Strabismus Surgery in Thyroid-Related Eye Disease: Strategic Decision Making

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Abstract Thyroid-related eye disease represents a unique clinical spectrum of autoimmune inflammation of the orbital tissues. The exact immunopathogenesis is still not fully elucidated, and the disease can sometimes manifest itself as a chronic and unrelenting condition with complex interplay between environmental, genetic, and immune factors. The inflammatory changes result in alterations to muscle anatomy and physiology as well as iatrogenic alterations preceding surgical intervention; therefore, the response to conventional surgical doses in strabismus surgery is not predictable. This unpredictability is exacerbated by an evolving clinical picture that may result in new-onset deviations despite an initial good surgical outcome. Management of strabismus in patients with thyroid-related eye disease can be challenging. This review discusses the various surgical options available, their success rates, and the complications. This strategic decision-making will aid the ophthalmologist in choosing among possible options for these patients and counseling them accordingly.

Keywords TED · Strabismus surgery · Thyroid and strabismus

Introduction

Thyroid-related eye disease (TED), also known as thyroid ophthalmopathy, thyroid orbitopathy, or Graves's ophthalmopathy, is a distinct clinical entity characterized by autoimmune inflammation of ocular and orbital tissues in patients generally also affected by autoimmune dysthyroidism. This manifests itself in a myriad of ophthalmic symptoms and signs, significantly that of proptosis and a restrictive-type strabismus. Diplopia is one of the commonest and most distressing symptoms, other than proptosis/disfigurement, that brings a patient with autoimmune dysthyroidism to the ophthalmologist. However, despite more than two centuries having passed since the first description of the ophthalmic signs of TED, management of associated strabismus still remains a challenge.

Strabismus in TED occurs in 17–51 % of patients with TED, whereas diplopia as the initial presentation occurs in 15–20 % [1–4]. There is a female preponderance in TED, with a female-to-male ratio of 5:1 to 8:1 [1, 5]. There is a bimodal age presentation in both genders. Female patients present at 40–44 years and 60–64 years, whereas male patients present at 40–45 years and 65–69 years. However, severer disease requiring surgical intervention is more frequently described in older men [6]. TED can occur in any thyroid state (including euthyroid), the commonest being hyperthyroidism (77–90 %) [7]. It has been shown that the thyroid hormone levels are associated with the clinical course of TED. Abnormal thyroid hormone levels have been associated with greater severity of disease, although the pathogenesis is still not understood [8–10]. It has also been noted that Graves's disease and ocular myasthenia gravis (MG) can coexist. It has been found that 3–10 % of patients with MG will have Graves's disease, whereas up to 1 % of patients with Graves's disease can

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develop MG [11–13]. This is attributable to the autoimmune mechanism of both diseases.

Pathogenesis

The exact pathophysiology of TED is still not clearly elucidated. It has been established that an autoimmune mechanism exists in TED, with the thyroid stimulating hormone receptor (TSHR) of the thyrocyte being one target antigen for antibody production [14, 15, 16, 17, 18]. An immunological cross-reactivity between the thyroid and orbital tissue is responsible for ophthalmopathy. The most widely accepted hypothesis is that of the TSHR in orbital tissue being the common autoantigen inciting cross-reactivity.

More recently, the discovery of TSHR expression on orbital fibroblasts has marked these cells as the “target cells” responsible for initiating the inflammatory process [19]. These cells are found in the fat or connective tissue compartment, as well as in the interstitium between muscle cells. Antibody binding to the TSHR activates T-cell infiltration, with cytokine release. Stimulation of hyaluronan by orbital fibroblasts results in imbibition of water in muscle and various other orbital tissues. This initial reaction is characterized by T-cell infiltration of the orbital tissues. The result can be thought of as analogous to “goiter of the eyes.”

There is also the presence of a specific type of orbital fibroblasts, preadipocytes, with greater TSHR expression [19, 20]. Direct stimulation of these cells results in fat expansion. The cytokine release also stimulates infiltration of other mononuclear cells in a complex interaction. Continued fibroblast stimulation results in collagen deposition with subsequent fibrosis that characterizes the later stages of TED.

