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ARTICLE

Overcorrection after vertical muscle transposition with augmentation sutures in sixth nerve palsy

Amr Elkamshoushy[1], Ahmed Awadein[2], Hala Elhilali[2] and Dina H. Hassanein[2]✉

PURPOSE: To report a series of cases, who developed consecutive exodeviation after vertical muscle transposition (VRT) performed for sixth nerve palsy, describe their management and analyse their outcome.
DESIGN: Retrospective case series.
METHODS: This is an institutional study on patients who developed consecutive exotropia following VRT for sixth nerve palsy in two different centres. The age, gender, cause, and time to surgery were reviewed. Ductions, versions and angles of misalignment were analysed. In those who developed an exotropia >10 PD after surgery, a second surgery was performed. The time to the second surgery, intra-operative findings, surgical procedure and outcome were studied.
RESULTS: A total of 164 cases of VRT for sixth nerve palsy were identified. Nine patients developed consecutive exotropia >10 PD (5.5%). There were no significant differences in the characteristics of those who developed overcorrection compared to those who did not. Five patients had full-tendon muscle transposition, three patients had Hummelsheim procedure and one patient had Jensen procedure. The average angle of consecutive exotropia was 26 ± 9 Δ (range 10–40 Δ). After the second surgery, angle of exotropia decreased to 21 ± 15 PD. Seven patients still had residual exotropia ≥10Δ and the exotropia was corrected in the remaining two patients. The time to second surgery in those two patients was much shorter than the other seven patients.
CONCLUSIONS: Patients who undergo VRT should be followed up in the early post-operative period and revisiting the transposition should be done immediately in case of consecutive exotropia to avoid permanent overcorrection.

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INTRODUCTION

Paralytic strabismus poses a significant challenge in both diagnosis and management. Sixth nerve palsy, whether congenital or acquired, represents about 45% of cranial nerve palsies. Due to its special anatomical features and its long intracranial course, the sixth nerve is more susceptible to damage by head trauma or intracranial pathologies such as increased intracranial pressure, meningeal inflammation or oedema [1, 2].

A variety of vertical rectus muscles transposition (VRT) procedures have been proposed for the treatment of unresolving sixth nerve palsy [3]. Full tendon transposition of the vertical rectus muscle was initially described by O'Connor 1935 [4]. Hummelsheim was the first to describe transposing the lateral halves of the split superior and inferior rectus muscles to the lateral rectus insertion [5]. Foster suggested augmentation of the transposed muscles using non- absorbable sutures to enhance lateralisation of each transposed rectus muscle and to increase its abducting force [6]. Another alternative for muscle transposition is the use of Jensen muscle union sutures without muscle disinsertion [7]. VRT may be combined with recession or injection of botulinum toxin into the medial rectus muscle to reduce contracture of the medial rectus muscle and to augment the effect of surgery [8, 9].

One of the challenges of VRT is the lack of an accurate surgical dose for different procedures. In surgical model simulation, the Hummelsheim procedure resulted in a 28 PD reduction of total deviation, the Jensen procedure achieved a 34 PD reduction, the Foster procedure led to a 57 PD reduction, and the muscle union procedure yielded a 57 PD reduction in esotropia in sixth nerve palsy [10]. Nevertheless, in clinical practice, the reduction of total deviation is influenced by many variables such as the degree of medial rectus muscle tightness, the degree of recovery of the lateral rectus muscle function, and the chronicity of the condition.

While undercorrection is far more common than overcorrection after VRT, overcorrection poses the risk of creating diplopia in different gaze and reducing the binocular field of vision. Overcorrection is seldom reported as a complication after VRT. Moreover, management of such overcorrection is not well-studied. In this study, we report a series of cases, who developed consecutive exodeviation after various VRT procedures performed for sixth nerve palsy, and we describe their management and analyse their final outcome.

