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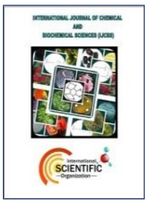

Muscle Transplantation for Large Angle Horizontal Strabismus Esotropia versus Exotropia: A Review Article

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Abstract

This review article thoroughly investigates muscle transplantation for managing large-angle horizontal strabismus, comparing esotropia and exotropia. It delves into various aspects including the anatomy and function of extraocular muscles, the pathophysiology and types of strabismus, and the complexities involved in surgical management. Emphasizing the potential of muscle transplantation as an innovative approach, the article presents comprehensive insights into its viability, challenges, and the promising outcomes demonstrated in patient follow-ups. This research contributes significantly to the understanding of strabismus treatment, offering a new perspective on surgical intervention for large-angle deviations.

Keywords: Strabismus Surgery, Muscle Transplantation, Large Angle, Esotropia, Exotropia.

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1. Introduction

Large-angle constant esotropias or exotropia's impact self-perception and social perception [1]. Established surgical treatments for horizontal strabismus in adults enhance psychosocial functioning and may restore binocular vision [2]. Managing large-angle horizontal strabismus poses challenges, with recent studies focusing on binocular or uniocular surgical approaches. Binocular surgery, involving three or four horizontal rectus muscles, is preferred for good visual acuity in both eyes to avoid significant limitations in eye movement [3-4]. Uniocular surgery, specifically a unilateral recess-resect procedure for amblyopic eyes, offers advantages such as preserving muscles for potential future surgeries [5-6]. Concerns with supermaximum recession-resection surgery include limited eye movement and potential complications. Various uniocular approaches involve additional surgery on the visually poorer eye, with techniques like rectus muscle recessions, central tenectomy, hangback-hemihangback recession, muscle recession with a spacer, and muscle elongation using autogenous homograft or artificial materials. Our study evaluates muscle transplantation during monocular recession-resection in patients with large-angle strabismus, demonstrating promising results in terms of graft stability, eye alignment, and motility after 6 months of follow-up [7].

Surgical management should consider visual acuity, potential complications, and the need for stable alignment, with muscle transplantation emerging as a promising procedure to avoid risks associated with exogenous materials

2. Gross Anatomy of Extraocular Muscles

The six extraocular muscles, identified by their position and direction of insertion, include four rectus muscles and two oblique muscles (Figure 1) [8-9]. The rectus muscles, namely the superior, inferior, medial, and lateral muscles, extend straight from the top of the orbit to the eye. The superior oblique muscle extends anteriorly from the apex, transitioning into a tendon as it passes through the trochlea, and then attaches to the trochlear fossa of the frontal bone. The tendon of the eye then goes under the superior rectus muscle and attaches at the back of the eye, namely in the upper outer area. The inferior oblique muscle originates from the front edge of the floor of the eye socket and attaches to the back of the eye, namely in the lower outer region. The rectus muscles, which have an average length of around 37 mm, along with the superior oblique and lavatory palpebrae muscles, create the "annulus of Zinn" at the highest point of the orbit [8-9].

2.1. Innervation and Blood Supply

The innervation of the ocular muscles is carried out by three cranial nerves: the oculomotor nerve (CN III), which primarily controls both the extraocular and intraocular muscles; the abducens nerve (CN VI), responsible for the lateral rectus muscle; and the trochlear nerve (CN IV), which governs the superior oblique muscle [10]. The CN III nucleus is located inside the periaqueductal gray matter of the mesencephalon. The nerve bifurcates into superior and inferior divisions, with the superior division innervating the lavatory palpebrae and superior rectus muscles, and the inferior division innervating the medial rectus, inferior rectus, and inferior oblique muscles. The oculomotor nerve (CN III) also provides parasympathetic innervation to the muscles within the eye via the "Edinger-Westphal" nucleus, which then reaches the eye as "short posterior ciliary nerves." Cranial nerve VI innervates just the lateral rectus muscle on the same side, whereas cranial nerve IV controls the superior oblique muscle on the same side [11]. The ophthalmic artery, a major offshoot of the internal carotid artery (Figure B), is responsible for providing blood flow to the extraocular muscles. The artery passes via the optic canal and then moves towards the center of the orbit. It gives birth to many branches, including the central retinal artery, short and long posterior ciliary arteries, lacrimal artery, supraorbital artery, supratrochlear artery, and ethmoidal arteries. The extraocular muscles get their blood supply from the lateral and medial muscular branches of the ophthalmic artery. Additionally, the anterior ciliary arteries originate from branches that feed the rectus muscles [12].

3. Arc of Contact

The rectus muscles all originate from the annulus of Zinn and stretch forward towards the eyeball. The "arc of contact" refers to the circular path from the point of first contact to the anatomical insertion site. This idea is important for estimating force vectors (18). When a muscle experiences recession, it decreases both its effective length and the arc of contact. In contrast, resection improves both metrics by elongating the effective length and curvature of contact [13].

4. Eye Movements

Monocular motions along Fick's axis include adduction, abduction, elevation, depression, intorsion, and extorsion [14]. Binocular movements include simultaneous and coordinated motions of both eyes. These movements include turning the eyes to the right (dextroversion) or left (levoversion), raising (elevation) or lowering (depression) the eyes, and rotating the eyes to the right (dextrocycloversion) or left (levocycloversion). There are also combinations of these movements, such as turning the eyes to the right and raising them (dextroelevation) or turning the eyes to the left and lowering them (levodepression). In all, there are 20 possible combinations of these movements. Simultaneous, deconjugate motions that occur on both sides of the body entail the act of converging and diverging [14].

5. Positions of Eye

Primary eye position is the position of the eyes while facing straight ahead with an erect head and body, focusing on a distant object. In this posture, the eyes intersect the sagittal plane of the head and align with a horizontal plane that passes through the center of rotation [15]. Secondary eye positions are attained by performing movements along the X and Z axes, which include adduction, abduction, elevation, or depression [16]. Tertiary eye positions include the rotation of the eyeball around the Y axis, which includes downward movement, upward movement, rightward movement, and leftward movement [17].

6. Positions of Gaze

The cardinal positions consist of six distinct eye motions, where each position corresponds to a primary muscle responsible for that particular action. Aside from the six main positions shown in green, the diagnostic positions consist of nine distinct eye movements. These movements include the primary position, which is denoted by a pink circle, as well as elevation and depression (Figure 2) [18].

7. Laws of Ocular Motility

In the context of eye movement, the agonist refers to the main mover, whereas the antagonist refers to the muscle that acts in the opposite direction. For example, the left medial rectus muscle moves the eye inward, whereas its antagonist, the left lateral rectus muscle, moves it outward [19].

7.1. Synergist

Synergists are muscles in the same eye that collaborate to move the eye in a unified direction. As an example, the combined action of the left inferior rectus and left superior oblique muscles contributes in a coordinated manner to the downward movement of the eye [20].

7.1.1. Contralateral synergists

The yoke muscles, also known as contralateral synergists, are pairs of muscles located in each eye that work together to generate synchronized eye movements. For example, the right superior rectus muscle and the left inferior oblique muscle combine to create coordinated eye movements [19].

7.2. Donder's Law

Donder's Law states that the spatial orientation of the eye remains unchanged and independent of past eye orientation or gaze directions for any given direction of look [21].

7.3. Listing's Law

Listing's Law states that any eye orientation may be attained by rotating about the axis inside the Listing's plane, starting with a fundamental eye position [22].

7.4. Herring's Law

Herring's Law states that synchronized eye movement is achieved by equal innervation directed to yoke muscles, however exceptions may occur in cases of dissociated vertical or horizontal deviation. Paralytic strabismus occurs when there is an overstimulation of the muscles responsible for fixation, causing an increased flow of nerve signals to the yoke muscle. This leads to a larger secondary deviation, which is the difference between the actual eye position and the desired position, relative to the main deviation [23].

