinal blood vessel and hemorrhage into the vitreous. Patients report diffuse blurry vision that may have a red-tinged appearance. Physical examination may reveal the absence of a red reflex with the direct ophthalmoscope because the blood obscures visualization of the fundus. Patients require urgent referral to an ophthalmologist to rule out a concomitant retinal detachment, which can be detected by ultrasonography. When there is no retinal detachment, treatment involves conservative measures, including avoiding vigorous activity and sleeping with the head of the bed elevated, which allows the hemorrhage to clear. Close observation is required because there is a high incidence of retinal breaks in this population, which may lead to a retinal detachment in the future.[47]

Orbital injuries

Injuries to the orbit may occur in conjunction with ocular injuries or may be isolated. One of the most frequent facial injuries in sports is orbital bone fracture, which is leading cause of injury from blunt trauma in fighting in hockey, boxing, and martial arts.[48] Patients who sustain an orbital bone fracture may present with symptoms that vary from mild pain at the site of injury to reduced vision, severe pain, and diplopia. The diplopia can be secondary to extraocular muscle injury, muscle entrapment within a fracture, or orbital hemorrhage. When an orbital bone fracture is suspected, a CT scan of the orbits is the test of choice to confirm the diagnosis because the orbital bones are well visualized. It is always important to rule out a concomitant globe injury, especially when there is significant periorbital edema and the eye cannot be easily visualized. Surgical repair of the fracture is indicated if there is diplopia when looking straight ahead or in the reading position, significant enophthalmos (sunken eye), or a very large fracture.

Other injuries in the orbit can involve injuries to the extraocular muscles from blunt trauma, such as hematomas. The cranial nerves may be injured in the orbit or as they enter through the superior orbital fissure in the setting of orbital bone fracture. Abnormalities in extraocular movements or the position of the globe, such as enophthalmos or exophthalmos, warrant urgent consultation with an ophthalmologist.

EYE PROTECTION

The occurrence of the serious eye injuries discussed earlier can be completely prevented with the use of proper protection. Sport-specific issues related to eye protection are discussed later.

Racquet Sports

Racquet sports, such as squash, badminton, and racquet ball, have a high risk of eye injuries because of the small ball and high velocity at which the game is played.[49] Contrary to popular belief, experienced players are at high risk of eye injuries.[50,51] In 1983, the United States Squash Racquets Association required all participants in national championships to wear eye protection meeting American Society Testing and Materials (ASTM) standard F803.[1] The ASTM F803 is a rigorous standard used in sports and testing requires that no eye contact be made by a squash or racquetball traveling at speeds of 90 mph when hitting the eye protectors from the front or side.[52] The material of these glasses is polycarbonate, which is a highly shatter-resistant material with approximately 150 times the strength of the material in conventional glasses.[53] There have been no reports of significant ocular injury when ASTM eye guards are worn in squash or racquetball.

Hockey

Professional and amateur sports associations have varying legislation with regard to the use of eye protection in hockey. The National Collegiate Athletic Association (NCAA) requires all players to wear full-face cages and there has been no significant eye injury reported in this setting. The National Hockey League in June 2013 mandated that all nonrookie players must wear half-visors, and the number of eye and orbital injuries has continued to decline as more players use visors.[48,54,55] Studies have found that younger players are using half-visors at a faster pace than would be expected from mandatory legislation.[56]

Despite increased use of half-visors in professional and junior hockey leagues, serious eye injuries continue to occur.[48] One reason for this is that the visors are not being worn in the proper position (angled upward with too much space between the nose and visor). Even when worn in the proper position (with not more than 1 finger able to fit between the visor and nose), half-visors are not adequate to prevent all injuries[57] because the force of a high stick, body check, or deflected puck is usually sufficient to cause a shift in the helmet and leave the upper face exposed. In addition, fighting, which is the third leading cause of eye and orbital injuries in hockey, usually takes place without the use of helmets, leaving the eyes exposed to a punch.[48] A new trend of longer, three-quarter visors is starting to gain popularity in professional hockey leagues and may contribute to the further prevention of eye injuries in hockey.[56] Further collaboration between amateur and professional hockey leagues and ophthalmologists is required to study the eye injuries that continue to occur and to optimize protective equipment.[55] However, the National Hockey League and the National Hockey League Players Association has not been willing to collaborate with this group of physicians in studying eye injuries.