However, this hypothesis does not clearly explain the different manifestations of TED, which may be purely congestive, myopathic, or a mixture of both. Therefore, it is felt that other antigenic stimuli may exist, including specific extraocular muscle antigens, namely, calsequestrin, that may be released secondary to tissue damage following the initial cell-mediated inflammation [21, 22].

Other proposed antigens include IR-1, and genetic predisposition has also been proposed, although no conclusive evidence has been reported [23, 24, 25]. Various environmental factors have also been found to be associated with the development of TED. The most important of these environmental factors is smoking [26]. A review of the literature on the subject by Thornton et al. [27] points to definite evidence of its role in TED, with smokers at ten times higher risk.

Nonsurgical Management of TED

It is well described in the literature that management of thyroid myopathy is complex owing to the dynamic and

progressive nature of the disease as well as the differing behavior of fibrosed muscles [28, 29]. As in many forms of strabismus, surgery is generally avoided in the absence of functional disability.

Conservative measures, such as use of Fresnel or ground-in prisms for smaller deviations or monocular occlusion are preferred to relieve diplopia during the active phase [30, 31]. During this period of observation, control of the thyroid hormone level and cessation of smoking are key clinical interventions. A study by Rajendram et al. [26] on smoking and strabismus surgery in TED showed the hazard ratio of strabismus surgery in nonsmokers, as compared with smokers, to be 2.19. They concluded that cessation of smoking early in the course of the disease would decrease the severity and need for surgery. Other means of conservative management include the use of intravenously administered methylprednisolone or other immunomodulators and injection of botulinum toxin type A. There are limited studies regarding the use of botulinum toxin type A specifically for management of thyroid myopathy. Dunn et al. [32] and Lyons et al. [33] described its use in a series of eight and 38 patients, respectively. Both studies showed improvements in patients during the active stage of the disease, but not once fibrotic changes had set in. A dose of five units per muscle was used. Dunn et al. [32], at a mean follow-up of 9.8 months, found that each patient required a mean of 2.1 injections. Preoperative deviations ranged from 9 to 30 PD (average 19.5 PD), and this improved to 0–6 PD (average 2.25 PD) at the last follow-up. Lyons et al. [33] found improvements in the angle of deviation in 75 % of patients, with a mean change in deviations of 14 PD. The mean preoperative deviations were 23.3 PD for hypotropia and 27.8 PD for esotropia. Six of the patients required no further surgery at 1 year of follow-up. Granet et al. [34] reported similarly that smaller deviations in the active phase responded well to intervention with botulinum toxin type A. Larger doses were often needed, with resultant reduction of the operative deviation or elimination of the need for surgery. Intravenously administered methylprednisolone functions by immunomodulation of the inflammatory cascade that occurs in Graves’s disease, as described above [10]. It is therefore only effective during the active phase of the disease, in patients with clinical signs of activity, and not necessarily in patients with severe disease once fibrotic changes have set in. The reduction in inflammation may improve ocular motility [35]. However, the consequences of steroid use are significant, and may not be worth the improvement in inflammation. Other immunomodulators that have been shown to be effective include cyclosporin A, methotrexate, somatostatin analogues, and rituximab [36, 37]. Cytokine antagonists are a newer therapeutic option under investigation for management of inflammatory diseases.

Challenges of Strabismus Surgery in TED

Traditionally surgical intervention for strabismus in TED should only be advised in cases of significant disability in functional positions of gaze. When indicated, the goal of surgery is for binocular single vision in primary and reading positions. More recently, newer surgical goals have included expansion of a single binocular field and even the elimination of prism use.

Various authors' experiences over the years have established basic, accepted tenets about the features distinguishing thyroid myopathy from other forms of strabismus. Imaging techniques have been described that aid the strabismologist in the diagnosis and management of TED.