7.5. Sherrington's Law

Sherrington's Law states that as one muscle receives greater innervation, the antagonist muscle experiences a corresponding reduction in innervation. This phenomenon is known as reciprocal innervation. Nevertheless, there are cases that deviate from the norm, such as in Duane's retraction syndrome [24].

7.6. Muscle Orientation

The vertical recti muscles, namely the superior and inferior rectus, are inclined at a 23° angle in relation to the visual axis. When the eyes are abducted at an angle of 23°, the visual and orbital axes align, and the recti muscles just act as elevators or depressors. When the visual axis is at 67° adduction, it forms a 90° angle with the orbital axis, and the recti muscles function only as torsional muscles [19]. The oblique muscles are inclined at a 51° angle relative to the visual axis. When the eyes are turned inward at an angle of 51°, the visual and orbital axes become aligned, and the oblique muscles just act as elevators or depressors. When the abduction angle reaches 39°, the ocular and orbital axes become perpendicular to each other, and the oblique muscles function only as torsional muscles [19].

8. Extraocular Muscle Microscopy

Under transmission electron microscopy, the extraocular muscle fibers in healthy eyes exhibit distinct striations, indicating the presence of intact basal membranes, sarcolemma, and tightly organized myofibrils with well-structured sarcomeres, Z lines, and H zones. The distribution of mitochondria seems to be normal, as seen in Figure 3 [25]. In contrast, alterations were reported in the form and size of muscle fibers in strabismic eyes. Significant observations consist of diminutive, enlarged, spiral-shaped fibers inside the myofibrils, in addition to documented impairments of sarcomeres in sections measuring 2-3mm. An examination of the cellular structure shows the presence of small fluid-filled sacs inside bundles of protein filaments, blurring of the structures that anchor the filaments, and the presence of slender rod-like structures known as nemaline rods. Anomalies in the mitochondria and foreign objects referred to as "Zebra" or "Striated" were also detected in a small number of extraocular muscles. In their study, Falki et al., also observed structural abnormalities such as disordered, atrophied, inflated, or disintegrating skeletal muscle fibers in individuals with strabismus. Strabismic eyes exhibited vacuolation, degeneration of myofibrils, accumulation of lipid droplets, and clustering of mitochondria, as seen by electron microscopy [25-26].

9. Strabismus Overview

Strabismus, derived from the Greek name for "squinting," is a disorder where the eyes are misaligned, resulting in the colloquial terms "crossed eyes," "wall eyes," or "eyes looking obliquely" [27]. In typical circumstances, both eyes maintain equal fixation. However, in instances of strabismus, one or both eyes exhibit a deviation either inward or outward, resulting in a misalignment towards a targeted object. Possible causes may include refractive problems, irregularities in binocular fusion, or neuromuscular impairments impacting ocular movements. Early detection and prompt medical intervention lead to a positive outlook, with treatments include addressing vision problems, doing eye exercises, using eye patches, applying topical drugs, and conducting surgery on the muscles around the eye [28].

9.1. Etiology

Strabismus may be classified into three main types: pseudostrabismus (a squint that appears but is not really present), latent squint (also known as heterophoria), and obvious squint (which can be further divided into concurrent and incomitant). Pseudostrabismus may result from strong epicanthal folds, causing pseudoesotropia, or hypertelorism, causing pseudoexotropia. Heterophoria is caused by anatomical and physiological causes, while apparent squint is a consequence of sensory and motor problems that influence the alignment of the eyes [29].

9.2. Risk Factors

Strabismus is linked to many disorders, such as Down syndrome, cerebral palsy, and Apert-Crouzon syndrome. It is more common in preterm newborns who have a low birth weight. Additionally, there is evidence of a genetic connection, which highlights the need for early screening of siblings of children with strabismus [27].

9.3. Epidemiology

Strabismus is seen in around 2 to 5 percent of the general population [30-31]. Exotropia is seen in 2.1 percent and esotropia in 1.2 percent of adults between the ages of 4 and 74, according to a National Health Survey. The increased occurrence of exotropia in the age group of 55 to 75 years is the reason for this discrepancy Exodeviations have a higher prevalence compared to esodeviations [32]. Half of all childhood esotropias are either entirely or moderately accommodating. Non-accommodative esotropia constitutes 10 percent of all occurrences of strabismus and ranks as the second most prevalent kind of pediatric esotropia [33]. Infantile esotropia has a prevalence of around 0.2% to 1% in the general population, making up 8.1% of all instances of esotropia [34]. Intermittent esotropia, which is the most prevalent kind of exotropia, is seen in around one percent of the population [35-36]. Exotropia is more common in Asian and African American groups than to White ones [37]. Exotropia affects women in around 60 to 70 percent of cases [38].

9.4. Pathophysiology

The exact cause of strabismus is still not fully understood. There are two primary hypotheses that attempt to explain it. The first hypothesis, known as the Claude Worth theory, suggests that strabismus is caused by a natural lack of ability for the brain to fuse images from both eyes. The second theory, known as the Chavasse theory, proposes that strabismus is caused by a misalignment of the eye muscles, which leads to impaired sensory function. The involvement of both extraocular muscles and their regulatory mechanisms in the development of strabismus justifies the need for early intervention, such as surgery, in diseases such infantile esotropia [27].

9.5. Overview of Esodeviations

Esodeviations are characterized by the misalignment of visual axis, either in a latent or visible convergent manner.

They account for more than 50% of occurrences of infantile strabismus. Their occurrence is similarly widespread among adults [39]. Potential contributors to the development of esotropia include anisometropia, hyperopia, neurodevelopmental impairment, preterm, low birth weight, craniofacial or chromosomal abnormalities, maternal smoking during pregnancy, and a family history of strabismus. The incidence of esotropia tends to rise with age, particularly between 48 and 72 months. It is more common in cases with moderate anisometropia and moderate hyperopia. A subset of families have a mendelian inheritance pattern, with about 50% of occurrences of esotropia leading to amblyopia [40]. Esodeviations can stem from innervational, anatomical, mechanical, refractive, or accommodative factors, leading to various comitant or incomitant types (Table 1).

9.5.1. Infantile (Congenital) Esotropia

Infantile esotropia, defined by an esotropia emerging by 6 months, often presents with variable, intermittent strabismus in early months. Persistence beyond 2 months, constant deviation of 30 prism diopters (D) or more, especially in premature infants, may necessitate surgical intervention. Family history links to esotropia, more in premature births, and in 30% of cases with neurological issues. An increased risk of mental illness in adulthood is associated with infantile esotropia [41].

9.5.2. Pathogenesis

Debates on etiology include Worth's "sensory" concept citing congenital brain fusion center deficit, and Chavasse theory attributing it to motor development issues. Early surgery (6 months to 2 years) shows sensory improvement, influencing the practice [41].

9.5.3. Clinical Features and Evaluation

Equal vision or alternate fixation in infantile esotropia may coexist with amblyopia, necessitating fixation preference observation. Initial normal versions and ductions may evolve into overelevation in adduction and dissociated strabismus Complex, particularly after 1–2 years. Fusion maldevelopment nystagmus syndrome often accompanies [41].

9.5.4. Management

Correction of hyperopic refractive error and surgical intervention are key. Severe cases like Ciancia syndrome may involve large-angle esotropia, abducting nystagmus, and mild abduction deficits. Correcting significant hyperopic refractive error is critical, and surgical alignment is aimed for optimal binocular cooperation, preferably by age 2 [42].

9.6. Accommodative Esotropia

Onset typically between 6 months and 7 years, this condition is hereditary, often intermittent initially, and associated with amblyopia. Diplopia, if present, usually disappears with a facultative suppression scotoma in the deviating eye [43].

