Review article

Extraocular Muscle Trauma: Clinical Approach to Diagnosis and Surgical Management of Rectus Muscle Disruptions

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ABSTRACT

We aimed to review the clinical approach to diagnos and surgical management of traumatic extraocular rectus muscle disruptions, a rare but significant cause of strabismus and diplopia in the adult trauma patients. This review examined the anatomy of the four rectus muscles, mechanisms of injury, clinical presentation, imaging evaluation, classification of injury types, management strategies, outcomes, and future directions in treatment. Extraocular rectus muscle disruptions occur through blunt trauma (typically causing muscle entrapment in the orbital fractures) or penetrating trauma (causing laceration or avulsion). Clinical features include diplopia, restricted eye movement, and in some cases, visible muscle prolapse. Imaging evaluation includes computed tomographyas first-line approach, with magnetic resonance imaging providing superior soft tissue detail, and anterior segment optical coherence tomography offering valuable information for surgical planning. Management focuses on early intervention, with surgical repair ideally performed within 24-48 hours for entrapped muscles and within days for lacerations or avulsions. Outcomes vary based on injury severity and timing of treatment, with better prognosis associated with early intervention. While traumatic extraocular rectus muscle disruptions present complex challenges, prompt diagnosis and surgical management often yield favorable results. Future advances in treatment might involve advanced imaging techniques, engineered tissue for muscle reconstruction, refined surgical approaches, and improved interdisciplinary trauma care protocols.

KEYWORDS
Extraocular muscles; Diplopia; Muscle avulsion; Orbital trauma; Strabismus

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INTRODUCTION

Traumatic disruption of extraocular rectus muscles presents a rare but significant cause of strabismus and diplopia in adult trauma patients. While cranial nerve palsies and muscle entrapment in the orbital fractures are more common causes of ocular motility limitations, direct injury to the rectus muscles through blunt force or penetrating trauma requires prompt recognition and specialized management [1]. In ocular injuries, motility limitation and double vision are the mostly due to the cranial nerve palsies or entrapment of muscles in orbital fractures [2]. Direct injury to the extraocular muscles themselves – via blunt force or penetrating trauma – is comparatively rare [3].

In fact, isolated rectus muscle rupture without an associated globe rupture or significant orbital fracture is an extremely rare clinical entity [3]. Nonetheless, such injuries are important to recognize because they can lead to persistent misalignment of the eyes and functional vision deficits if not managed appropriately. Recent case reports and small series highlight the distinct mechanisms, imaging findings, and management challenges of extraocular muscle injuries in trauma [4, 5].

This review focuses on the disruptions of the four rectus muscles (medial, lateral, superior, and inferior rectus) in the adult trauma patients, encompassing both blunt trauma (e.g. orbital fractures) and penetrating injuries (e.g. lacerations by foreign objects), and draws on original research from 2020–2025. Key topics include relevant orbital anatomy, injury mechanisms, clinical presentation, imaging diagnosis, classification of injury types, acute management strategies, outcomes, and future directions for improving care.

Anatomy of the Extraocular Rectus Muscles

The medial, lateral, superior, and inferior recti are the four rectus muscles that are responsible for the movement of each eye. These muscles are derived from the common tendinous ring at the orbital apex and insert into the sclera anteriorly. The medial and lateral rectus muscles insert closest to the corneoscleral limbus (5–6 mm distance), while the superior and inferior recti insert slightly further posterior [6]. This anterior insertion makes the medial and inferior rectus particularly vulnerable to traumatic injury: their close proximity to the globe's anterior segment and the orbital walls means they can be directly impacted by blunt force or lacerated by sharp objects [6]. In contrast, the superior and inferior oblique muscles are concealed deeper in the orbit, protected by the adjacent bony structures, while the lateral rectus is somewhat shielded by the sturdy lateral orbital rim. In fact, the medial rectus is the extraocular muscle injured the most frequently in trauma, while the lateral rectus is the least frequently injured [3].