Imaging Techniques for Thyroid Myopathy

Imaging techniques have been used to aid in the diagnosis and management of TED. Features on imaging suggestive of TED include bilateral thickening of the muscle belly (more than 4 mm) with tendon sparing, usually multiple extraocular muscle involvement, and increased intraconal and extraconal fat volume. The main differential diagnosis is myositis. It is characterized by a similar affection of the extraocular muscles, but is differentiated from TED by the presence of tendon involvement. Other differential diagnoses that may exhibit a similar picture on imaging include soft tissue masses, meningiomas, non-Hodgkin's lymphoma, vascular lesions, osseous lesions, and metastasis [38]. Various imaging modalities have been described, including ultrasonography, computed tomography, magnetic resonance imaging, and octreotide scanning. Magnetic resonance imaging has the advantage of better soft tissue delineation, as well as providing information on disease activity using special "weighting" on T1 or T2 imaging that can help distinguish water from fat, and therefore edema [10, 39]. However, this is not used routinely in cases of TED because of cost constraints. A computed tomography scan also provides precise imaging as well as delineation of bony structures, with the only drawback being the nonavailability of information on disease activity.

The inferior and medial rectus muscles are the commonest muscles affected, in 60–80 % and 42–44 % of cases, respectively [2, 40]. This results in the typical presentation of hypotropia (with restriction of upgaze) and esotropia (restriction of abduction) in patients with thyroid myopathy [2]. However, any muscle or combination of muscles may be affected.

Most surgeons agree that surgery should be undertaken during the inactive stage of the disease. As this cannot be definitely ascertained clinically, an arbitrary cutoff of a

minimum of 4–6 months of stable deviation, the absence of congestive signs, and stable systemic control is taken as convention [41–44]. However, this is not a guarantee of stability of deviation [45–48]. Sugar [29] described 16 patients treated for thyroid myopathy, and illustrated evolving clinical pictures in most of these patients. One patient showed changes in deviation up to 20 years after the initial surgical intervention. Follow-up of the individual patients varied, and only six of the 17 patients were described fully. As described by Sugar in the summary of his study, two patients had fixed orbits, ten patients had inferior rectus contracture, three patients had superior rectus contracture, and two patients had contracture of the inferior rectus with simultaneous contracture of the contralateral superior rectus on presentation. Three patients had increasing esotropia following inferior rectus recession (one patient), and following decompression (two patients). A review of strabismus surgery in adults by Mills et al. [48] reported overall reoperation rates as high as 21 %, which increases to 50 % in TED specifically. It is therefore prudent that the patient, as well as the surgeon, be aware of the possibility of several operative procedures despite good initial postoperative results. In fact, most reported surgical outcomes to date are limited by relatively short follow-up periods (Table 1). Most of the studies reporting better surgical success rates are those with limited follow-up. Keeping in mind the behavior of the disease, one might expect longer follow-up periods to show a worsening in success and reoperation rates than currently reported.

A greater challenge exists in patients with debilitating signs and symptoms necessitating earlier surgical intervention. A study by Coats et al. [49] looking specifically at strabismus surgery during the active phase of disease in eight patients reported binocular single vision in the primary position in 50 % of patients (four of eight patients) after single surgery at a mean follow-up of 20.5 months. However, the study was limited by the small sample size. Other authors have reported a worsening of orbital inflammation as a consequence of surgery during the active phase [42, 43].

Because the myopathy is restrictive in nature, recession of muscles is taken as the rule. It is felt that resection of muscles may aggravate inflammation, and is best avoided as progressive fibrosis of a resected or shortened muscle may result in overcorrections and new-onset deviations that would be difficult to reverse. There are no specific studies in the literature reporting flare-up of symptoms following resection in TED. Difficulties arise in cases of large angle deviations where maximal recessions may not be able to correct the deviation and therefore require an additional resection of the antagonist muscle. A recent study by Yoo et al. [50] on muscle resections in thyroid strabismus showed good short-term postoperative results, with 87.5 %