9.6.1. Pathogenesis and Types of Accommodative Esotropia

9.6.1.1. Refractive accommodative Esotropia

Refractive accommodative esotropia occurs due to the combined influence of three primary factors: uncorrected hyperopia, accommodative convergence, and inadequate fusional divergence. When a patient with hyperopia adjusts their focus to bring the retinal picture into clarity, it stimulates the process of convergence and miosis. Esotropia occurs when the fusional divergence process is unable to sufficiently counterbalance the heightened convergence tonus. The degree of esotropia stays constant during both distant and close focusing, often falling within the range of 20 prism diopters to 30 prism diopters. Patients diagnosed with refractive accommodative esotropia often have an average hyperopia of +4.00 D [44].

9.6.1.2. High AC/A Ratio Accommodative Esotropia

High AC/A ratio accommodative esotropia is defined by an exaggerated convergence response compared to the necessary amount of accommodation, even when fully corrected with cycloplegic treatment. This kind of esotropia is often limited to close distances or is notably more pronounced while focusing on nearby objects. The average refractive error with high AC/A ratio accommodative esotropia, commonly referred to as nonrefractive accommodative esotropia, is +2.25 D. Significantly, this condition of inward deviation of the eye may manifest in individuals with normal or high farsightedness, perfect vision, or nearsightedness [45].

9.6.1.3. Partially Accommodative Esotropia

Patients diagnosed with partly accommodating esotropia see a decrease in the degree of inward deviation of the eyes while wearing glasses. However, there is still a remaining inward deviation of the eyes even after getting complete correction for farsightedness. This scenario is more probable to happen when there is a protracted delay in correcting refractive errors. This situation may occur due to the decompensation of a purely refractive accommodative esotropia or the emergence of an accommodating component in an originally nonaccommodative esotropia [46].

9.6.2. Evaluation

During the examination, it is crucial to ascertain if there is similar visual acuity in both eyes or whether there is presence of amblyopia. Normal versions and ductions may be present, or there may be an excessive upward movement in adduction or a fragmented strabismus complex may be noticed. The examiner assesses the deviation by using an accommodating target during both distant and close focus. During the first assessment, alternate cover testing often uncovers an intermittent comitant esotropia that is more pronounced when looking at objects up close compared to when looking at objects far away [44].

9.6.3. Management

9.6.3.1. Refractive Accommodative Esotropia

The main strategy for treating refractive accommodative esotropia consists of fully correcting the determined quantity of hyperopia under cycloplegia.

By maintaining binocular fusion, it is possible to progressively decrease the refractive correction to a level that is 1.00–2.00 D lower than the entire cycloplegic refraction. If amblyopia is present, it may be effectively treated with spectacle correction alone. Nevertheless, if amblyopia continues to exist even after wearing spectacles for a certain duration, further therapy using occlusion or atropine could be required. Parents must recognize the need of consistently wearing glasses, since it is vital. Although refractive correction may assist in managing strabismus, it cannot completely eliminate it. If the patient is unable to attain ocular alignment within the fusion range, which results in a partly accommodating esotropia, surgery may be an option [47].

9.6.3.2. High AC/A Ratio Accommodative Esotropia

Treating accommodative esotropia with a high AC/A ratio may entail options such as optical correction, surgical intervention, or just monitoring the condition. It is advisable to use bifocals, namely flat-top design bifocals with the minimum required plus power, in order to minimize or eliminate the need for adjustment while focusing on objects up close. Surgical procedures may seek to achieve a normal ratio, which might possibly lead to the cessation of bifocals. Observation considers the inherent reduction in hyperopia and high AC/A ratio as time progresses, resulting in enhanced binocular vision [48].

9.6.3.3. Partially Accommodative Esotropia

The standard approach for partly accommodating esotropia usually entails performing strabismus surgery to rectify the ongoing misalignment, even after fully correcting the hyperopia. Patients and parents must comprehend that the primary objective of surgery is to get properly aligned eyes while still requiring the use of glasses, rather than completely ceasing to use them. Refractive surgery may be an option for elderly individuals to decrease hyperopic refractive error and enhance ocular alignment [47].

9.7. Acquired Nonaccommodative Esotropia

9.7.1. Basic Acquired Nonaccommodative Esotropia

Acquired nonaccommodative esotropia, which is a kind of inward eye deviation that occurs after six months of age and is not caused by focusing issues, might have several underlying reasons. It may appear suddenly, resulting in double vision. A comprehensive assessment is necessary to exclude the possibility of accommodating or paretic factors. Hyphema, preseptal cellulitis, or mechanical ptosis are conditions that may briefly compromise binocular vision and lead to acquired nonaccommodative esotropia. Neuroimaging and neurologic evaluation are required when there are indications of abnormalities. The outlook for recovering the ability to see with both eyes is positive, and the treatment entails addressing amblyopia if needed, as well as promptly correcting the deviation by surgery or injecting botulinum toxin if the deviation occurs [49].

9.7.2. Cyclic Esotropia

Cyclic esotropia is a condition characterized by periodic inward deviation of the eyes, typically seen in preschool-aged children. Periods of divergence hinder the ability to see well with both eyes, while alignment is enhanced on alternating days. Occlusion treatment has the potential to transform cyclic patterns into a consistent deviation. Surgery, which is determined by the extent of inward deviation, is often successful [50].

9.7.3. Sensory Esotropia

Sensory esotropia occurs as a result of a decrease in vision in one eye, such as from conditions like cataracts, corneal clouding, or optic nerve diseases. Timely recognition and management of disorders that result in indistinct retinal pictures and uneven visual stimulation are essential to avoid permanent amblyopia. Typically, surgical procedures or injections of botulinum toxin are done on the eye that has a considerable impairment in vision [51].

9.7.4. Divergence Insufficiency

Divergence insufficiency is a condition where there is a higher inward deviation of the eyes while looking at far objects compared to close objects. This is generally accompanied with a decrease in the ability to separate the eyes' focus. There are two kinds of this condition: primary and secondary. The secondary variant is associated with neurological abnormalities that need neuroimaging. Primary divergence insufficiency, also known as age-related distance esotropia, occurs in adults aged 50 and beyond. It is characterized by a progressive emergence of horizontal double vision while looking at objects in the distance. Management include the use of prisms, the administration of botulinum toxin injections, and the implementation of strabismus surgery [52].

9.7.5. Near Reflex Spasm

The near reflex spasm, which may be caused by psychological causes or biological illness, manifests with diverse anomalies in the near response. Possible symptoms include of exaggerated convergence, heightened accommodation, and miosis, characterized by sudden esotropia alternating with orthotropia. The treatment includes the use of cycloplegic medications, correction of hyperopia, and the prescription of bifocal spectacles. Therapeutic intervention for fundamental psychological problems is advantageous. If the patient does not respond, it may be advisable to carefully examine the option of administering botulinum toxin injection or undergoing strabismus surgery [53].

10. Exodeviations

10.1. Exophoria

Exophoria, a controlled outward deviation of the eyes noticed during normal simultaneous vision, becomes noticeable in situations when vision is disturbed, such as during an alternative cover test. Asthenopia is a frequently occurring illness that usually does not show any symptoms, however engaging in extended close work might cause symptoms to manifest. During periods of sickness or when under the effects of sedatives or alcohol, a person may have decompensation leading to exotropia. Treatment is necessary for symptomatic exophoria [54].

10.1.1. Intermittent exotropia

Intermittent exotropia, the primary outward deviation of the eyes, often starts before the age of 5 and may continue throughout adulthood. The expression of this phenomenon is affected by circumstances such as lack of focus on visual stimuli, tiredness, psychological strain, or physical ailment. Parents often see incidents during the latter part of the day or when the youngster is fatigued. Bright light exposure may induce exodeviation and reflexive closure of one eye. Exodeviations may be more noticeable while focusing on objects that are far away and may be difficult to see when focusing on objects that are close. Untreated instances of intermittent exotropia have the potential to settle, resolve, or advance to continuous exotropia, which might result in the development of amblyopia. Individuals who have difficulty controlling exotropia in adulthood may encounter psychological distress and a diminished quality of life [55].