METHODS

The study protocol was approved by Cairo University Research Ethics Committee and Alexandria University Research Ethics Committee. The

[1]Ophthalmology Department, Faculty of Medicine, Alexandria University, Alexandria, Egypt. [2]Ophthalmology Department, Faculty of Medicine, Cairo University, Cairo, Egypt. ✉email: dina.hassanein@kasralainy.edu.eg

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study and data collection conformed to all local laws and were compliant with the principles of the Declaration of Helsinki. The medical records of all patients who underwent VRT for chronic sixth nerve palsy between January 2008 and December 2019 were reviewed. Patients with history of prior eye muscle surgery were excluded from the study. Records of patients who developed consecutive exotropia were studied, and the data of those patients were tabulated and analysed. Consecutive exotropia was defined as exotropia ≥10 PD in the primary position persisting for more than 1 week after surgery. This number was considered large enough that the condition might not get better with time.

The age, gender, eye affected, underlying cause and time from onset to surgery were reviewed. All patients had measurement of uncorrected and best-corrected visual acuity, cycloplegic refraction and fundus examination before surgery. In addition, a detailed sensorimotor examination was performed during the initial evaluation and at each follow up. Ductions and the versions were analysed. The primary and secondary angles of misalignment were measured in the primary position using the prism and cover test with the prism placed in front of the paretic eye (to measure the primary angle) and in front of the non-paretic eye (to measure the secondary angle). In addition, the angles of horizontal and vertical misalignment were measured in side gazes as well as in straight up and down gazes. Measurement of the angle in up and down gazes was done by tilting the head ~25° down and up, respectively, with the patient fixing on a distance target. In addition, the presence and degree of any compensatory head posture was recorded. Worth 4-dot test was used to assess fusion for distance.

All patients had vertical muscle transposition (VRT), using full muscle transposition, Hummelsheim or Jensen technique. The choice of surgery was at the surgeon's discretion. All surgeries were done through a fornix approach to minimise the risk of anterior segment ischemia.

In those who had full muscle transposition, the whole width of the superior and inferior rectus tendons was disinserted and then sutured superior and inferior to the lateral rectus muscle insertion, respectively, perpendicular to the corresponding border of the lateral rectus muscle, while preserving the spiral of Tillaux.

In those who had Hummelsheim procedure, the lateral halves of the superior and inferior rectus muscles were isolated, care was taken to ensure that the remaining nasal ciliary arteries were left intact. The two halves were then disinserted and sutured to the sclera superior and inferior to the lateral rectus muscle insertion.

In those who had Jensen procedure, the superior, inferior and lateral rectus muscles were split along the muscle length for at least 15 mm posteriorly. The lateral halves of the superior and inferior rectus muscles were sutured to the upper and lower halves of the split lateral rectus muscles using 5/0 polyester sutures.

Scleral augmentation sutures were then placed in all patients using 5/0 polyester sutures, ~7–8 mm posterior to the insertion of the lateral rectus muscles. [6].

When the angle of deviation was deemed too large for correction with muscle transposition, medial rectus muscle recession or botulinum toxin injection was performed. The recession was done through a fornix approach and using fixed scleral sutures. In cases, who received additional botulinum toxin, 6–8 IU of botulinum toxin A (Dysport, Ipsen, Berkshire, UK) were injected into the medial rectus muscle.

Patients were prescribed topical antibiotic-steroid eye drops combination for 2–4 weeks after surgery. Patients were examined at the first day and the first week after surgery for signs of anterior segment ischemia. In addition, duction, versions and ocular alignment were evaluated. The frequency of further follow-ups was based on the post-operative outcome.

In those who developed a considerable exotropia after surgery, the patients were monitored closely for improvement. If the exotropia persisted, a second surgery was performed. The time to the second surgery was at surgeon's discretion but was influenced by the degree of patients' dissatisfaction. Forced duction test was first performed. The muscles were then explored, and a corrective surgery was performed based on the clinical and the intra-operative findings. The details of the second surgery were tabulated. The authors confirm that the patients have consented for their image(s) to be published.

