Journal of
Modern Rehabilitation

October 2024, Volume 18, Number 4

Review Article

Investigating the Overaction of the Inferior Oblique Muscle and Associated Vertical Strabismus: Indications, Timing, and Methods of Surgical Intervention

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Citation Khorrami-Nejad M, Masoomian B, Saad SD, Noori AM, Khodair A, Gheibi A, et al. Investigating the Overaction of the Inferior Oblique Muscle and Associated Vertical Strabismus: Indications, Timing, and Methods of Surgical Intervention. Journal of Modern Rehabilitation. 2024; 18(4):399-406. http://dx.doi.org/10.18502/jmr.v18i4.16908

http://dx.doi.org/10.18502/jmr.v18i4.16908

Article info:
Received: 10 Mar 2023
Accepted: 05 Sep 2023
Available Online: 01 Oct 2024

Keywords:
Strabismus; Inferior oblique overaction; Strabismus surgery

ABSTRACT

Treatment of the vertical strabismus due to the overaction of the inferior oblique extraocular muscle usually requires surgical intervention. In addition to the cosmetic issues, the main indications for surgical treatment of the inferior oblique overaction are the presence of cyclotropia and torsional diplopia. Most procedures target the weakening of the inferior oblique muscle; however, there is the risk of some intraoperative and postoperative complications, including highly invasive procedures, difficulty of technical implementation because of the need for manipulations in inaccessible locations of the globe near the optic nerve, macular area, and large vessels, long duration of the surgery, inability to determine the dosage of the outcomes of the surgery, and poor functional outcomes. Most complications are absent in the procedure of anterior transposition in which the neuro-fibrovascular bundle serves as the axis of rotation of the inferior oblique muscle. This technique changes the inferior oblique muscle's action field and increases treatment effectiveness. Despite the advantages of this technique, its application is still limited because of the lack of methods for controlling the amount of anterior transposition to treat inferior oblique overaction, particularly of small degrees.

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Introduction

Strabismus is a severe functional disease with apparent cosmetic defects and affects the patient's psychological behavior. The overacting inferior oblique (IO) muscle is manifested by overelevation of the adducting eye. There is a distinction between two clinical types of overacting IO muscle: Primary and secondary to a palsied cyclovertical muscle [1]. A primary overacting IO muscle is not associated with either an ipsilateral superior oblique or a contralateral superior rectus muscle palsy. Secondary overacting IO muscle is a late-associated finding in ipsilateral superior oblique muscle palsy or an early-associated finding in contralateral superior rectus muscle palsy [2, 3]. Patients with secondary overacting IO muscles have a significant vertical and cyclovertical deviation in the primary position. The primary overacting IO muscle may or may not be associated with other strabismus findings. Either esotropia or exotropia may be associated with overacting IO muscles but is most frequently associated with congenital esotropia. Overacting IO muscles are often associated with the "V" pattern. The condition may be symmetric, with an exact degree of involvement bilaterally, or asymmetric. If asymmetric, the overacting IO muscle may be unilateral or bilateral. Overacting IO muscles occurs in approximately 65% of the congenitally esotropic children [1, 4].

Materials and Methods

In this comprehensive review paper, PubMed, Google Scholar, and ScienceDirect databases were used for searching the articles using the following keywords: Vertical strabismus, IO overaction, strabismus surgery, and anterior transposition. Articles published from 1970 to 2023 pertinent to the title of this review study were included. The selected papers and scientific evidence were selected, summarized, classified, and evaluated.

Results

Physical appearance is an essential aspect of the socialization process. In 2002, Menon et al. described psychosocial difficulties in people with strabismus [5]. Another study found a subnormal quality of life in parents of children with strabismus [6]. Some reports eliminating strabismus as a cosmetic defect significantly increases patients' self-esteem and improves their socialization [7]. Another study showed that eliminating strabismus improves children's and their parents' health-related quality of life [8].

The presence of forced abnormal head posture leads to facial asymmetry [9-11]. Facial asymmetry can likely be prevented by early treatment of the underlying condition. Another reason for early strabismus treatment is that secondary scoliosis and neck muscle contracture can develop from ocular abnormal head posture [12, 13]. In such cases, torticollis may persist even after the strabismus has been completely corrected [14].