10.2. Assessment and Management of Exodeviations

The clinical assessment of exodeviations involves a thorough examination of the patient's medical history, which includes gathering information on the age when the misalignment first occurred, how often it happens, and how long it lasts. Medical professionals examine the factors that cause the appearance of symptoms and analyze issues such as double vision, eye strain, or challenges in social relationships. The assessment of exodeviation control is categorized as either excellent, fair, or poor, and may be quantified using techniques like as the Newcastle Control Score for Intermittent Exotropia [57]. Visual acuity and alignment tests are performed after sensory assessments to assess stereopsis and fusion. Prism and alternative cover tests are used to assess exodeviation at different distances of fixation. To differentiate between fundamental intermittent exotropia and convergence insufficiency, it is necessary to assess the aberrations in both distant and near fixation [58].

10.2.1. Nonsurgical Management

The main focus is to correct refractive defects, while also carefully managing hyperopia in situations with intermittent exotropia. Treatment options for amblyopia include occlusion therapy and the use of prisms to facilitate fusion. Excessive correction of myopia by 2.00-4.00 D may cause a delay in surgery but may lead to asthenopia [59].

10.2.2. Surgical Treatment

Patients with exotropia that is often seen, inadequately managed, or causing symptoms are advised to have surgery. Common surgical methods include either bilateral lateral rectus muscle recession or a combination of unilateral lateral rectus muscle recession and medial rectus muscle excision. Factors such as diminished self-perception and deteriorating deviance might impact surgical choices. Following surgery, there may be a tiny inward deviation of the eyes, known as esotropia, which is beneficial in minimizing the likelihood of the condition returning [60].

10.3. Convergence insufficiency

Convergence insufficiency, which is defined by a higher degree of outward deviation while focusing on nearby objects, is treated by the use of orthoptic exercises, base-out prisms, and convergence training. If symptoms continue, surgical intervention, namely medial rectus muscle excision, may be explored as a therapy option [61].

10.4. Constant Exotropia

Constant exotropia, which is often seen in elderly people, is treated in a similar manner as intermittent exotropia. It may also happen in infantile exotropia, a less common disorder than infantile esotropia, which necessitates early surgical intervention for improved results and to mitigate related risks [62].

10.5. Infantile Exotropia

Infantile exotropia, however less prevalent than esotropia, manifests as a significant deviation occurring before the age of 6 months. Intermittent exotropia has a lower risk of amblyopia compared to constant infantile exotropia. Although babies with this disease have good overall health, they are at a higher risk of experiencing neurologic or craniofacial problems. Therefore, it is important to get a detailed developmental history and consider doing a neurologic examination to identify any symptoms of delay. Constant infantile exotropia, like to infantile esotropia, necessitates early surgical intervention. Although it may result in immunofixation with gross binocular vision, total restoration of normal binocular function is rare. Dissociated vertical deviations and excessive upward movement while looking inward may occur after surgery (Figure 6) [63].

10.6. Sensory and consecutive exotropia

Esotropia or exotropia may arise from significant visual impairment or visual field deficit in one eye. The precise determinants of whether a person develops esotropia or exotropia after experiencing visual loss in one eye are yet unknown. Although both sensory esotropia and sensory exotropia may be seen in newborns and early children, sensory exotropia is more often seen in older children and adults [69]. Surgical realignment offers the potential to restore peripheral fusion if vision improves in the exotropic eye, as long as sensory exotropia has not persisted for a prolonged duration. Nevertheless, in instances of adult-onset sensory exotropia persisting for an extended period prior to rehabilitation, there is a possibility of enduring and continuous diplopia caused by central fusion disruption [65]. Consecutive exotropia is the term used to describe the occurrence of exotropia after a time of esotropia. It may occur spontaneously or, most often, following surgery for esotropia, which is referred to as postsurgical exotropia. Consecutive exotropia may sometimes develop in adults after undergoing surgery for infantile esotropia. The condition may appear sporadically or continuously [66].

11. Strabismus Management: Extensive Surgical Approaches

11.1. Introduction

Strabismus, which is defined by the misalignment of the eyes, requires a careful and systematic approach to its therapy. In advanced situations, surgical intervention is typically seen as the main approach and requires following particular rules that are based on the underlying diagnosis [67-68].

11.2. Infantile Strabismus

Infantile Strabismus, specifically infantile exotropia, is a less common condition compared to esotropia. It becomes noticeable at the age of six months and is characterized by a significant deviation in eye alignment. Given its infrequency, it is advisable to do surgery at an early stage, usually within the first few years of life, using a same method as for infantile esotropia. Possible outcomes for esotropia may include the possibility for monofixation with gross binocular vision, however the restoration of normal binocular function is uncommon [69].

11.3. Sensory Exotropia

Sensory Exotropia refers to the occurrence of either esotropia or exotropia as a result of disorders that significantly impair vision or the visual field in one eye. Sensory exotropia has a higher prevalence in older children and adults. If the vision in the exotropic eye can be enhanced, surgical realignment may be an option. However, instances with adult-onset sensory exotropia that continue for long durations pose complications because to the disruption of central fusion [69].

11.4. Consecutive exotropia

Consecutive exotropia is a condition that arises following esotropia, and it may manifest either naturally or as a result of surgery. Postsurgical exotropia often appears within a few months or years after surgery, requiring a customized and careful therapy for each individual patient [69].

11.5. Principles of management and techniques used in surgery

Surgical decision-making entails a thorough orthoptic diagnostic evaluation, which takes into account the horizontal, vertical, and torsional aspects, as well as gaze orientations and the presence of A or V syndrome. The objective is to get the most favorable results with the fewest interventions, ideally during a single session [67-68].

11.6. Weakening Procedures

11.6.1. Muscle Recession

Careful execution is crucial to avoid overcorrections; inaccuracies can lead to unfavorable outcomes (Figure 7). Techniques include standard recession, hang-back technique, and adjustable suture technique [70].

11.6.2. Disinsertion

Primarily used for overacting inferior oblique muscles, disinsertion involves detaching a muscle without reattachment [71].

11.7. Muscle Shortening Procedures

11.7.1. Resection

Tightens a muscle by removing its anterior part and reattaching the shortened muscle to the original insertion site (Figure 8) [72].

11.7.2. Tuck and Plication

While tuck procedures have fallen out of favor, plication involves suturing the muscle to the scleral insertion, offering reversibility and safety against a lost muscle [73].

11.7.3. Faden Procedure

Pins the rectus muscle to sclera, reducing rotational force, particularly beneficial for incomitant esotropia (Figure 9) [74].

11.8. Muscle Transposition Procedures

Adjusting muscle insertion locations allows for changing the vector of force. This is particularly useful for addressing small vertical deviations or severe rectus muscle palsies, with techniques like Knapp, Jensen, and Hummelsheim, each having modifications for optimal correction [73].

11.9. Complications of Strabismus Surgery

Strabismus surgery, while effective, poses potential complications. Operatively, challenges include the risk of a 'lost' or 'slipped' medial rectus muscle, globe perforation (particularly in high myopia with thin sclera), and fibrosis involving fat and extraocular muscles due to the opening of the posterior Tenon capsule. Postoperatively, over-correction, under-correction, and anterior segment ischemia risks exist, especially in older patients with systemic vascular disease [73].