Table 1 Strabismus surgery in thyroid-related eye disease

Method	Sample size	Follow-up	Preoperative ductions/deviations	Muscle procedure	Amount of recession	A/ NA	Results	Comments
Dyer [28]	Retrospective	116	–	IRrec (<i>n</i> = 48), MRrec + MRrec (<i>n</i> = 35), other combinations (<i>n</i> = 33)	–	NA	Single surgery: 55 %. Reoperation: 45 %—3 surgical procedures: 3 %; 4 surgical procedures: 2 %	Prior decompression surgery: <i>n</i> = 68
Ellis et al. [46]	Retrospective	30	–	IRrec (<i>n</i> = 28), MRrec (<i>n</i> = 9), SRrec (<i>n</i> = 1) IRrec (<i>n</i> = 36), MRrec (<i>n</i> = 1), C/L SRrec (<i>n</i> = 1), combined IRrec + MRrec (<i>n</i> = 7)	–	A	Success: 83 %. Reoperation: 17 %—2 surgical procedures: 17 %; 3 surgical procedures: 7 %	
Mourits et al. [52]	Retrospective	38	Hypotropia: 4–22 PD. Esotropia: 8–45 PD	–	IRrec: 2.5–5 mm (mean 3.3 mm). MRrec: 3.5–8 mm 4–8 mm (3–14 mm)	NA	Success: primary and reading gaze: 89 %; single surgery: 71 %; reoperation: 29 %	Success includes with and without prisms
Lueder et al. [79]	Retrospective	47	Mean: 41 months (6–168 months)	–	–	NA	Success: primary and reading gaze: 72 %; postoperative adjustment: 66 %	New or progressive restrictions: 23.5 %
Kraus et al. [83]	Interventional case series	52	A: preoperative hypotropia: 8–36 PD (mean 23.8 PD) NA: preoperative hypotropia: 4–40 PD (mean 16.24 PD)	Only IRrec (<i>n</i> = 37)	A: mean . NA: mean 4.7 mm (2.5–9 mm)	A: 11. NA: 26	Success: A 64 %; NA 38 %; fusion with prisms: A 91 %, NA 65 %; reoperation: A 9 %, NA 35 %	Success: fusion in primary and reading gaze
Prendiville et al. [82]	Retrospective	32	Preoperative hypertropia: 14.4 ± 12.1 PD (1–35 PD)	Combined vertical and horizontal (<i>n</i> = 15) IRrec (<i>n</i> = 20; U/L 14, B/L 6), MRrec (<i>n</i> = 4; U/L 2, B/L 2), B/L LRrec (<i>n</i> = 1), combined vertical and horizontal (<i>n</i> = 12)	–	NA	Reoperation: 29 %	
Sharma et al. [55]	Retrospective	7/12 ^a dysthyroid	Vertical: 5–75 PD. Horizontal: 5–55 PD	IRrec (<i>n</i> = 2), SRrec (<i>n</i> = 1), B/L LR (<i>n</i> = 1), combined (<i>n</i> = 3)	–	A	Overcorrection: 29 % (14 % reoperation?)	
Mocan et al. [54]	Retrospective	32	Horizontal: D: 38.3 ± 25.4 PD (7–110 PD); N: 32.9 ± 25.6 PD (3–100 PD). Vertical: D: 10.7 ± 10.2 PD (2–35 PD); N: 10.4 ± 11.9 PD (1–40 PD)	B/L MRrec (<i>n</i> = 23), U/L MRrec (<i>n</i> = 9), combined MRrec + IRrec (<i>n</i> = 26)	Mean MRrec: 6.0 ± 2 mm	A	BSV: 73 %; BSV with prisms: 10 % Reoperation: 16.7 %	Prior decompression surgery: 75 %. Prior radiation therapy: 15.6 %. Prior systemic steroids: 25 %

Table 1 continued

Method	Sample size	Follow-up	Preoperative ductions/deviations	Muscle procedure	Amount of recession	A/NA	Results	Comments
Jellema et al. [91]	42	12 months	Elevation: 12 ± 6.9 . Depression: 54 ± 6.2	B/L IR rec ($n = 33$), combined B/L IR rec + horizontal muscle rec ($n = 9$) Symmetric IRrec ($n = 18$) Asymmetric IRrec ($n = 24$)	Mean: 3.6 ± 1 mm Mean: 4.2 ± 1.2 mm	NA	Success: 64 %. Reoperation: 36 %—1 horizontal: 20 %; 1 or more vertical: 17 %; mean: 2 surgical procedures per patient (1–6)	
Volpe et al. [13•]	54	Mean: 38 weeks (4 weeks to 8 years)	Vertical: mean 16 PD (4–50 PD)	IRrec ($n = 30$; U/L 23, B/L 7), IRrec + C/L SRrec ($n = 16$), B/L IRrec + C/L SRrec ($n = 8$)	3–6 mm	A	Success: 65 %. Reoperation: 3.7 %	Success: fusion in primary and reading gaze. Prior decompression: 29 %