Several anatomic factors influence how a rectus muscle may be damaged and how it behaves if ruptured. The medial and inferior recti lie adjacent to the thin ethmoid (medial) and maxillary (floor) bones, respectively – bones that commonly fracture in orbital blunt trauma [6]. This anatomical relationship explains why blowout fractures often involve the inferior rectus or medial rectus (via entrapment or contusion). The rectus muscles are anchored to orbital periosteum by fascial connections (check ligaments especially for the medial and lateral rectus), which can limit how far a torn muscle retracts. For example, if a rectus muscle is avulsed right at its scleral insertion, the residual stump tends to remain nearby, held by surrounding Tenon's fascia and connective tissue, which can aid surgical retrieval [7, 8]. Conversely, a rupture that occurs more posteriorly (toward the muscle's origin) allows the muscle to retract deeper into the orbit and can be much harder to locate and repair [9, 10]. These anatomical considerations (sites of bony support, fascial attachments, and blood supply) underpin the patterns of injury and inform the surgical approach to rectus muscle trauma.

Mechanisms of Injury: Blunt vs. Penetrating Trauma

Blunt Trauma

In blunt orbital trauma, rectus muscle injuries often result from sudden globe displacement or orbital fractures. In "blowout" fractures, the inferior rectus might become entrapped in the orbital floor [2], or the medial rectus in a medial wall fracture. Entrapment means the muscle is compressed by bone fragments, causing mechanical restriction without actual muscle fiber tears [11]. This constitutes a surgical emergency because prolonged incarceration can lead to ischemia and contracture [2]. In adults, orbital fractures are often comminuted; the muscle may prolapse into the sinus without being tightly pinched. Blunt trauma can directly contuse or rupture a rectus muscle if severe. Protective reflexes like Bell's phenomenon may paradoxically expose certain muscles to injury [6]. Isolated rectus muscle ruptures from blunt force without fracture are exceedingly rare, with fewer than a dozen reported cases [12].

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Penetrating Trauma

Penetrating mechanisms can directly lacerate or avulse an extraocular muscle. Various objects have caused such injuries, including glass shards, metal fragments, and animal-inflicted trauma [3, 5]. The medial and inferior rectus are common victims due to their location. In penetrating trauma, the muscle may be partially cut ("flap tear") or completely transected. Penetrating injuries can also be iatrogenic, as in sinus surgery [5, 13]. High-velocity projectiles can disrupt muscles at any location and cause complex injuries.

Clinical Features and Examination

Symptoms: Patients typically present with diplopia, especially on gaze directed by the affected muscle. In complete ruptures, the misalignment is often large and incomitant. For example, an inferior rectus rupture causes hypertropia that worsens on downgaze [5]. Such patients often adopt compensatory head postures [6]. In partial tears, strabismus can be subtle or absent in primary position [3].

Pain and nausea: Pain is important in muscle entrapment cases. Attempting to move the eye stretches the entrapped tissue, causing sharp orbital pain. One review found pain with eye movement and diplopia in about 87.5% of orbital floor entrapment patients [2]. Entrapment can trigger the oculocardiac reflex, causing bradycardia, nausea, or syncope [14]. Approximately 30–50% of entrapped muscle cases have associated nausea, vomiting, or heart rate drops [15]. Pure muscle lacerations are often less painful once the acute injury passes, with diplopia being the primary complaint [16].

External signs: On examination, one may find periorbital swelling and ecchymosis (bruising) in the setting of trauma. These can hinder the ocular exam, so gentle lifting of swollen lids is necessary [2]. A conjunctival laceration or scleral wound in the area of a rectus muscle insertion is a red flag for muscle injury. In some penetrating cases, the torn end of a muscle may be visible prolapsing through a conjunctival wound. For instance, in the cat-scratch injury mentioned above, a pink-white piece of lateral rectus muscle was seen protruding from a lateral conjunctival laceration [17]. Another case showed a dark red fragment of lateral rectus muscle belly exposed in the canthal area after a fist trauma, clearly visible on exam [18]. If such tissue is visible, it virtually confirms a muscle rupture or avulsion. In blunt injuries without an open wound, there may be chemosis (conjunctival swelling) or subconjunctival hemorrhages that obscure direct view of the muscles.