11.10. Options for Large-Angle Strabismus

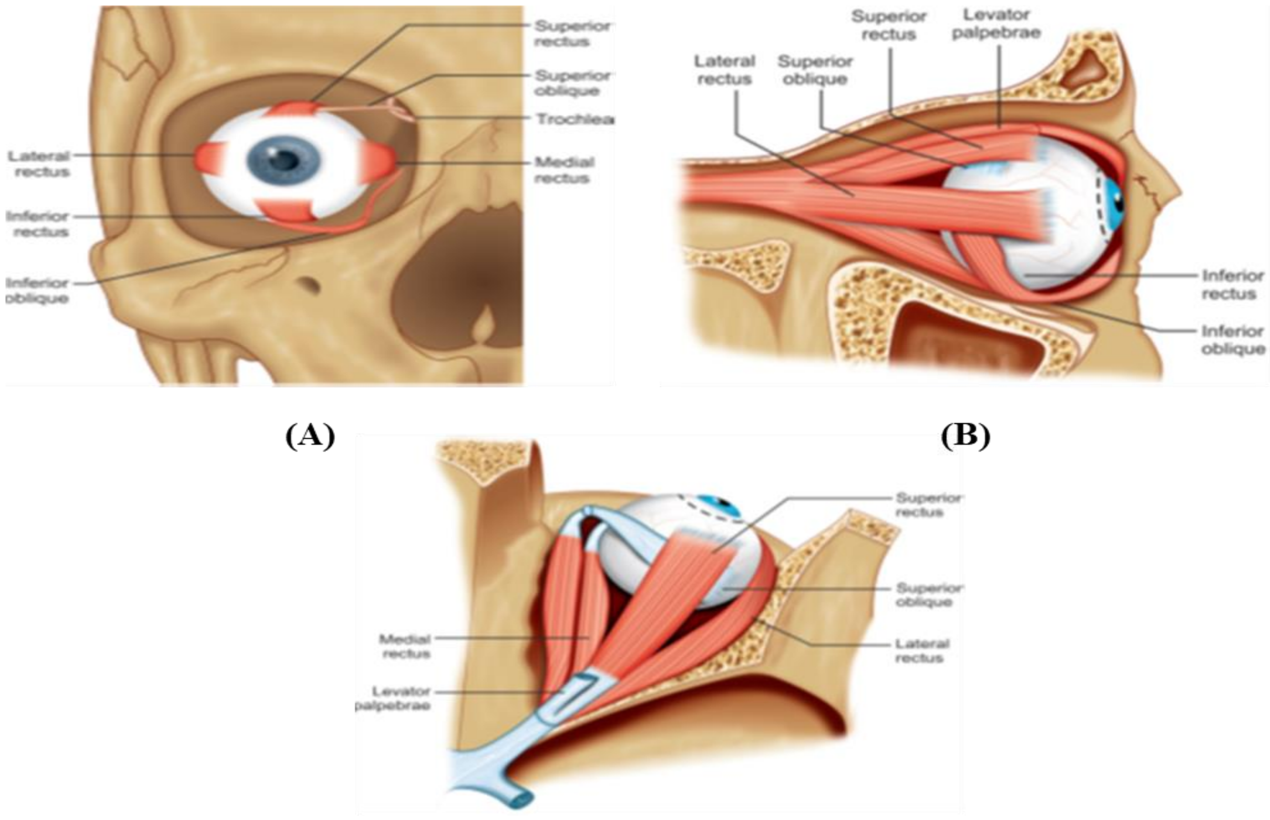
Managing large-angle strabismus, defined with varying cutoffs, involves complex surgeries. Procedures include two, three, or four muscles operations, Botox injections, tenectomy, and medial rectus elongation [75]. One-stage surgery on three muscles, supra large bilateral medial rectus recession, and unilateral recession/resection have gained popularity [76]. While three-muscle surgery may decrease undercorrection rates, it increases overcorrection and surgical time [30]. Lack of standardized tables for lateral rectus resection complicates procedures for large angles [77].

11.11. Muscle Transplantation Procedure

Muscle transplantation for strabismus challenges involve maintaining blood and nerve supply integrity while transferring functionality. Various methods, including fascia lata, allograft materials, and artificial materials, elongate extraocular muscle tendons [78]. Viability and functional benefits are explored through microsurgical techniques, considering tissue reactions, healing rates, and muscle adherence [79]. Healing involves interactions between muscles, sclera, and Tenon's capsule, with studies examining different suture materials [7].

11.12. Synthetic and Organic Materials

In addressing muscle adherence, studies explore silicone, cyanoacrylate adhesives, and Tenon's capsule to reduce adhesions between muscles and sclera [80].



(C)

Figure 1: Extraocular muscles as seen in: (A) Anterior view of the eye; (B) Lateral view of the eye; (C) Superior view of the eye.

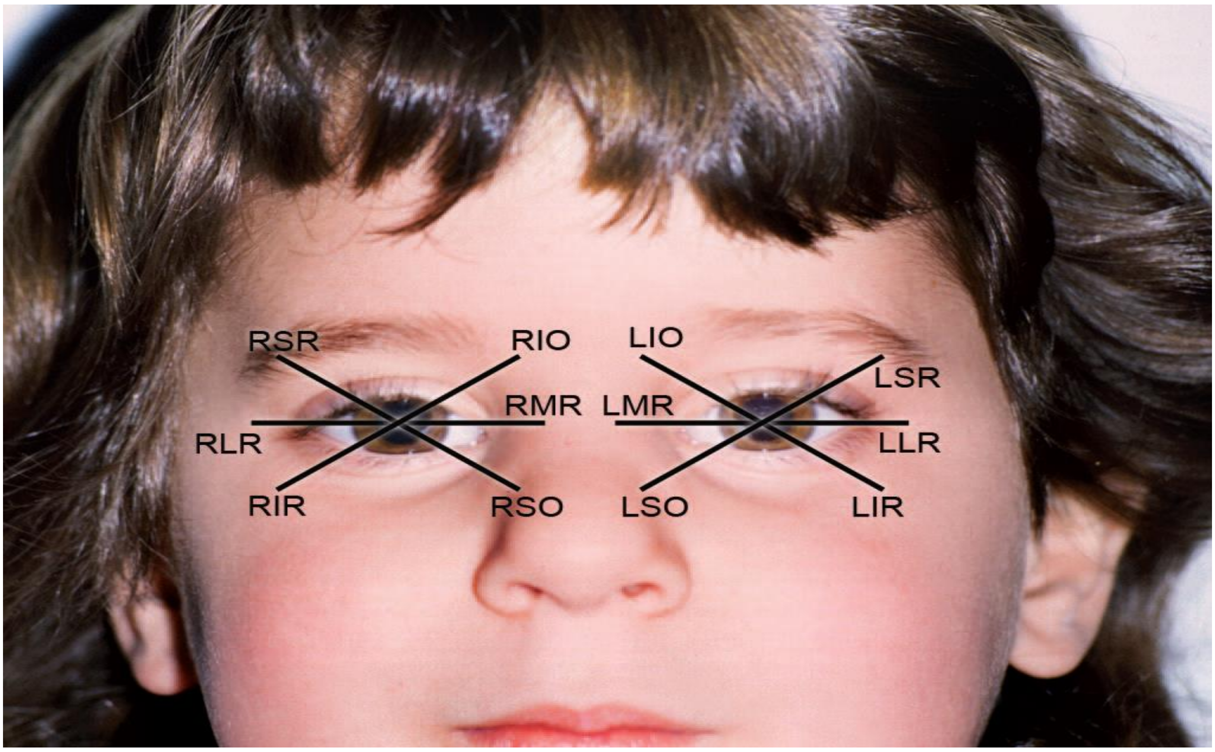


Figure 2: Primary muscles that act in the six cardinal positions of gaze for each eye. *RSR: Right superior rectus; RLR: Right lateral rectus; RIR: Right inferior rectus; RSO: Right superior oblique; RMR: Right medial rectus: RIO: Right inferior oblique; LIO: Left inferior oblique; LMR: Left medial rectus; LSO: Left superior oblique; LIR: Left inferior rectus; LLR: Left lateral rectus; LSR: Left superior rectus