Lacrosse

Facial protection with cages is mandatory for male lacrosse players at the amateur and professional levels and no significant eye injuries have occurred with this equipment. However, according to the international women's lacrosse rules, eye guards may be worn but are not mandatory for women.[58] Previous studies have shown that the use of protective eyewear was associated with a decrease in eye injuries in women's lacrosse.[59] Recently, United States Lacrosse has introduced new legislation and an eyewear standard, ASTM 3077, that will become mandatory in 2017. Expanding the progress that United States Lacrosse has made in mandating eye protection in this sport is required in other regions and leagues to adequately protect athletes.

Paintball

Although use of ocular protection is mandatory at most paintball sites, most injuries are caused by not following the rules and not using eye protection at all times.[60] Acrylic goggles provide adequate protection provided that they have a tight seal to the face.[61] Ensuring a good fit to the goggles with no space between the skin and frame is important because serious ocular injuries have been reported when the paintball goes underneath the eye protection.[62] Newer facial gear that has full facial protection and goggles that permit a wide field of view can help overcome any visual limitations of traditional goggles.[62]

Other Sports and Considerations for Eye Protection

Significant eye injuries have been reported in baseball and basketball and polycarbonate eye or facial protection is available, although it has not become widely popular.[18]

Other sports, such as soccer, wrestling, rugby, and water polo, do not have accepted standards for eye protection and present a unique challenge because of the difficulty of wearing protection during the games. Any monocular athlete should always wear polycarbonate eye protection in any sport in which there is potential for injury. Extra precaution should be taken in sports like hockey in which it is recommended that polycarbonate eyewear be used underneath a full face shield.[53]

OCULAR MOTOR ASSESSMENT IN CONCUSSION

Concussion is increasingly being recognized as a public health concern and there is a need to develop sensitive tests to detect and evaluate the brain dysfunction that occurs in this condition. More than half of the brain's circuitry is involved in eye movements and vision and this is corroborated by the common visual complaints that are seen in concussed athletes.[63,64] Saccades and smooth pursuit are two types of eye movements that have shown abnormalities with detailed testing in concussed athletes.[65] The former refers to rapidly shifting simultaneous movements of the eyes from one target to another, whereas the latter involves the eyes slowly following an object. Previous studies have also shown that concussed athletes have difficulties with accommodation and increased levels of photophobia.[64]

Testing complex visuospatial tasks in athletes may provide valuable information in determining when an athlete should be removed from play, especially when the athlete does not endorse any concussive symptoms after taking a hit in a game. The King-Devick test is one such sideline test that allows a rapid, reliable, and objective assessment of an athlete.[66] This test requires patients to read numbers with variable spacing as quickly as possible on 3 test cards. Because saccades, attention, and language are required to read these cards quickly, diffuse networks in the brain are being evaluated, including the areas for saccade generation. At the beginning of a season, baseline testing is performed, which serves as a reference to evaluate the same athlete if that athlete experiences an injury. Worsening of the time required to complete the test provides objective evidence to remove the player from play. In a meta-analysis evaluating the ability of the King-Devick test to detect concussions in sports such as hockey, lacrosse, football, basketball, soccer, and boxing, the test was found to have a sensitivity and specificity of 90% and 86%, respectively.[67] On average, baseline times worsened by 4.8 seconds in concussed athletes.

In summary, eye and orbital injuries are significant risks to athletes and can result in permanent blindness. Eye injuries can be classified as open or closed globe injuries and red flags in the history or physical examination should alert the first responder to arrange an urgent ophthalmology consultation. Eye protection is available for most sports and should be worn in accordance with the standards of regional authorities. Protective eyewear should be made from polycarbonate material to ensure the highest levels of safety. Vision and eye movements involve a large proportion of the brain's circuitry and can provide objective evidence of brain dysfunction in athletes suspected of having a concussion.

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