In addition to cosmetic problems, vertical strabismus due to the overaction of the IO muscle is accompanied by serious functional deficiencies and visual impairment [1, 4]. To treat strabismus, surgical methods are used conservatively to ensure the formation of optimal conditions for the development of normal binocular vision. The possibilities of conservative treatment of vertical strabismus are limited due to small physiological vertical and cyclofusion reserves. Vertical strabismus with IOOA is characterized by a change in the angle of deviation from primary position to side gazes, making prismatic correction ineffective. This occurrence is because prisms compensate only for a certain fixed angle of deviation of the eye [15, 16]. A patient with left hypertropia in the primary position and left IO over action in the right gaze due to left superior oblique palsy is shown in Figure 1. Another patient with small-angle esotropia and bilateral primary IO overaction is illustrated in Figure 2.

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Figure 1. A patient with left hypertropia in the primary position and left Inferioroblique over action in the right gaze due to left superior oblique palsy

Figure 2. A patient with small angle esotropia and bilateral primary inferior oblique overaction

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Hypertropia in adduction of the eye and weakness of vertical fusion make conservative treatment methods ineffective. In these cases, the presence of a forced head posture and vertical and torsional diplopia are indications for early surgical correction of IO muscle overaction (IOOA).

Regardless of the reason for IOOA, the authors intend to review and describe the different methods of IO overaction surgeries.

Development and improvement of methods of surgical treatment of vertical strabismus caused by inferior oblique muscle overaction

Surgical treatment of IOOA is based on the weakening or altering of muscle function. Currently, there are many methods for the weakening of IO muscle [17]. The first surgical method explained for treating vertical strabismus with IOOA was IO tenectomy at the site of its insertion, proposed by Landolt in 1885 [15]. However, this treatment method was not popularized until 1906 by Duane. According to various studies, the first IO tenectomy procedures were performed through the lower eyelid's skin instead of the conjunctiva incision [18, 19].

Operations of complete myotomy of the IO muscle proposed by Dunnington, as well as full tenotomy of the IO muscle at the site of its insertion, have become common gradually [20]. The main indication for these interventions was the presence of torticollis. At the beginning of the last century, tenotomy and complete myotomy were replaced by the operation of myectomy of the IO muscle. It is implemented with an excision of a part of this muscle for 4-8 mm between its origin and the nasal border of the inferior rectus muscle (IR). This procedure effectively eliminated hypertropia in adduction and significantly reduced hypertropia in the primary gaze position [21-23]. In addition, it was technically simple to perform and remained the operation of choice for the weakening of IO muscle for a long time [24].

Currently, the lateral myectomy technique is used, during which the section of the IO muscle is excised from the place of its attachment to the sclera to the lateral edge of the IR muscle. This modification of myectomy makes it possible to eliminate the marked IOOA but does not allow additional interventions on the IO muscle. In addition, the described methods of weakening the muscle can be accompanied by several serious complications and adverse effects, including postoperative under-action of the IO, the development of the sticking syndrome in which the cut-off IO is attached to fatty tissue or the Tenon's capsule, as a result of which the eye in the primary position deviates downward, and a limitation develops in adduction or abduction of the operated eye [25, 26].

In 1990, Kalachev et al. proposed a method for partial lateral myectomy of the IO muscle. During the operation, the outer half of the IO is excised between the outer edge of the IR and the lower edge of the lateral rectus muscle, preserving the neurovascular bundle located in the medial part of the IO thickening, corresponding to the zone of its intersection with the IR. The positive effect of the method is to preserve the neurovascular bundle of the IO and thereby prevent the possibility of developing paralysis of the IO. In addition, the preservation of the anatomical connection of the membranes of the IO and the IR ensures that the sufficient function of the IO is preserved [27, 28].

In 1943, White described a graded recession of the IO muscle [29]. Until recently, this operation is the most frequently used in the practice of strabismus surgeons, being considered the most physiological interference [30-32]. The main principle of the operation is to transfer the place of attachment of the muscle to the sclera without changing the plane of its action, but not further than the equatorial line. Muscle recession is carried out within 6-12 mm, depending on the magnitude of hypertropia and the degree of IOOA [33].

Along with high efficiency, IO recession surgery has some noticeable risks, such as trauma, difficulty in technical implementation, the need to manipulate in a hard-to-reach area of the eye near the optic nerve, large vessels, and a long duration of the operation [34, 35]. During the operation, there is a threat of perforation of the sclera near the macula during the suturing of the muscle. To reduce the risk of developing this complication, some authors proposed to cut off the IO from its anatomical site of attachment to the sclera without prior suturing [36, 37]. With a recession of 12 mm, the new muscle attachment site recedes only 1 mm from the lateral border of the IR. Therefore, a large degree of IO recession is almost impossible, making this method ineffective in correcting large angles of vertical deviation [30, 38].