Data obtained after surgery were compared with the baseline measurements using the paired *t*-test for continuous variables and Wilcoxon signed-rank test for ranks and scores. Statistical analysis was performed using SPSS for Windows (SPSS Inc, Chicago, IL).

RESULTS

A total of 164 cases of muscle transposition for unilateral sixth nerve palsy were identified. Full tendon transposition was done in 65 cases. Hummelsheim was done in 61 cases and Jensen was done in 38 cases. Surgeries were performed by four surgeons (AE, AA, HE, DH).

A total of nine patients (5.5%) developed consecutive exotropia after surgery of whom six were males (66.6%). The cause of sixth nerve palsy was trauma in eight patients and a surgery for a brain tumour in one patient (Table 1). The mean age at the first surgery was 25.0 ± 16.0 years (range 2–52 years). The average time from the onset of the symptoms to the first surgery was 14.7 ± 8.1 months (range 6–30 months) and the average pre-operative angle of esotropia was 52.2 ± 13.7$^{\Delta}$ (range 35–70$^{\Delta}$).

Five patients had full-tendon muscle transposition, three patients had Hummelsheim procedure and one patient had a Jensen procedure (Table 2). Scleral augmentation sutures were used in all patients. The augmentation sutures were placed 7 mm posterior to the muscle insertion in seven patients and 4 mm posterior to the muscle insertion in two patients. Ipsilateral medial rectus muscle recession was performed in two patient and two patients received additional botulinum injection to the medial rectus muscle. All patients had ≥−4 limitation of abduction on versions and ductions testing. None of the patients had other abnormalities of ocular motility.

The average angle of consecutive exotropia was 26 ± 9$^{\Delta}$ (range 10–40$^{\Delta}$). All patients had some improvement of abduction. However, eight patients (89%) developed −1 to −2 limitation of adduction. None of the patients showed measurable vertical deviation.

There was no significant difference in the pre-operative and intra-operative characteristics of those who had overcorrection compared to those with satisfactory outcome/undercorrection (Table 2).

The average duration from the first to second corrective surgery was 37.3 ± 40.4 weeks (range 1–104 weeks). Forced duction test showed some restriction to adduction in all patients. Surgery was done through a fornix approach and the transposed muscles as well as the augmentation sutures were identified in all patients. The augmentation sutures were cut and removed in all nine patients. In addition, in two of the five patients who had full tendon transposition, the transposed muscles were re-sutured to the original muscle insertion. In the patient who had Jensen procedure, the sutured halves of the muscles were mechanically isolated from each other and the transposed halves were gently moved back towards the original course of the muscle. In addition, medial rectus resection 6 mm was added in one patient

Following the second surgery, the angle of exotropia decreased to 21 ± 15 PD. Seven patients still had residual exotropia of 10 PD or more (e-supplement-1). In the remaining two patients, the exotropia disappeared completely in one patient (e-supplement-2) and was reduced to 5 PD in the other patient (e-supplement-3). The mean time to second surgery in those two patients was significantly less than the other seven patients. In one patient the second surgical procedure was performed 1 week after the first surgery and in the second patient, it was performed 3 weeks after the first surgery. The degree of limitation of adduction improved in three of the eight patients who developed a limitation after the first surgery. The degree of limitation of abduction remained unchanged in all patients. The operative and post-operative data of the second surgery are summarised in Table 3.

DISCUSSION

To date, there have been many studies investigating the efficacy of various VRT techniques for chronic sixth nerve palsy, but in the absence of any prospective randomised controlled trials, it is hard

to conclude and to accurately compare the outcome of all those techniques. Moreover, most transposition techniques are usually not graded and there is no specific algorithm for calculating the surgical dose of the transposition procedure. The surgical outcome can usually be modified only by changing the VRT technique or modifying the amount of medial rectus recession if performed. While the use of adjustable sutures might improve the surgical outcome in the immediate post-operative period, [11–13] their use remains controversial, with no available prospective randomised controlled studies. [14].