A adjustable sutures, B/L bilateral, BSV binocular single vision, C/L contralateral, D distant, IR inferior rectus, L/R lateral rectus, MR medial rectus, NA nonadjustable/fixed sutures/PD prism diopters, SR superior rectus, rec recession, U/L unilateral

^a Seven patients of a total of 12 patients had thyroid-related eye disease.

of patients orthotropic in primary gaze. The minimum duration of follow-up of these patients was 6–10 weeks, and the mean duration of final follow-up was 6 months, with one patient lost to follow-up. There was no case of overcorrection or worsening of inflammation in their series of patients. Only two other studies have mentioned outcomes specific to resection in thyroid-associated strabismus [51•, 52]. Yan and Zhang [52] and Mourits et al. [53] advocate the use of resections in the case of large deviations that cannot be corrected with maximal recessions. These studies indicate that with careful case selection, depending on the degree of deviation and forced duction testing intraoperatively, resections may not be contraindicated. As a rule of thumb, resections can be considered if (1) they are limited to the tendon or (2) the muscle appears to be uninvolved.

As mentioned earlier, the fibrosed or inflamed extraocular muscle does not behave predictably to standard surgical nomograms. The general dictum is larger than expected recessions for smaller deviations and smaller than expected recessions for larger deviations as described by Buckley and Von Noorden [53]—the “a lot gets you a little and little gets you a lot” dictum. A more recent study by Mocan et al. [54] on medial rectus recession using standard nomograms in TED supports this. They studied the ratio of expected versus observed corrections and found consistent undercorrections in most patients almost in the range of half the expected correction. However, there is no specific nomogram for thyroid strabismus correction because of the high variability in muscle response to inflammation and fibrosis affecting surgical outcomes [55]. The role decompression plays in strabismic outcomes is also unclear. This difficulty would account for the relatively high reoperation rate in thyroid strabismus and the support for adjustable sutures to improve postoperative results.

The inferior rectus is the commonest muscle involved, and surgical correction of vertical deviations by inferior rectus recession is most commonest procedure performed. The challenge lies in correcting an incomitant strabismus for both functional positions of primary gaze and reading position. Correction of a hypotropia in primary gaze may result in hypertropia in downgaze. Most authors therefore advocate bilateral inferior rectus recessions to improve the symmetry of ductions in both eyes—especially when there is bilateral restriction. This would be guided by intraoperative forced duction testing in deciding the surgical dose for each eye. In large vertical deviations, it may be necessary to recess the contralateral superior rectus as well as the ipsilateral inferior rectus. Because the inferior rectus is an adductor, another problem that may arise with large recessions is the induction of an “A” pattern with resulting diplopia in downgaze. Therefore, care must be taken in a combined procedure with medial rectus recession for

esotropia as this can exacerbate an A pattern. The usual surgical correction for an A pattern may also not be possible in these cases. Recession of a tight inferior rectus may result in incyclotorsion. Superior transposition of the medial rectus or nasal transposition of the inferior rectus to correct an A pattern may worsen incyclotorsion. Similarly, transposition for the cycloduction deficit may worsen the A pattern. Large recessions of the inferior rectus can also decrease innervation to the contralateral superior oblique muscle—its yolk muscle—and thus apparent inferior oblique overaction contralaterally. Dagi et al. [30•] described transposition of the inferior oblique border to the superior border of the lateral rectus to manage diplopia from torsion. These factors make the aim of binocular single vision in both primary and reading gaze difficult to achieve. In fact, most studies looking at the outcome of inferior rectus recession or combined procedures in TED usually describe the use of prisms postoperatively to achieve single vision in both functional gazes, or else report success in only primary gaze.