Ocular alignment and motility: Detailed motility testing is crucial. The examiner should note which gaze directions provoke limitation or diplopia. A rectus muscle that is completely torn will not exert force, so the eye cannot move in that direction beyond a certain point. On duction testing (one eye at a time), there will be a marked deficit. For example, with a complete lateral rectus rupture, the affected eye cannot abduct normally, leading to an inability to look fully toward the ear and a convergent strabismus (esotropia). In partial tears, there may be mild limitation or none at all if enough fibers remain functional [3].

A key test is the forced duction test: anesthetizing the eye and physically moving it with forceps. In an entrapment, the globe will not rotate freely in the direction of the entrapped muscle (the movement is mechanically restricted) [2]. In a nerve palsy or a complete muscle rupture, forced duction will be free (nothing is pulling back). Distinguishing these scenarios is critical – a patient with limited upgaze could have an entrapped inferior rectus (positive forced duction) or a superior rectus/III nerve palsy or rupture (negative forced duction). In practice, significant trauma with a negative forced duction raises concern for a muscle rupture or nerve injury rather than entrapment [19].

Associated injuries: A thorough eye exam will assess the globe integrity (to rule out rupture), the cornea (for lacerations or foreign bodies), and the pupil. A dilated or unreactive pupil might indicate optic nerve damage or traumatic mydriasis, rather than muscle injury, but it may co-exist [20]. Notably, one reported case of isolated inferior rectus tear had a mid-dilated pupil and elevated intraocular pressure, suggesting angle recession or nerve trauma concurrently [4]. Because multiple structures can be injured in orbital trauma, clinicians should not attribute all findings to one cause. A complete muscle transection can occur alongside a blowout fracture and nerve damage, for example. Careful documentation of cranial nerve function (III, IV, VI) is necessary to evaluate for concomitant neuropathies. To sum up, the clinical picture of a rectus muscle disruption includes diplopia with gaze restriction, often an identifiable

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strabismus in primary gaze (except in some partial injuries), possibly visible muscle prolapse (in penetrating cases), and in entrapments, significant pain or systemic symptoms. Early recognition of these signs triggers the need for detailed imaging and urgent management as described below.

Imaging Evaluation

CT Scans: Thin-slice orbital CT (≤1mm) is the first-line imaging modality for suspected orbital injury with ocular motility problems, as standard CT may miss subtle findings [2]. Extraocular muscles appear as distinct soft-tissue bands from orbital apex to globe. Key findings include fractures (especially orbital floor/medial wall) and muscle-fracture relationships. A "teardrop" hernia into the maxillary sinus indicates orbital floor fracture; a rectus muscle abnormally bent into the fracture suggests entrapment ("muscle incarceration"). CT shows high sensitivity (>70%) for detecting muscle entrapment [11], typically appearing as muscle kinking at the fracture site, but has lower sensitivity for muscle lacerations [11]. Partial tears may appear only as ill-defined margins or swelling, while complete ruptures might show an "absent" muscle or gap where the muscle should attach to the globe [11]. Careful scrutiny is essential when clinical findings suggest muscle damage [12]; irregular muscle outline, discontinuity, or abnormal spacing between muscle and globe warrant further investigation. Contrast enhancement may help identify tears but is often not used in routine trauma imaging. Despite CT's utility, subtle injuries can be missed; one case of inferior rectus transection was initially read as "unremarkable" until closer review [4].