While undercorrection after VRT is far more common that overcorrection, there is limited information regarding the rate of overcorrection after VRT, its underlying risk factors and its intricate management. To our knowledge, this is the first study to evaluate the overcorrection after VRT for sixth cranial nerve palsy.

In the current study, all patients had augmentation sutures and the overcorrection rate was 5%. Overcorrection has been reported in patients who underwent augmented transposition and it has been recommended that this technique should be used in cases with large angles of esotropia. [6, 15, 16]. Nevertheless, the majority of patients who developed the overcorrection had relatively large pre-operative angles.

In another retrospective study, Leiba et al. demonstrated the long-term outcome after full-tendon VRT combined with chemo-denervation of the ipsilateral medial rectus muscle for acquired sixth nerve palsy. They had a 9% incidence of overcorrection (2 out of 22 cases) and attributed the exotropia in one of both cases to the post-operative late visual loss in the non-paretic fellow eye [17]. A similar incidence (10%) of overcorrection was reported by Couser et al., who studied the outcome of the augmented Hummelsheim procedure combined with medial rectus muscle recession. The one patient, who developed consecutive exotropia in their study had a coexisting oculomotor nerve palsy. [18] On the contrary, most other studies on transposition procedures for sixth nerve palsy did not report cases of overcorrection [6, 15, 16].

A possible cause for such an overcorrection in our cases might be the presence of residual lateral rectus function. In our study, the cause of abducent nerve palsy was trauma in eight out of the nine patients. All cases had a −4 or −5 abduction deficit in both ductions and versions which would be classified as a "complete" abducens palsy in prior studies. In the current study, lateral rectus muscle function was assessed by office force generation test, which is a qualitative test. Saccadic velocity test may be a more sensitive test for evaluation of the lateral rectus functions [19]. Our cases may have had some residual LR activity if we had used the aforementioned technique.

There were no significant risk factors for overcorrection in our study and there were no significant differences in the pre-operative characteristics and the surgical procedure between those who developed an overcorrection and those who didn't. The incidence of overcorrection was a bit higher among those who had full tendon transposition, though the difference was not statistically significant.

Management of overcorrection after VRT was difficult. The outcome of surgery for the overcorrection was unsatisfactory with the majority of cases showing little improvement even after removal of the augmentation sutures or even complete reversal of the transposition. The only two cases which showed improvement of this overcorrection were those who had very early re-intervention surgery; namely 1 and 3 weeks after the initial overcorrection, as compared to the other seven cases, in which the second surgery was performed at 4 months at earliest. This suggests that the early intervention after a consecutive exotropia is necessary to enable its correction.

While it is not clear why the overcorrection persisted even after reversal of the transposition, we propose that keeping the eyes in a fixed position for a certain period of time might cause some contracture of the transposed muscles and alter the orbital static forces. These forces might cause the globe to adapt permanently to

Table 1. Summary of the pre-operative characteristics of patients who developed overcorrection.

No.	Demographics			Preoperative			Operative details			Postoperative		
	Age	Gender	Cause	Angle of ET	Abduction	Time to surgery (months)	Transposition type	MR recession	BTX to MR	Angle of XT (Δ)	Adduction	Abduction
1	23	M	Trauma	60	−5	24	Full tendon	No	Yes	20	−2	−1
2	9	F	Trauma	50	−4	6	Full tendon	No	No	35	−2	0
3	41	M	Trauma	70	−5	18	Full tendon	No	Yes	30	−2	−1
4	19	M	Trauma	40	−4	12	Hummelsheim	No	No	20	−3	−1
5	52	F	Brain Surgery	50	−5	30	Full tendon	No	No	30	−2	−1
6	14	M	Trauma	70	−6	9	Full tendon	No	No	40	−3	−1
7	34	M	Trauma	60	−4	12	Hummelsheim	No	No	10	−3	−2
8	30	F	Trauma	35	−4	15	Jensen	4.5 mm	No	25	−2	−1
9	2	M	Trauma	35	−5	6	Hummelsheim	4 mm	No	20	−1	−1

MR medial rectus, *XT* exotropia.