Another known entity is progressive overcorrection after inferior rectus recession, a term coined by Sharma and Reinecke [55]. It has been reported in 42–50 % of patients postoperatively following inferior rectus recession [56, 57•]. It is one of the commonest causes of recurrent diplopia in vertical strabismus, especially TED. Similar findings have not been found in recession of other recti. The exact mechanism that predisposes the inferior rectus for overcorrection is not known. Various hypotheses based on the anatomical position of the inferior rectus have been put forward. One explanation given by Sharma and Reinecke is Bell's phenomenon, which produces repeated contraction of the inferior rectus, predisposing it to shifts resulting in overcorrection. In a study by Wright [58] on inferior rectus recession without TED, 12 % of patients showed overcorrection. In those who underwent reoperation, slippage was not seen, but instead a scarring of Lockwood's ligament and the capsulopalpebral head, causing a slackening of the inferior rectus, was present. This was postulated to be a result of extensive posterior dissection of the inferior rectus in an effort to separate the inferior retractors to prevent postoperative lid retraction. This can be aggravated by phenomena such as scar elongation and remodeling [59]. It has also been thought that ipsilateral superior rectus or contralateral inferior rectus muscle contracture, specifically in cases of TED, may predispose to overcorrection [60]. Keeping this in mind, some authors advocate slight undercorrection at the initial surgery to take into account an expected drift toward overcorrection [53]. This has several advantages: (1) with a small head position the patient can fuse in the primary position; (2) with no head position the patient can fuse in downgaze; and (3) if progressive overcorrection after inferior rectus recession does

occur slowly, the patient may develop increased fusional vertical amplitudes and thus function quite well. The hypothesis of slippage and scar elongation has fueled debate as to the use of absorbable versus nonabsorbable sutures, and adjustable suture versus fixed suture surgery [53, 61]. It is felt that the use of absorbable and adjustable sutures impedes anchorage of the muscle to the sclera, which can result in slippage, scar elongation, and therefore overcorrection [56]. This is especially so with the inferior rectus muscle because of its anatomical position, as previously described, so adjustable suture surgery may be avoided for this muscle, or else semiaadjustable sutures should be considered [12]. If both inferior rectus muscles are being operated on, symmetric surgery (i.e., both adjustable or both nonadjustable) seems to allow for more predictable changes postoperatively.

As noted, orthophoria in the primary position may be accompanied by a reversing hypertropia, that is, contralateral hypertropia in upgaze and ipsilateral hypertropia in downgaze. The duction deficit can be matched by a posterior fixation suture on the contralateral inferior rectus. It is generally advised to wait for final inferior rectus recession "overcorrection" before using this technique. The contralateral posterior fixation can create a significant broadening of the binocular field and improved patient function.

Other challenges faced during surgery for thyroid-associated strabismus include the often friable or fore-shortened conjunctiva, especially after radiation therapy, and tight muscles making exposure difficult. Care in handling of the muscle is mandatory to avoid rupture, or "pulled in two" syndrome. The use of special hooks such as the Wright, Wilson, Suh, Kowal, or Bishop grooved hook to avoid excessive traction may be necessary [46, 53]. Insertion of the blade of the tenotomy scissors between muscle insertion and sutures, to disinsert the muscle, may not be possible because of a tight muscle. The use of a no. 15 Bard-Parker blade may be safer and make it easier to cut the tendon over the hook instead. Care must be taken when finishing surgery to maintain (1) adequate conjunctival closure and (2) prevent conjunctival restriction of ductions. The eye should be held in the position of fullest possible duction while the conjunctiva is closed.

Most patients undergoing strabismus surgery for thyroid myopathy may have also undergone orbital decompression surgery. This has been shown to be associated with new-onset strabismus as a result of changes in muscle path [62–64]. Shorr et al. [64] found a 30 % incidence of diplopia in the primary position following decompression surgery. They also found that bony decompression surgery was associated with worsening of esotropia and hypotropia, specifically, in their group of 50 patients. They also found that those patients more likely to develop diplopia in the