MRI: Magnetic resonance imaging of the orbit provides superior soft tissue contrast and can be invaluable in ambiguous cases. MRI can depict intramuscular edema or hemorrhage (for example, a T2-weighted image might show hyperintense swelling in a bruised muscle). It is also more sensitive in showing partial-thickness injuries – a flap tear might be seen as a flap of muscle hanging off, which could be missed on CT. MRI is especially useful for visualizing the posterior orbit and apex [21]; if a muscle has retracted far back from an avulsion, MRI may locate the retracted stump. MRI clearly demonstrated a discontinuity and "fuzziness" of a traumatically avulsed superior rectus muscle, confirming the diagnosis [17]. The downside is that acute trauma patients may not readily get MRI, especially if there are contraindications (metallic foreign bodies must be excluded). Besides, small insertional injuries can elude MRI due to limited spatial resolution in the very anterior orbit. In a recent series on incomplete rectus lacerations, standard CT/MRI were able to suggest muscle injury in 91% of cases, but they often could not delineate details of the muscle's insertion on the sclera – information crucial for surgical planning [5]. In that study, the authors augmented imaging with high-resolution anterior segment optical coherence tomography [5].

Ultrasound and OCT: Adjunct imaging modalities have emerged to fill the gaps in CT/MRI. B-scan ultrasonography, performed by experienced ophthalmologists, can sometimes identify a disinserted muscle end or scar in the orbit. Ultrasound is useful if the globe is intact but opaque (e.g., vitreous hemorrhage preventing view), to ensure the muscle is attached. More novel is the use of Anterior Segment OCT, which is essentially a microscopic ultrasound-like scan using light, to visualize the anterior sclera and muscle insertion [22, 23]. In the 11-patient series of penetrating rectus injuries, anterior segment OCT was used to visualize how much of the tendon remained attached to the globe [5]. This technique provided "surgically useful details" in 90% of patients, guiding the surgical approach [5]. For example, Anterior Segment Optical Coherence Tomography (AS-OCT) could show a portion of the tendon still on the sclera vs. completely detached, which informs whether one will find a stump to suture [24, 25]. This is a promising tool in complex anterior orbital injuries where MRI/CT aren't resolving the question.

Imaging differential diagnosis: It is important to interpret imaging in the context of clinical findings. The clinical vs. imaging terminology for extraocular muscle injuries is list in Table 1. A muscle found displaced on CT with an adjacent fracture may indicate either entrapment or rupture. Distinguishing entrapment from a complete rupture on imaging can usually be done by looking at continuity: an entrapped muscle will trace continuously (though bent) from origin to insertion, whereas a ruptured muscle will show an abrupt end [19]. In difficult cases, comparison with the uninjured side can help reveal if a muscle's course is abnormal. Sometimes both

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can occur – e.g., a fracture fragment could lacerate a muscle (so the muscle is both torn and stuck). Furthermore, radiologists should be mindful of "pseudo-injuries": in scans after surgical repair, an absent muscle could mean it was surgically repositioned or partially removed [25]. Chronic muscle atrophy (from a nerve palsy) can mimic a severed muscle on imaging because it appears thinned or "missing" – thus the clinical history is vital [26].

In the imaging evaluation, CT remains the primary tool for orbital trauma evaluation, showing fractures and gross muscle position. MRI provides superior soft tissue detail and posterior orbit visualization, while newer techniques like AS-OCT offer fine detail of anterior muscle attachments. Together, these modalities help determine if a rectus muscle is intact, partially torn, or completely ruptured—critical information for surgical planning. Due to the subtlety of some findings, radiologists and surgeons should collaborate closely. When clinical suspicion exists, dedicated orbital imaging is essential. One author aptly warned not to be deceived by normal-appearing initial scans in trapdoor fracture cases, recommending re-imaging or specialist interpretation to avoid missing an entrapped or severed muscle [2].

Classification of Injury Types

Traumatic injuries to the extraocular rectus muscles can be classified by their extent and nature. The main categories are partial tears, full-thickness (complete) ruptures, and avulsions. These terms are defined in Table 2. It is clinically useful to distinguish these, as they have different implications for treatment and prognosis. A partial tear may leave some degree of function, whereas a complete rupture means the muscle is entirely nonfunctional until repaired. An avulsion is a specific type of complete rupture where the muscle is detached from the globe; this often requires a different surgical strategy (Reattachment of tendon to sclera or muscle substitution if reattachment is not possible).