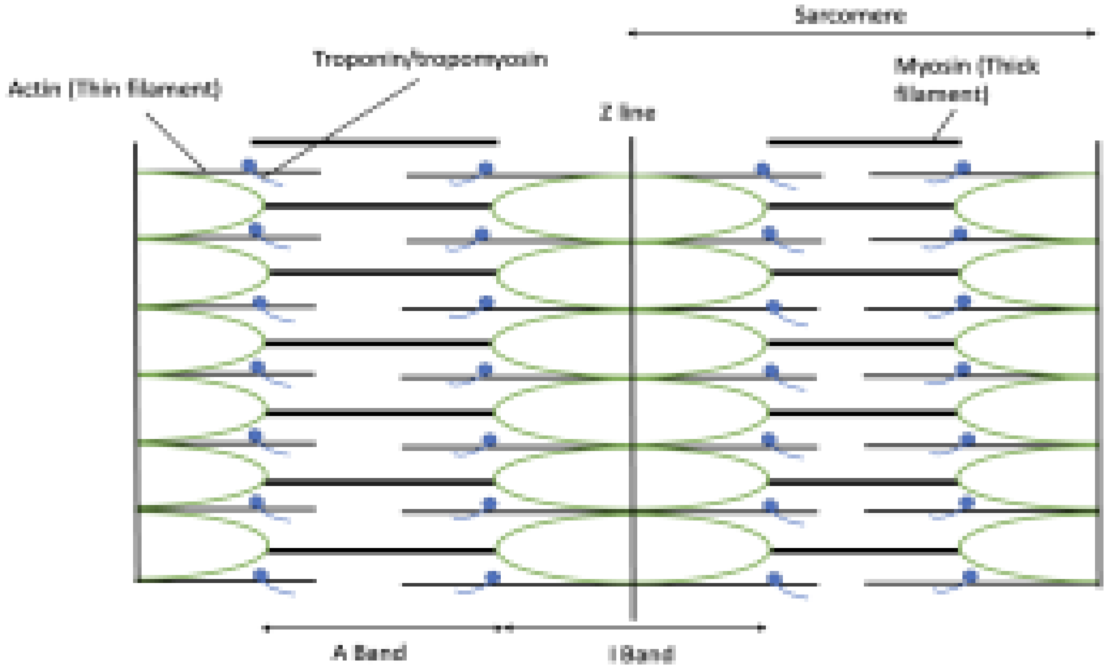


Figure 3: Schematic diagram depicting normal sarcomere structure, consisting of A band and I band in an extraocular muscle.

Table 1: Major Types of Esodeviation.

Comitant Esotropia
Infantile (congenital) esotropia Ciancia syndrome
Accommodative esotropia Refractive (normal AC/A ratio) Nonrefractive (high AC/A ratio) Partially accommodative
Acquired nonaccommodative esotropia Basic Cyclic Sensory (deprivation) Divergence insufficiency Primary (age- related distance esotropia) Secondary Spasm of the near reflex Consecutive esotropia Spontaneous Postsurgical
Nystagmus and esotropia Fusion maldevelopment nystagmus syndrome Nystagmus blockage syndrome

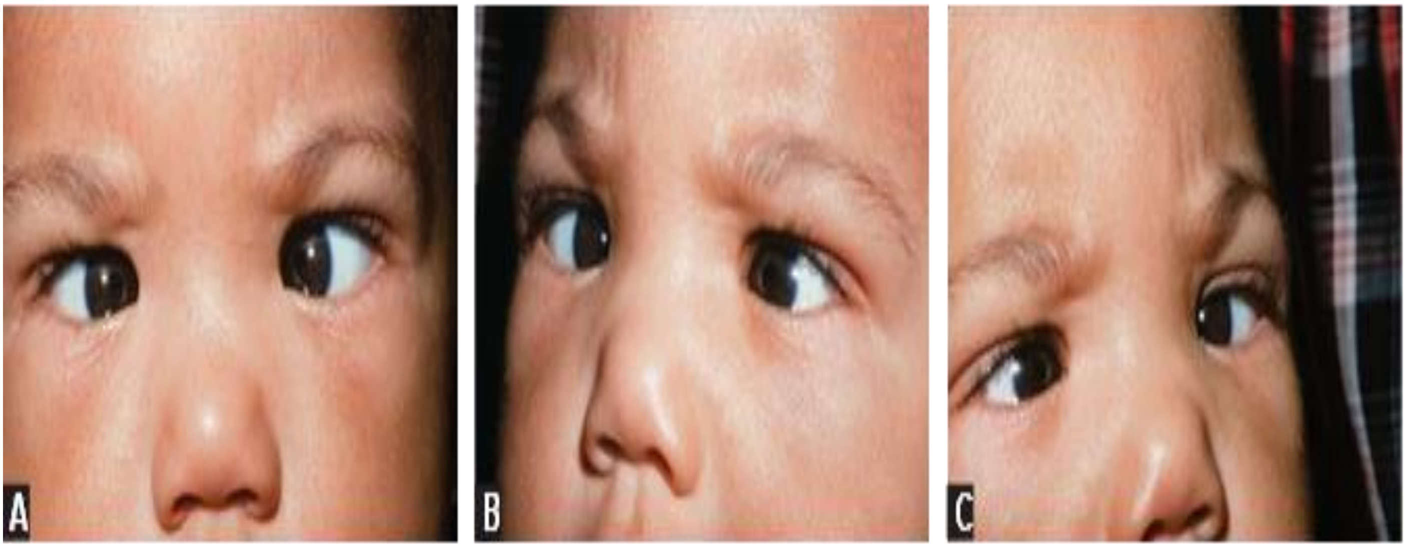


Figure 4: (A) Congenital esotropia with a large esodeviation; (B) Cross-fixation with the right eye looking to the left; (C) Cross fixation with the left eye looking to the right [50].