primary position were those with preexisting limitation in ductions. A discussion of this study by Rosenbaum et al. reviewed the incidence rate of new-onset diplopia following bony decompression and it was found to range from 3 to 42 %. More recently, it has been observed that differing approaches to decompression are associated with differing rates of postoperative diplopia, ranging from 0 to 73 % [65–75]. It is therefore better to perform strabismus surgery after decompression. Prior decompression surgery has been found to be an adverse factor in surgical outcome [76]. Ruttum [76] found that in patients who had undergone prior decompression, the success rates were significantly lower, and surgery was usually required on a greater number of muscles. In contrast, a study by Gilbert et al. [77] on strabismus surgery after orbital decompression found no effect of prior decompression on surgical outcome. They also suggested that the worse outcome found in other studies may be due to severer ophthalmopathy in this subset of patients. As the aforementioned authors all used differing surgical indications, techniques, and interventions, comparison is difficult. Giving stretched but inflamed and fibrotic enlarged muscles more room to move may well improve ductions and change an incomitant deviation to a comitant one. The role of decompression on muscle pathway and duction/alignment response needs further study. It should also be noted that strabismus surgery itself may induce differing degrees of proptosis as a result of muscle recession [78].

The postoperative regime may need to be TED-specific. Various authors use differing postoperative routines. The use of oral steroids, for even a short pulse, may have an effect like oral steroids have after administration of radioactive iodine; that is, decrease the statistical risk of the surgery itself causing reactivation.

Another point that needs to be considered is the association of Graves's disease with MG. This can lead to a confusing clinical picture as both diseases can have similar eye manifestations of ocular motility problems [11]. MG can mimic myopathic or neurological disorders of the eye. However, the presentation of ptosis in TED is rare, and so a possible diagnosis of coexistent MG must be kept in mind and investigated in these cases. Similarly, a changing clinical picture over short periods may be attributed to MG rather than TED [79].

Newer Concepts

In an attempt to overcome the difficulties faced by surgeons in the management of thyroid-associated strabismus, various modifications of standard strabismus surgery have been described.

Dal Canto et al. [80] have described the “intraoperative relaxed muscle positioning technique” for thyroid

strabismus. This involves the positioning of disinserted muscle at its relaxed position with the globe in the primary position. Preoperative deviations are not taken into account when deciding on the amount of recession. Of 24 patients at an average follow-up of 5.4 months, 83.3 % had excellent outcomes of no diplopia in primary or reading gaze after single surgery, and the reoperation rate was 8 %.

Nguyen et al. [81] conducted a case–control study to assess the outcome of surgery on the basis of correction of limitation of ductions rather than preoperative deviations. The surgical procedure involved disinsertion of the muscle to be recessed, followed by forced duction testing of both eyes. The muscle was then reattached at a point on the globe when fully stretched, and with the globe in a position matching the maximum eccentric position of the contralateral eye. They found a 74 % success rate in their case group as compared with 44 % in the control group. The reoperation rate was also lower in the case group (27 %) as compared with control group (44 %). Similar findings were found in an earlier study by Prendiville et al. [82] that analyzed factors associated with postoperative vertical deviation. They found that extraocular muscle restriction, particularly the restriction between opposing recti in the contralateral eye, was a significant factor affecting surgical outcome. The surgeon was not masked in this study. On the other hand, a study comparing surgery for correction of ductions versus surgery for correction of deviation by Thomas et al. [2] showed no difference in success rate between the two groups (72 % vs 66 % respectively; $p = 0.55$).

The most significant introduction into the management of strabismus surgery is the use of adjustable sutures. In 1978, Ellis et al. [28] reported a reoperation rate of 17 % with the use of adjustable sutures, which was significantly less as compared with other reported outcomes at the time. With greater numbers of studies since, there is evidence to suggest that use of adjustable sutures improves the short-term outcome of strabismus surgery in TED. Kraus and Bullock [83], in a review of their patients from 1981 to 1992, compared the success rates for adjustable and non-adjustable suture surgery. They found better ocular alignment with the use of adjustable sutures: success rate of 77 % versus 46 % and reoperation rate of 11 % versus 29 % for adjustable and nonadjustable suture surgery, respectively. Similar findings were found by other authors with a follow-up of 3–4 months [13•, 55]. Lueder et al. [79] reported an excellent outcome in 47 % of patients who underwent adjustable suture surgery with a mean follow-up of 41 months and a reoperation rate of 15 %. However, concerns about adjustable suture surgery in TED include the possibility of muscle slippage, scar elongation, and progressive overcorrection. In the study by Lueder et al. with long term follow-up, of the patients with fair to poor

outcomes, one patient was reported to have an overcorrection, whereas the remainder had progressive restriction of the muscle operated on, other muscles, or persistent diplopia. Sharma and Reinecke [55] reported two cases of overcorrection in seven TED patients following single-stage adjustable suture surgery, one of which occurred in the immediate postoperative period.