Management Strategies

Management of extraocular muscle injuries in trauma requires prompt decision-making and often surgical intervention. The overarching goals are to restore anatomical continuity of the muscle (if possible), relieve any mechanical restriction, and ultimately achieve the best possible ocular alignment to preserve binocularity.

Table 1: Clinical vs. Imaging Terminology for Extraocular Muscle Injuries

Clinical Term	Imaging Term	Explanation
Muscle entrapment	Muscle incarceration	An intact muscle trapped in a fracture without fiber rupture. Clinically shows positive forced ductions and possible oculocardiac reflex [2]. On CT, the muscle appears pinched between bone fragments but maintains continuity [11].
Muscle rupture	Muscle discontinuity	The muscle fibers are torn. Clinically causes loss of function in that direction [6]. Imaging shows a break in the muscle or a retracted stump [11].
Avulsion (complete disinsertion)	"Missing" muscle at insertion	The muscle's tendon is torn off the globe. Clinically shows lax movement, sometimes with visible muscle end in a wound [3]. On imaging, the muscle will not be seen attaching to the sclera [11].

Table 2: Classification of Extraocular Muscle Injuries in Trauma

Injury Type	Definition	Clinical Note
Partial tear (Flap tear)	Incomplete laceration of the muscle – some fibers remain intact	May cause minimal limitation if sufficient fibers remain attached [3]
Full-thickness rupture	Complete transection dividing the muscle into two segments	The affected eye cannot move in the direction of this muscle, leading to large, incomitant strabismus [6]
Avulsion (Disinsertion)	Traumatic detachment of the muscle's tendon from the eyeball	Presents similarly to complete rupture; often the tendon is visibly stripped from the globe [17]

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Initial management and timing: In the acute trauma setting, life-threatening and globe-threatening injuries take priority. Once those are addressed, attention turns to the motility injury. If a muscle is entrapped in a fracture, this is considered an acute surgical emergency. Entrapment can cause ischemia within hours; experimental data and clinical experience show that extraocular muscles can suffer irreversible changes if strangulated for too long [2] . Therefore, most experts advocate surgical release of an entrapped muscle within 24–48 hours of injury [2]. Early intervention is associated with better functional recovery of the muscle. In a 21-patient series of orbital fracture entrapments, 19 patients underwent repair within 48 hours (13 within 24 h) and the vast majority recovered full extraocular movement with no or minimal diplopia; by contrast, one patient whose surgery was delayed to 7 days had persistent diplopia on extreme gaze at long-term follow-up [27]. While each case must be individualized, but the general consensus is "the sooner, the better" for releasing trapped muscles [27] – ideally in the first one to two days, and urgent (same-day) if there are oculocardiac reflex symptoms (severe bradycardia) or a pediatric trapdoor scenario [2].

For muscle lacerations or ruptures, timing of intervention is nuanced. In open-globe injuries, globe repair takes precedence, though muscle repair can often occur in the same session if the patient's condition permits. When only the muscle is injured, early repair—ideally within days—offers significant advantages, as waiting allows muscle retraction and scarring that complicate surgery [2]. Many authors recommend repair within the first week to maximize successful reattachment [3].

A case of partial lateral rectus avulsion from a cat scratch demonstrates the benefit of prompt intervention: repair occurred within ~5 hours, and the patient regained full eye movements by the next day [3]. This early reattachment likely preserved muscle viability and prevented contracture. For completely severed muscles, early exploration (within days) is advised to locate the retracted end before atrophy or scarring [6]. If other urgent injuries exist or specialized ophthalmic surgical expertise is unavailable, a short delay is acceptable provided the muscle isn't entrapped and ischemic. During delays, oral corticosteroids are sometimes administered to reduce inflammation and potentially limit scarring, though evidence for this practice remains largely anecdotal [20].