In 1950, Brown proposed to weaken the effect of IO by its marginal myotomy. The disadvantage of this method is the unreliability of the effect achieved by the operation, which is associated with the regeneration of the excised muscle area and the restoration of its overactivity [22, 39]. To date, there are several modifications to this operation. Double marginal myotomy is used to treat patients with insignificant IOOA. Reports on the combined use of this operation with recession or myectomy to treat asymmetric bilateral secondary IOOA allowed the surgeon to reduce or eliminate hypertropia in the primary gaze position [40].

Several techniques have been developed for the use of triple marginal myotomy of the IO in treating its overaction from the degree of +1 to +4. During the operation, the authors proposed to make marginal incisions using an electric knife. The width of the incision was two-thirds of the width of the muscle, two incisions were made from the anterior edge of the muscle, and the third is from the posterior edge in the interval between the first two. Some authors proposed a method for grading marginal myotomy surgery [41]. Furthermore, marginal Z- or W-shaped incisions are made on the IO perpendicular to its axis, 1/2-2/3 of the width of the muscle, using electro-coagulator equipment or using scissors. After early electrocoagulation of the vessels along the lines of planned incisions, the width of which depends on the magnitude of the hypertropia eye when it is brought, with a distance between the incisions equal to 2-5 mm [41, 42]. The procedure is as follows:

With a hypertropia of up to 7 prism diopter, a Z-shaped marginal myotomy of the IO is performed for 1/2 of the muscle width; with a hypertropia of 8°-12°, a Z-shaped marginal myotomy of the IO muscle is performed on 2/3 of the width of the muscle; with a hypertropia of 13°-15°, a W-shaped marginal myotomy of the IO is performed for 1/2 of its width; with a hypertropia of 16°–20°, a W-shaped marginal myotomy is performed for 2/3 of its width [1, 43, 44].

Some authors advocated using radio wave technology to perform Z-shaped myotomy of IO in cases with secondary IOOA [45]. This is a non-contact method for cutting and coagulating soft tissues using high-frequency radio waves (3.8–4.0 MHz). The dissecting effect is achieved due to the heat released during tissue resistance due to the penetration of directed high-frequency waves into them.

Anterior transposition of the inferior oblique muscle

The first studies of the effects of IO weakening by its transposition were published in 1940 [18, 46]. However, the term “transposition” at that time was widely used to refer to traditional methods of recession in the case of high magnitudes of IOOA [47, 48]. In 1981, Elliot and Nankin proposed a radically different approach to eliminate large degrees of bilateral IOOA which was called anterior transposition (anteriorization) [49]. The principle of the operation is that the natural place of attachment of the muscle to the sclera is transferred from the posterior pole of the eye to the anterior segment. This changes the plane of action of the operated muscle, and the IO itself takes the form of the English letter “J”. In this case, the axis of muscle rotation is the Lockwood ligament, and the neuro-fibrovascular bundle [50].

The weakening effect observed after the anterior transposition of the IO results from the muscle’s transformation from the elevator into the depressor. This procedure makes it possible to correct eye hypertropia to a greater extent in comparison with other methods of surgical treatment [51, 52]. At present, there is an unambiguous explanation of the mechanism for this transformation. The fixation of the IO with the IR is carried out utilizing a neuro-fibrovascular bundle, which is a dense fibrous structure formed by the connection of the fascial membranes. A neuro-fibrovascular bundle 14 mm posterior to the site of attachment to the sclera of the IR connects the middle of the distance between the beginning of the IO and 2 mm temporally to the site of its attachment to the IR [53-55]. After anterior transposition of the IO, the neuro-fibrovascular bundle will automatically act as a new site for applying muscle force, and muscle contraction will lead to the lowering of the eyeball [53, 54].

The disadvantage of the proposed transposition method is the impossibility of grading the desired outcome and the incidence of anti-elevation syndrome in several patients. It can lead to overcorrection and the operated eye will suffer from hypotropia in abduction. This disadvantage will require additional surgical intervention to correct the consequences of the operation.

Wright and Spiegel proposed their - surgical strategy for weakening the IO muscle [55]. However, the authors used anterior transposition with J-deformity only in cases of IOOA with the degree of +4 and patients with dissociative vertical deviation, and dosed recession was still performed at lower degrees [55].