Older procedures such as central or marginal myotomy, small rectus muscle offsets, and conjunctival recession in people with foreshortened tissue may eliminate smaller deviations [84–88]. Oblique-like strabismus patterns have been reported both preoperatively and postoperatively. These result from restrictive (not paretic) patterns preoperatively and large recessions of yolk muscles postoperatively. Some of these procedures can be performed during the eyelid surgery sitting as they usually will not affect eyelid contour or margin to reflex distances. Careful planning and even waiting for the result of the major alignment correction can elucidate the path to a greater binocular field.

Intraocular pressure is also a consideration in TED. The restricted enlarged muscles can affect intraocular pressure both in the primary position and in upgaze. Several reports have noted a significant decrease in intraocular pressure with both muscle surgery and Botox use [89, 90].

Conclusion

Management of strabismus in TED continues to be a challenge. Somewhat amazingly, the exact pathogenesis, for more targeted therapy and control of the disease, is still not clearly known. However, advances in this field have pointed toward a complex interplay between the immune system, genetic factors, and various environmental factors. This needs to be kept in mind while treating patients as cessation of smoking and thyroid hormone control are factors that can be altered and have been shown to improve outcome.

The difficulty in treating the condition stems from the evolving and dynamic nature of the disease. Careful preoperative and intraoperative examination, in the form of forced duction testing, and modifications in surgery have improved the overall outcome of strabismus in TED.

Important points to be noted while treating a patient suffering from the consequences of strabismus in TED are as follows:

- Avoidance of surgery unless the patient is functionally or cosmetically disabled. The goals of surgery should be limited to achieving and expanding fusion in functional gazes.
- Look for signs of clinical activity. It is best to avoid any surgical intervention during this period. Newer imaging

modalities may help in deciding about the presence of active disease. Various modalities of conservative therapy, including the use of prisms, immunomodulation and botulinum toxin type A, have been described.

- Cessation of smoking and thyroid hormone control is important in overall disease control and for better outcomes. Often these require the participation of patients in their own care.
- Standard surgical nomograms may not apply for muscle surgery in TED because of the variable response of fibrosed/inflamed muscles to the surgical dose. Forced duction testing intraoperatively is crucial when deciding on or varying the surgical plan. The dictum noted by Jampolsky is that one should either release the restriction or match the duction deficit applies.
- Resection of muscles is generally avoided unless large-angle deviations mandate it. Smaller resections, limited to tendons or in seemingly uninvolved muscles, allow careful surgeons to add this procedure to their armamentarium in TED.
- Progressive overcorrection following inferior rectus recession is an important cause of recurrent diplopia in a case of TED; therefore, planned undercorrection of patients undergoing inferior rectus recession is advocated.
- The coexistence of MG and TED should be noted and investigated in cases of short-term variability of clinical signs, unusual strabismus-like exotropia in TED, or a presentation of ptosis in TED.

The use of adjustable suture surgery points toward improved success rates as compared with fixed suture surgery. The ability to titrate the dose postoperatively and the patient's subjective input allow better short-term postoperative outcomes. However, the debate still remains about the possible complications of slippage and scar elongation in the setting of restrictive strabismus. Asymmetric doses but symmetric surgery is advocated when operating on both eyes.

In TED, comparison between studies is often limited by their retrospective nature, variable clinical pictures, and variable means of reporting outcomes in different study groups, as well as short follow-up times.

However daunting the patient suffering from the disfiguring and dysfunctional complications of TED may be, the experienced adult strabismologist can approach the patient with a positive message that improvement can generally be accomplished. Reoperation rates are still higher than those for other forms of strabismus. Perhaps until the underlying pathological changes in TED are better understood and managed, we should expect that any patient with TED could potentially require multiple surgical procedures over time.

Setting patient expectations properly may be one of the most crucial parts of the surgeon's responsibility.

Conflict of Interest Batri S. Wallang, Ramesh Kekunnaya, and David Granet declare that they have no conflict of interest

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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- Of major importance

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