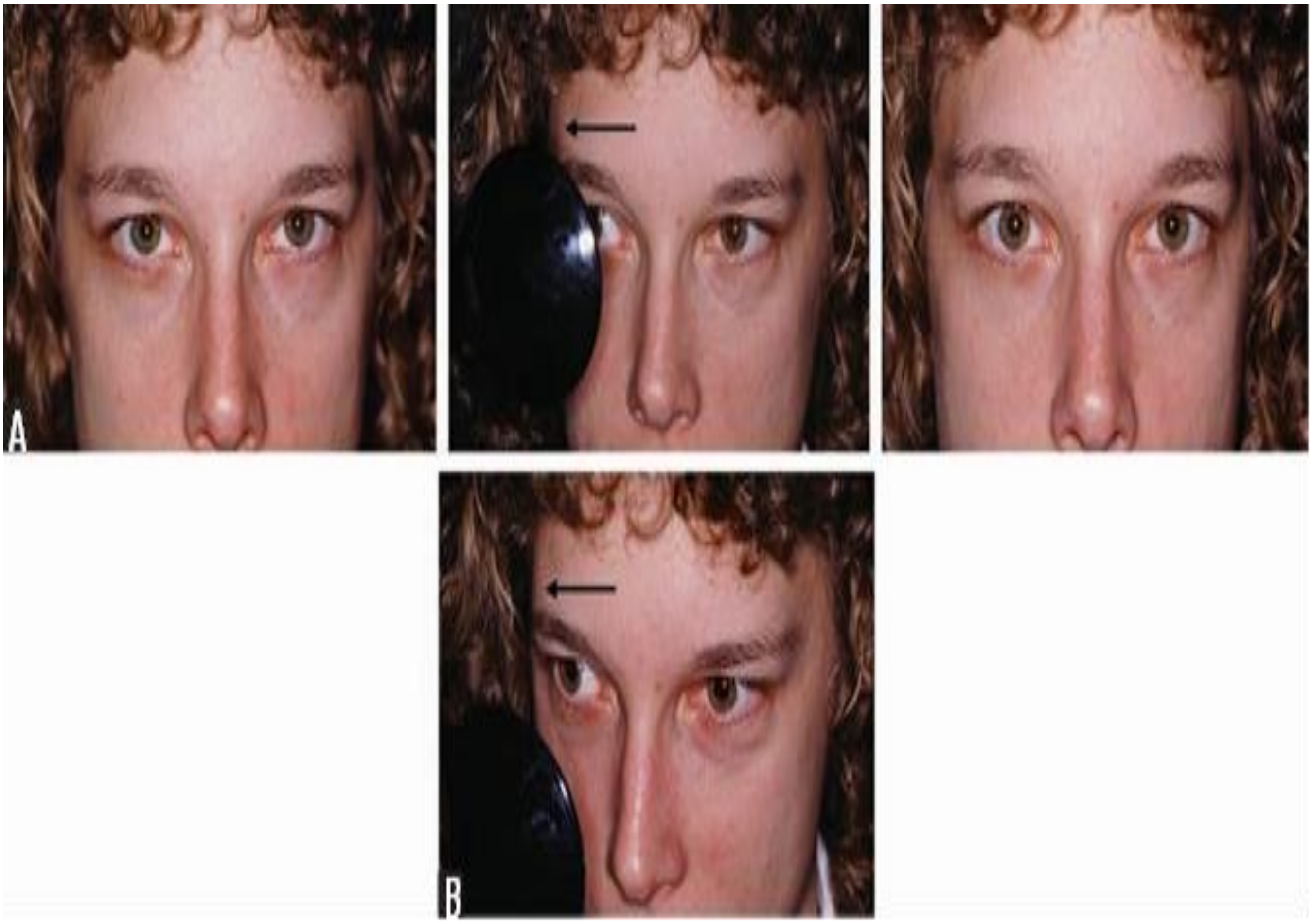


Figure 5: A and B: Patient with intermittent exotropia. Note that on occlusion, the eye under cover drift [56].

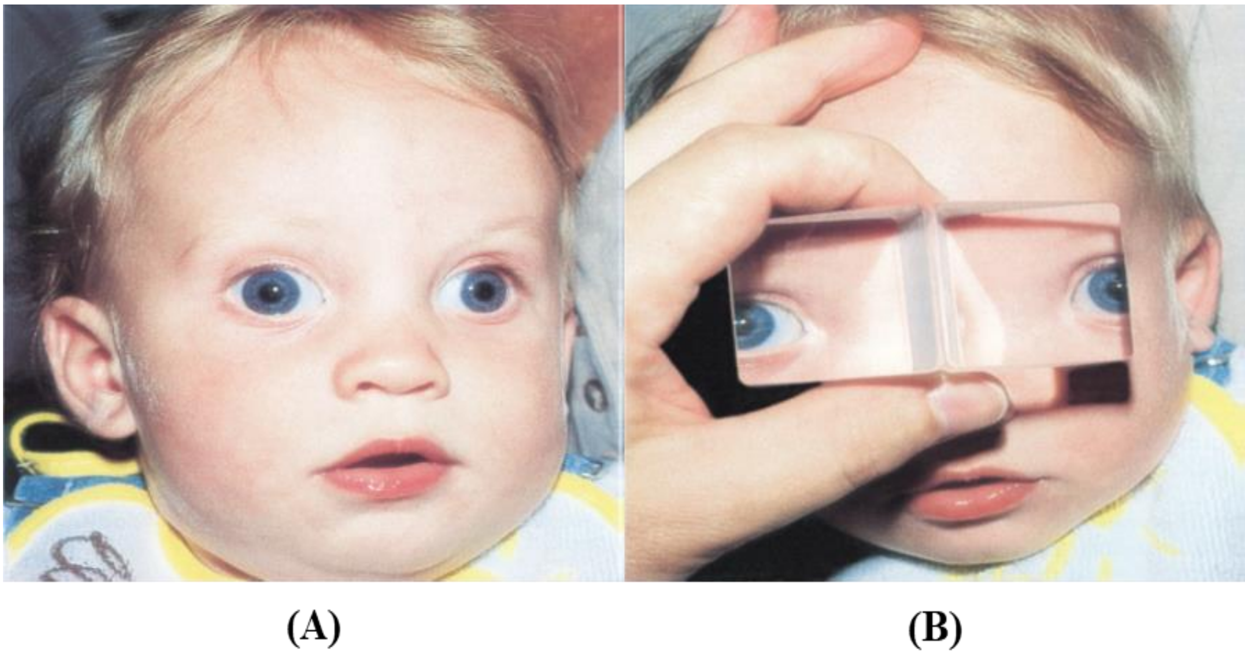


Figure 6: Infantile exotropia. (**A)** this 10-month-old infant with infantile exotropia also shows developmental delay. (**B)** Krimsky test. Two base-in prisms are used to measure the large exotropia [64].

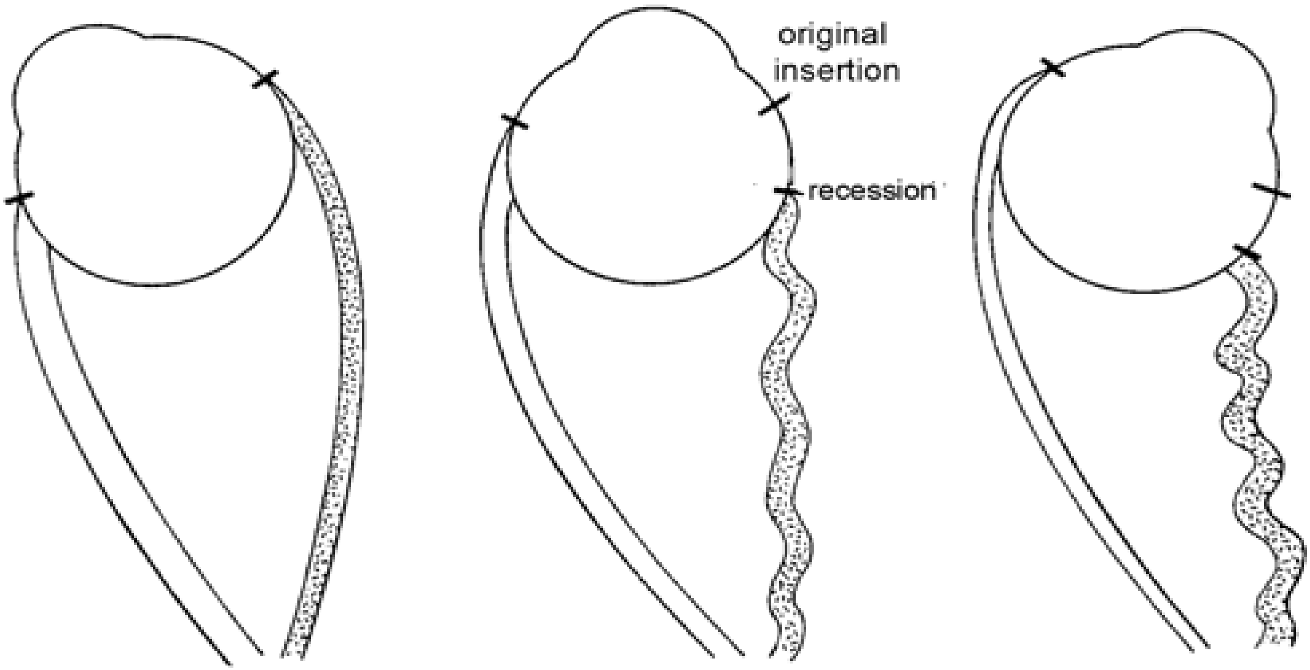


Figure 7: Illustration of rectus muscle recession (muscle darkened). The impact of the economic downturn is most evident when the attention turns towards the muscle that is set back. (A) The eye undergoes rotation towards the recessed muscle, resulting in the tightening of the recessed muscle and thus lowering muscular slack. (B) A surgical procedure involving the removal of a portion of the rectus muscle, leading to a loosening of the muscle. (C) The eye undergoes rotation towards the recessed muscle, resulting in an increase in muscular slack.