Some authors do not recommend performing anterior transposition in case of unilateral IOOA, believing that after such an operation, there is a possibility of the development of elevation restriction in the abduction and, as a result, the occurrence of IOOA of the opposite eye [56-58]. In 2001, anterior nasal transposition was described as a new technique for attenuating the function of the IO [59]. In this case, the place of attachment of the IO is transferred to the area 2 mm anterior to the nasal border of the IR and 2 mm posterior to the place of attachment of the IR [60]. The IO thus transforms from an extortor into an intortor and from an elevator into a tonic depressor [61]. Anterior nasal transposition of the IO can be used to eliminate or reduce severe excyclotorsion. In addition, this procedure appears to be particularly effective in patients with severe or recurrent congenital and acquired superior oblique palsies, especially as a secondary procedure for IO loosening. However, the described technique is capable of causing the development of exotropia in the primary gaze position. Therefore, it cannot be the method of choice in the surgical treatment of IOOA [62].

The IO's functioning mechanism after the anterior transposition operation can be explained in terms of its new location and attachment geometry. This theory, in turn, means that further studies of the muscle response after transpositional IO surgery are needed.

Complications and adverse effects of surgical treatment of vertical strabismus with inferior oblique overaction

Several serious adverse effects may develop as a result of the surgical loosening of the IO muscle. The most common is the recurrence of IOOA, requiring mandatory secondary surgical loosening. During IO transposition, due to the lack of methods for grading the operation, often the authors note the development of overcorrection of hypertropia of the operated eye, while recession or any other methods of weakening the IO, on the contrary, give an insufficient corrective effect [63].

The remaining IOOA immediately after the operation may be associated with the fibers missed at the time of muscle release at the site of its attachment to the sclera. Most often, this happens due to the wide place of attachment of the muscle. The literature describes cases of IO attachment in the form of two or even three separate muscle bundles. Insufficient attention from surgeons to such an anatomical anomaly leads to the inefficiency of the operation [64]. The complexity of the IO morphology and the risk of damage to the vorticose vein during recession or transposition at the time of muscle suturing explains the frequency of development of such a complication as profusion bleeding.

There are some reports of the development of serious retrobulbar hemorrhages that threaten visual functions [65]. While performing manipulations in a hard-to-reach area, the posterior pole of the eye, there is a threat of damage to the Tenon capsule at the time of muscle extraction. This incidence inevitably leads to the release of orbital fatty tissue, its invasion into the operation area, attachment to the tissues surrounding the muscle, and, as a result, the development of eye mobility limitation [63, 66].

Recurrence of hypertropia is also observed frequently after successful transposition of the IO muscle. This is because due to the transposition of the IO, the posterior temporal muscle fibers are stretched from the location of the neuro-fibrovascular bundle to a new place of attachment to the sclera. As a result, chronic tension of these fibers develops, and after resorption of the suture material, this can lead to the "retraction" of the temporal segments from the site of a new attachment to the sclera into the posterior pole of the eye and weaken the effect of the operation. There is also a viewpoint that the escape of this muscle is possible if its fibers are crushed by a clamp applied when the muscle is cut off from the natural site of attachment [67].

An intimidating complication of IO transposition is the development of anti-elevation syndrome, in which there is a restriction of raising the operated eye in abduction and hyper-elevation of the contralateral eye in adduction. Many researchers attribute the development of this syndrome primarily to overstretching of the distal muscle region from the neuro-fibrovascular bundle at the moment of transfer of its attachment site to the ante-

rior segment of the eye. In addition, overstretching of the neuro-fibrovascular bundle leads to partial paresis of the oculomotor nerve fibers, which is clinically manifested by transient pupil dilation during the postoperative period [57, 68, 69].

Conclusion

Despite the various surgical methods for IOOA, none is the method of choice for the surgical correction of its overaction. IO muscle surgery has some challenges, including the adaptation of the system for assessing cyclodeviation using modern diagnostic programs, conducting mathematical modeling, and considering the mechanism of functioning of the IO muscle before and after the muscle anterior transposition surgery. In addition, newly introduced methods, except for sufficient efficacy, should be accompanied by a less damaging effect on the structures of the eye and better functional results after the operation.

Ethical Considerations

Compliance with ethical guidelines

This article is a review with no human or animal sample.

Funding

This research did not receive any grant from funding agencies in the public, commercial, or non-profit sectors.

Authors' contributions

All authors contributed equally to preparing this article.

Conflict of interest

The authors declared no conflict of interest.

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