Table 2. Comparison of the pre-operative and intra-operative characteristics of patients with overcorrection and those with satisfactory outcome/undercorrection.

	Satisfactory outcome/undercorrection ($n = 155$)	Overcorrection ($n = 9$)	*P* value
Age	27. 7 ± 18.5 years (range 2–65 years)	25. 2 ± 15.4 years (range 5–52 years)	0.325
Gender	101 (65%)	6 (67%)	0.924
Duration to surgery	15.1 ± 10.2 months (range, 6–168 months)	14.7 ± 8.1 months (range 6–156 months)	0.281
Preoperative angle of deviation	48 ± 11$^{\Delta}$ (range 25–75$^{\Delta}$).	52 ± 14$^{\Delta}$ (range 35–70$^{\Delta}$).	0.127
Degree of limitation of abduction	−4.8 ± 0.8 (range, −4 to −6)	−4.6 ± 0.7 (range, −4 to −6)	0.156
Type of surgery			0.531
Hummelsheim	58 (37%)	3 (33%)	
Jensen	37 (24%)	1 (11%)	
Full tendon	60 (39%)	5 (56%)	
Medial rectus recession	61 (39%)	2 (22%)	0.304
Botulinum toxin injection	34 (22%)	2 (22%)	0.975

Table 3. Details of the second surgery and post-operative outcome.

Case	Duration between the two surgeries (weeks)	Second surgery	Postoperative		
			Angle($^{\Delta}$)	Abduction	Adduction
1	52	Release of augmentation	XT 30	−2	−1
2	16	Release of augmentation	XT 35	−2	0
3	104	Release of augmentation+ medial rectus resection 6 mm	XT 30	−1	0
4	16	Release of augmentation	XT 20	−2	−2
5	20	Reverse VRT	XT 20	−2	−1
6	104	Reverse VRT	XT 20	−3	−2
7	20	Release of augmentation	XT 10	−3	−2
8	1	Release of augmentation	0	−2	0
9	3	Release of augmentation	X 5	−2	0

XT exotropia.

the new position and prevent the eye from moving back to the centre even after reversal of the transposition. Such changes seem to occur in the first few weeks after VRT and might be hard to reverse. This might be similar to what happens when botulinum toxin is injected in an overacting muscle to temporarily align the eyes in the desired position just long enough for the re-distribution of forces to occur. These new forcers will maintain the eyes in the new position, even when the effect of botulinum toxin weans off.

Because muscle transposition remains the mainstay of treatment of cases with complete sixth nerve palsy and no previous study was able to grade the transposition and create a solid dose–response curve, the occurrence of overcorrection has to be anticipated. Patients who undergo VRT should be followed up in the early post-operative period and revisiting the transposition should be done immediately in case of consecutive exotropia for best results.

SUMMARY

What was known before

- One of the challenges of VRT is the lack of an accurate surgical dose for different procedures. Overcorrection is seldom reported as a complication after VRT.
- Moreover, management of such overcorrection is not well-studied.

What this study adds

- In the current study, all patients had augmentation sutures and the overcorrection rate was 5%.
- There were no significant risk factors for overcorrection in our study and there were no significant differences in the pre-operative characteristics and the surgical procedure between those who developed an overcorrection and those who didn't.
- Patients who undergo VRT should be followed up in the early post-operative period and revisiting the transposition should be done immediately in case of consecutive exotropia to avoid permanent overcorrection.

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AUTHOR CONTRIBUTIONS

Design and conduct of the study: AE, AA, HE, DH. Collection, management of data: AE, AA, HE, Analysis and interpretation: AE, AA, DH. Preparation, review or approval of the paper: AE, AA, HE, DH.

COMPETING INTERESTS

The authors declare no competing interests.

ADDITIONAL INFORMATION

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Correspondence and requests for materials should be addressed to DinaH. Hassanein