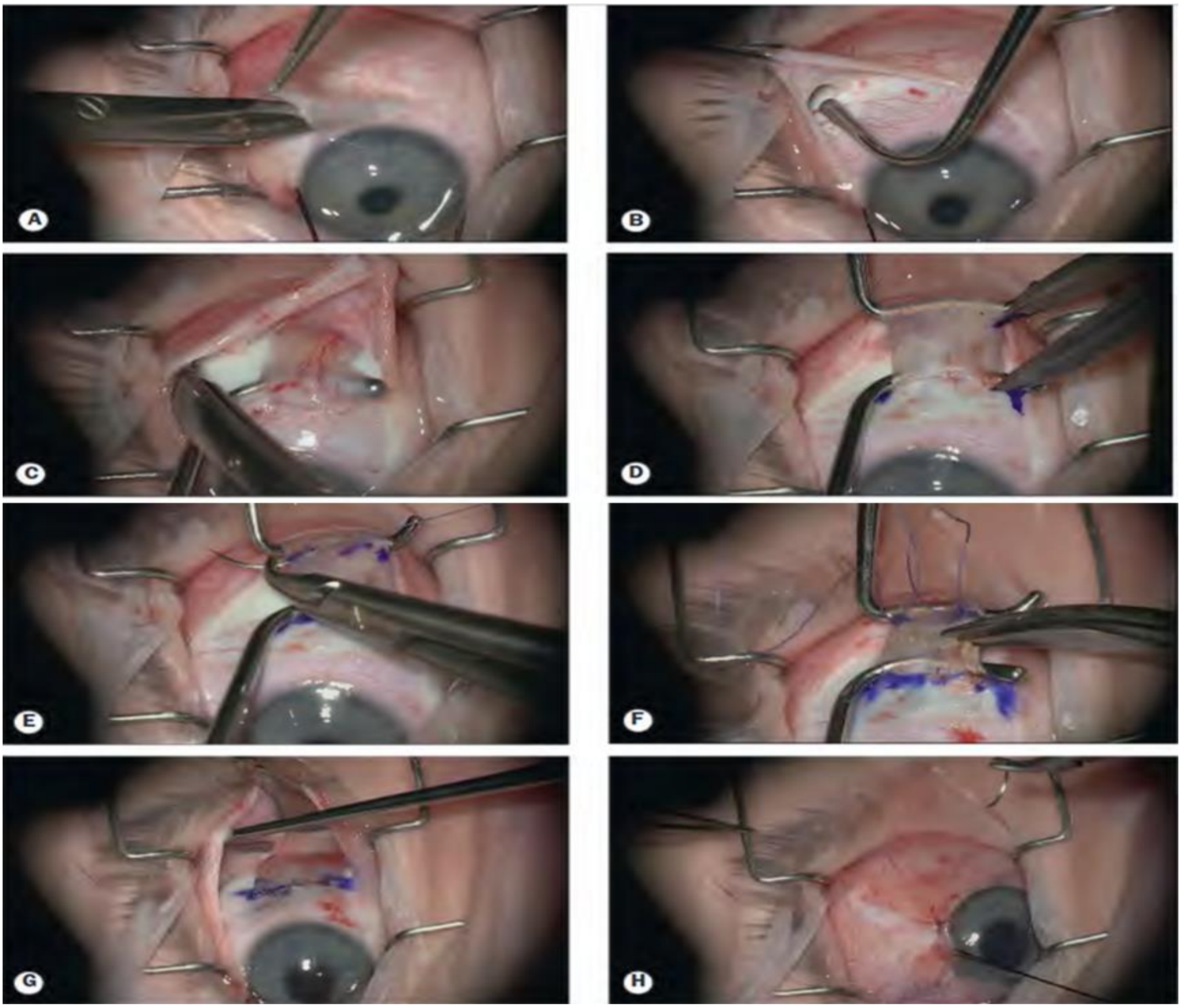


Figure 8: Resection of a horizontal rectus muscle. (A) Conjunctival incision with traction sutures to expose the operation site; (B) insertion of squint hook; (C) isolation of the muscle; (D) calliper set to the desired amount of resection; (E) muscle marked and initial 6-0 vicryl suture inserted; (F) muscle crushed, cauterized and then cut anterior to the sutures; (G) sutured muscle in position; (H) conjunctival closure [69].

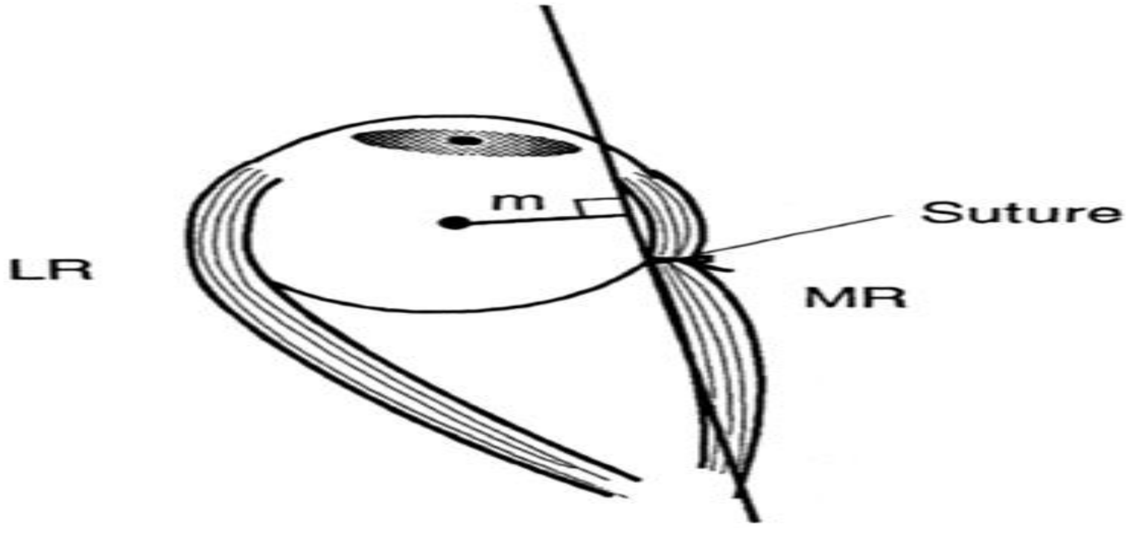


Figure 9: Faden of rectus muscle.

12. Conclusions

In conclusion, this review covers both esotropia and exotropia, presents a thorough exploration of the anatomy, function, and surgical techniques relevant to treating this condition. The analysis delves into the challenges and innovations in surgical management, highlighting muscle transplantation as a viable and promising approach. This method offers improved outcomes in terms of graft stability, eye alignment, and motility, underscoring its potential in enhancing patient quality of life. The review significantly advances our understanding of strabismus treatment options and sets the stage for future research and clinical practices that could further refine and optimize surgical interventions for those afflicted by large-angle deviations. By focusing on individual patient needs and the detailed intricacies of eye muscle anatomy and surgery, this work contributes to the ongoing evolution of strabismus management, aiming to achieve the best possible outcomes for patients.

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