Surgical repair of muscle lacerations: The preferred approach for torn rectus muscles is end-to-end anastomosis [6], typically requiring general anesthesia and orbital exposure via conjunctival incision. For anterior injuries, limbal or fornix incisions provide direct visualization of the muscle insertion. The distal (globe) end, if still attached to sclera, can be tagged with a traction suture while searching for the proximal stump.

Finding the retracted proximal segment can be straightforward or challenging, depending on retraction. Various retrieval techniques include gentle dissection along the muscle path, orbital sweeping with retractors, or adjunct approaches (orbitotomy through lid/sinus or endoscopic assistance) for deeply retracted muscles. One team reported using the adjacent inferior oblique as a "guide" to locate a ruptured inferior rectus [4]. Another case utilized endoscopic visualization through the ethmoid sinus to find a retracted medial rectus stump [28]. Once found, non-absorbable or long-lasting absorbable sutures (5-0 or 6-0 Vicryl) are placed in the muscle belly. The surgeon reattaches it either to the distal stump or directly to the sclera at the original insertion site. End-to-end reunification yielded good outcomes in most patients (23 of 36 eyes) when performed early [27]. Some cases require trimming damaged muscle ends before suturing to promote healing [27]. Post-repair, muscle tension may be adjusted using adjustable suture techniques to optimize alignment.

Dealing with missing tissue: If a muscle segment is lost or too ischemic for direct reattachment—occurring in about one-third of muscle rupture cases [6, 27]—alternative techniques must be employed. Tendon transposition uses adjacent intact muscles to substitute function. For a missing lateral rectus, the superior and inferior recti can be partially transposed laterally (using Nishida or Jensen procedures) to mimic lateral rectus action [3]. Modern approaches favor "vessel-sparing" transpositions to maintain blood supply while redirecting muscle force [3].

Another option is large recession of the antagonist muscle. If a medial rectus cannot be reattached, the lateral rectus can be surgically weakened to reduce imbalance [6]. Often, a combination approach is used: partial transposition plus antagonist recession to prevent overpull [6]. These techniques primarily aim to restore alignment in primary gaze, though full range of motion is rarely achieved.

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When the posterior segment is lost but the anterior segment remains attached (a "dangling" distal segment), muscle tucking or grafting can be attempted. However, if the gap is large, reattaching the distal piece to the residual stump typically yields poor functional results, as the muscle may scar but not contract normally. Some surgeons have used autologous tendon grafts or scleral bands to bridge gaps, though these approaches are rarely documented and beyond routine trauma management [29, 30].

Repair of entrapment: The surgical management of an entrapped muscle (with no tear) is to free it from the fracture. This is typically done by an orbital surgeon (ophthalmologist or plastic/ENT surgeon) via an incision that allows access to the orbital floor or medial wall. In an acute trapdoor fracture of the floor, for example, an inferior fornix conjunctival incision or transcutaneous subciliary incision can be made to access the orbital floor. The fracture edges are gently pried open and the muscle is released – often it will spring back to normal position once freed. Any herniated tissue is returned to the orbit, and the fracture may be repaired with an implant (e.g., absorbable plate or mesh) to cover the defect and prevent re-entrapment [27]. In cases described in the literature, this procedure, when done within the first day or two, led to full recovery of muscle function in most adult patients [27]. If the muscle was ischemic and became fibrotic (due to delayed treatment), the surgeon might later need to perform strabismus surgery (muscle recessions/resections) to correct any persistent deviation [29, 31].

Adjunct care: In all cases of muscle trauma, surgeons often administer systemic antibiotics if an open wound is present (to prevent orbital cellulitis, especially in penetrating injuries). Tetanus prophylaxis is given for open injuries. In animal-related wounds (like the cat scratch or any farming accident), rabies prophylaxis should be considered as indicated [3] , as well as thorough irrigation to reduce risk of infection. Postoperatively, patients are typically prescribed oral steroids to lessen inflammation of the muscle and orbital tissues, and topical antibiotics if conjunctival wounds were made. Prism glasses can be used in the interim (or postoperatively) to manage diplopia until final alignment is achieved [17]. If primary repair does not completely eliminate double vision, patients may be offered strabismus surgery a few months later once tissues have healed (for example, one case required an additional strabismus muscle surgery after an inferior rectus repair to fine-tune the vertical alignment [4, 7].

Therefore, early surgical intervention is the cornerstone of managing rectus muscle disruptions. Entrapped muscles are freed (ideally <48 h), and lacerated/avulsed muscles are explored and reattached whenever possible (ideally within days). When the muscle cannot be salvaged, strabismus surgeons utilize creative muscle transfers or adjustments to restore ocular alignment. The operative notes from recent cases uniformly emphasize the importance of locating the muscle stumps and performing meticulous microsurgical reattachment for the best outcome [6]. Close follow-up is required, as sometimes initial repairs need enhancement with additional procedures (prisms, Botox to opposing muscle, or second surgeries).

Outcomes and Prognosis

The prognosis after extraocular muscle trauma depends on injury severity, number of muscles involved, and treatment timing. Many patients achieve satisfactory alignment and functional vision in primary gaze, though subtle deficits may persist. Prognosis ranges from excellent (full recovery with early intervention) to poor (permanent motility loss with irreparable damage). Early detection and management significantly improve outcomes [3, 27]. Modern surgical techniques offer hope even for completely severed muscles, though multiple procedures may be needed to achieve the minimum goal: diplopia-free vision in primary gaze.

Early intervention yields favorable outcomes. In a series of 21 orbital fracture entrapments, surgical release within 1-2 days resulted in only 14% of patients having mild residual diplopia [27]. Similarly, case reports show excellent results for promptly repaired lacerations: a cat-scratch lateral rectus avulsion repaired within hours showed complete recovery at one-month follow-up [3], and an inferior rectus rupture patient achieved normal alignment after reattachment and adjustment surgery [4].

Delayed treatment can lead to lasting deficits. Entrapped muscles left for several days develop fibrous contracture, limiting elasticity even after repair [2]. One patient repaired at 7 days still had gaze-evoked diplopia 13 months post-operatively [27], highlighting the importance of timely intervention.

For complete ruptures, prognosis varies with reattachment success. Extraocular muscles have

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remarkable regenerative capacity compared to other skeletal muscles [26, 30]. However, reattached muscles often heal in a stretched or scarred state with reduced contractility. In one lateral rectus repair case, the muscle underwent fibrosis; while the patient had straight eyes in primary position, lateral movement was lost [18]. This "tethering effect" prevents gross misalignment despite limited active contraction. Unrepaired muscles result in marked misalignment requiring prism correction or multiple surgeries.

Multi-muscle injuries have a more guarded prognosis. In a case of simultaneous superior rectus and superior oblique avulsion from a goat horn injury, the patient had residual hypotropia and limited upgaze [17]. Interestingly, because an elevator and depressor were both injured, their losses partially offset, resulting in a relatively small deviation [17]—a fortunate but rare occurrence.

Even after successful muscle repair, patients require follow-up to monitor alignment as scar remodeling occurs. Some patients might heal with a tight scar that gradually pulls the eye, changing alignment over weeks (known as late overcorrection or undercorrection). Therefore, a prism adaptation or a delayed strabismus touch-up surgery (at ~3–6 months) is not uncommon. Additionally, if fibrotic tissue tethering the muscle to the orbit is present (from the trauma or surgery), it can cause restrictive strabismus. In a few cases, persistent diplopia in peripheral gaze may be something the patient has to accept if further surgery is too risky. Fortunately, humans tolerate some misalignment in far gaze positions if primary gaze is single.

On a positive note, visual acuity is usually preserved in pure muscle injuries, since the globe itself is often intact. Aside from transient diplopia, most of these patients do not lose vision. One must guard against amblyopia in a younger patient if long-term misalignment prevents binocular fusion – but in adults, amblyopia is not a concern. The main visual disability in adults is the diplopia and loss of depth perception until alignment is restored.

Future Directions and Emerging Considerations

Because traumatic extraocular muscle disruptions are relatively uncommon, high-level evidence on their management is limited. Looking ahead, several developments could improve outcomes further:

· **Advanced Imaging for Surgical Planning:** The use of high-resolution imaging like anterior segment OCT is an innovation that may become standard in evaluating anterior muscle injuries [5]. It allows the surgeon to map out what portion of the tendon is still attached and plan the repair accordingly. Future improvements in orbital imaging (such as ultra-high-field MRI or dedicated orbital ultrasound techniques) might enable visualization of the muscle fibers in real time, helping surgeons locate retracted stumps more easily. There is ongoing research into intraoperative imaging – for instance, intraoperative CT to confirm that a reattached muscle is in the correct position before finishing surgery – which could be expanded [28, 29].

· **Tissue Engineering and Grafts:** In cases where a segment of muscle is missing, one future solution could be tissue-engineered grafts [30, 32]. Extraocular muscle stem cells and transplant techniques are being explored in other contexts (e.g., treating strabismus from muscle loss) [32]. Although not yet in clinical use, a bioengineered muscle graft that could replace a lost rectus segment would be revolutionary [32]. Similarly, use of donor tissue (allografts) or synthetic materials as a bridge is an area for innovation. Historically, scleral bands or fascia have been tried to connect muscle ends, but the field of regenerative medicine may offer more robust options in the future.

· **Improved Surgical Techniques:** Strabismus surgeons are refining techniques for cases of lost or atrophic muscles. The Nishida vessel-sparing transposition (which avoids splitting muscles and thus preserves circulation) is a promising approach for longstanding sixth-nerve palsies and has potential in trauma cases where a lateral rectus is irreparably damaged [3]. Its use in traumatic cases could improve outcomes by minimizing collateral damage during transposition. Additionally, augmented reality or image-guided surgery might one day assist surgeons in locating a deeply retracted muscle by overlaying imaging data onto the surgical view.

· **Interdisciplinary Trauma Care:** As awareness grows, trauma protocols might incorporate early ophthalmology consultation for any orbital injury with motility issues. The creation of dedicated orbital trauma centers or teams can facilitate timely repairs. For example, involving oculoplastic and ENT surgeons together can be helpful – ENT endoscopic techniques have been used to retrieve muscles via trans-sinus approaches in tricky medial wall cases

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(this collaboration may become more routine with complex orbital apex injuries) [28]. Multidisciplinary management will ensure that muscle injuries are not missed or delayed. One study from a large trauma center advocated a standardized approach and showed improved outcomes when a specialized orbital trauma team was involved [33, 34].

• **Preventive strategies and education:** On the preventive side, understanding the mechanisms (why certain blows cause muscle tears) might inform protective equipment design. For example, could improve sports eyewear prevent a punch from causing a blowout entrapment? Educating emergency physicians and trauma surgeons to suspect muscle injuries is also key – simple measures like performing a forced duction test in the ER when a patient can't move an eye upward can expedite referral. Publications and case studies in trauma journals (not just ophthalmology) are raising this awareness [2].

CONCLUSION

While traumatic extraocular rectus muscle disruptions are challenging injuries, recent case literature demonstrates that with prompt diagnosis, modern imaging, and skilled surgical management, patients often do very well – regaining aligned, functional eyes. The period of 2020–2025 has seen incremental advances such as the integration of OCT imaging and refined transposition surgeries that have improved care for these rare injuries. Future improvements will likely come from multidisciplinary collaboration, technological adjuncts in surgery, and possibly regenerative medicine. For trauma surgeons and ophthalmologists alike, staying attuned to these developments will ensure that even in the rare event of a muscle being "pulled in two" by trauma, we can offer the patient the best shot at seeing single once again.

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CONFLICTS OF INTEREST

The authors affirm that they do not have any competing interests.

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